Hazard Analysis Methods for Ice-class Crude Oil Tankers in the Arctic region

Comparing Traditional and New Hazard Analysis Methods.

What are the widely used hazard analysis methods in the maritime industry?

What are the strengths and weaknesses of traditional hazard analysis methods?

What are the new hazard analysis methods?

What are the strengths and weaknesses of new hazard analysis methods?

What hazard analysis method is best suited for arctic operations?

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Abstract

With the visible effects of global warming staring right at us, it is difficult to deny the inevitable truth that global warming is here and its effect in the Arctic is evident. Nevertheless, the rapid thinning of the ice covering opens up the possibilities for new sailing routes, mining and drilling, and exploration. The objective of this master's thesis paper is to explore hazard analysis in reference to tankers vessels sailing in the Arctic. Various hazard analysis methods exist in the industry, but which is best suited for tanker vessels operating in the Arctic region. Using qualitative research design method and through the aid of the exploratory method, this thesis aims to study and understand the different methods used in hazard analysis.

This thesis paper elucidates the answer to the following five research questions: What are the widely used hazard analysis methods in the maritime industry; What are the strengths and weaknesses of traditional hazard analysis methods; What are the new hazard analysis methods in the industry today; What are the strengths and weaknesses of the new hazard analysis methods come on what has an analysis method is best suited for Arctic operation?

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Chapter 1: Introduction

1.1 Research problem/challenge

All scientific reports on global warming and climate change have one thing in common, which is the increase in temperature (UN, 2015). This increase in temperature will in turn sadly lead to the warming of the polar regions causing the ice to reseed. As these regions would be affected extensively by the rise in global temperature it also opens new a new frontier for scientific exploration, new shipping routes to both commercial shipping and tourism, and new areas for resource exploitation. Climate change is the most challenging problem of our time, and it is a problem every country and industry shares (UN,2021). Sailing in the arctic region is a high-risk endeavor due to the remote nature of the region and the harsh and unforgiving nature of the arctic climate. The artic regions are highly sensitive and protected, and the safety of the ecosystem is taken into the highest regard. Safety of lives and the ship cannot be comprised as this leads to a dire situation for lives and the environment in general.

The purpose of this study is to provide an overview of the various hazard analysis methods that apply to Ice class tankers operating in the arctic region. This paper tries to define hazard analysis methods as it is currently implemented in the maritime industry today and a breakdown of various types of hazard analysis methods applicable to Ice class tankers today. This paper considers different hazard analysis methods both traditional and modern methods currently applicable maritime and in the Arctic shipping region.

1.2 Background

In recent years, the number of vessels that have sailed through the polar regions has increased by 25% from 2013 to 2019, according to Arctic Shipping Status Report (ASSR), 2019 Arctic report (ASSR, 2019). The Arctic regions have recorded this increase in the various class of vessels from different types of tanker carriers, container ships, passage ferries, and cruise ships, to research vessels and recreational boats, and various military vessels (AMSA, 2019). As nations begin to set their sights on resources and transportation routes within the Artic these regions are inevitably going to witness much higher maritime traffic activities, (DNV GL, 2020). The Arctic Marine Shipping Assessment (AMSA) report published by the protection of marine environment PAME in 2009 identified four types of Arctic shipping.

Currently sailing in the Arctic region is a high-risk endeavor due to the remote nature of the region and the harsh and unforgiving nature of the arctic climate. The Arctic regions are highly sensitive and highly protected regions, and the safety of the ecosystem is paramount.

According to Murphy's law "What can go wrong will go wrong" (Murphy's law, 1950), accidents or incidence are bound to happen in the Arctic region, either due to human error or mechanical failure. Some examples of accidents that could happen are collision with other vessels or with icebergs, sinking, grounding, fire, structural failure due to stresses and forces. Life, ships, and the environment must be protected, to mitigate or prevent this incidence from taking place, a hazard analysis-based approach is used in different aspects and stages of an Ice Class vessel's life cycle. From the design stage, down to the materials and machinery selection to the construction phase, and to the operational lifecycle of the vessel this approach has in recent times been the method of choice wildly adopted for Artic ship design. Ships for ice have historically been designed based on practical experience rather than a thorough understanding of the physics of the ship-ice interaction (P. Kujala, 2019).

What can go wrong, what is the likelihood of this happening, and what are the consequences, (Kaplan 1997). Hazard analysis is the procedure of identifying and describing a system's hazards, threats, and hazardous situations (G.E. Apostolakis 2004). Hazard analysis answers the first question of what can go wrong, the principle is to first identify everything that could go wrong, in all aspects of a system, it is strongly focused on hazard identification. Other hazard identification methods are not just restricted to just hazard identification but also include the other two questions in the risk definition. When a method answered all three questions, this is considered as a "full" risk analysis (Haugen, 2020).

For many years, Hazard analysis has been regarded as a valuable technique in a range of disciplines (G.E. Apostolakis 2004). It has opened the door to an adequate risk assessment, as this helps to first identify hazards which if left on check become incidences.

1.3 Goal of this thesis

It is indeed challenging to come up with a Hazard analysis design for Arctic shipping as in certain cases, a lack of basic information and a lack of infrastructure, hinders a holistic scientific knowledge of the Arctic region and the effects of accidents on the environment and life and properties (P. Kujala, 2019). Further research into the effects of different accident scenarios on the Arctic environment is required.

The paper looks at the methods of hazard analysis currently used and aims to examine the strengths and weaknesses of the traditional hazard analysis methods. New and modern hazard analysis methods which can be also used for hazard analysis for ice-class tankers would be compared to the traditional methods and identify the most suitable method for the arctic.

a. RQ1: What are the widely used hazard analysis methods in the maritime industry?

b. RQ2: What are the strengths and weaknesses of traditional hazard analysis methods?

c. RQ3: What are the new hazard analysis methods.

d. RQ4: What are the strengths and weaknesses of new hazard analysis methods?

e. RQ5: What hazard analysis method is best suited for artic operations?

The thesis topic will be investigated by carrying out a literature review online using the university's database Oria, and Google Scholar, ScienceDirect, OnePetro, and Elsevier, to obtain relevant papers, journals, or publications on Arctic shipping and hazard analysis. This thesis will focus on Arctic shipping and risk analysis methods used currently in the industry, identifying the strengths and weaknesses of traditional and modern hazard analysis methods, and identifying what method is best suited for Arctic shipping.

This thesis paper complies with the Norwegian research data protection laws as well as the university's laws and regulations governing thesis writing.

The information gathered during the literature review will be thoroughly examined.

1.4 Chapter overview

In chapter two of this thesis, the literature review and the data collection process are discussed, giving an account of the search methods and literary works concerning the arctic region as this is the backbone of this paper. The literature review also covers the literary works that contributed to the knowledge for this paper concerning risk analysis as it applies to Arctic shipping and Ice class tankers. Risk influencing factors are discussed, this gives an account of the underlining factors that influence risk in Artic shipping and highlights some key elements. Ice class tankers operating in the artic and the requirements by classifications society Det Norske Veritas (DNV) is discussed.

Chapter three discusses the methodology used in this thesis paper in connection to the main research topic. The model used for this paper is discussed and, the exploratory approach is used to analyze the relevant data collected from various sources.

Chapter four points out the finds and the finds of this paper, chapter five the discussion and the conclusion in chapter six.

Chapter 2: Literature Review

In this chapter, a literature review is carried based on the topic of hazard analysis for arctic shipping, and a search for the types of hazard analysis methods with relation to Arctic shipping was also carried out. Data for this thesis came from various databases as stated above and various search engines. The thesis paper is modeled after the literature review process applied by P.Kujala (2018), on his Review of risk-based design for ice-class ships journal. Bushra Khan's (2018) paper on, An operational risk analysis tool to analyze marine transportation in Arctic waters, Reliability Engineering & System Safety, Volume 169 gave guiding insight on risk and hazard analysis tools for Arctic shipping.

Stein Haugen and Marvin Rausand's book on "Risk Assessment Theory, Methods, and Applications" considered as the industry's top handbook for risk assessment guided much of the study on understanding hazard and hazard analysis (Rausand, 2020). Ericson, Clifton's Hazard Analysis Techniques for System Safety contributed to the insight for this study.

In searching for relevant materials for the literature review it was important to use suitable search criteria and techniques to ensure that the relevant kinds of literature were properly covered.

The keywords, *"Arctic shipping", ''ice-class tankers'' and "hazard analysis"* were a few of the keywords used as search criteria to find relevant papers, although some very relevant articles were not included in the search result. Considering the limitation in first-hand experience and literary publications, and historical data from Ice class tankers in Arctic shipping operations in comparison to literary works on shipping in the Atlantic or Pacific, conventional procedures and standards for this region are not fully defined.

2.1 Arctic Region

Literature on Arctic regions and Artic shipping gives an insight into the areas considered Arctic regions and the characteristics of the environment and how shipping operations in these regions are carried out. It is necessary to define what constitutes the Arctic and the regions that can be included considered Arctic regions, (AMAP, 2010).

To have a better knowledge of the Arctic, it is also necessary to look at the unique characteristics of this environment and the problems they pose to shipping operations. The literature review gives an understanding of the proper definition of Arctic regions and Arctic operations. With the aid of the Polar code, a clear and precise definition is wildly considered the global standard for defining the Arctic region. The Polar Code is a functional, goal-based code. It applies to ships differently, depending on the ship's construction and how it operates in polar waters (MSC, 2014). The history of shipping in the Arctic region dates back centuries to the whale and seal hunting era in the 1500s (AMAP, 2010).

The Polar Code covers all aspects of design, building, machinery, operational, training, protection, and environment and search and rescue issues concerning ships operating in the inhospitable waters of the Arctic (PAME, 2009). One definition is based on temperature, implying that the areas in the north where the average temperature in July does not exceed 10 ∘C are considered as Arctic areas (FNI, 2012). The Arctic is described also as the area north of the Arctic circle, or the lands and waters north of about 66 degrees north latitude (Shanshan, 2021).

The Arctic is known for its isolation and severe climatic conditions.

There is a general lack of infrastructure in these areas, thus maritime activities are often conducted in areas that are far from the land. In addition, the Arctic is known for its lack of comprehensive satellite coverage, (NORSOK, 2007).

The significant features that define the Arctic regions are, darkness all year round, snowfall, freezing temperatures and atmospheric icing, marine icing, sea ice and icebergs in various forms and shapes, dense fog, strong winds, waves, and currents, polar low pressures (Gudmestad, 2012). A mixture of sea spray and low temperatures result in significant ice formation on surfaces and buildings, while the high humidity, chilly rain, causes thick fog buildup, (NORSOK, 2007). There are times in the Arctic when the sun does not rise above the horizon. This period is known as the "dark period", and it begins with the winter solstice. The duration of the darkness period lengthens as one travels northward, (met.no). The Arctic climate is also characterized by subzero temperatures. The northern regions of the Barents Sea in particular could experience annual low temperatures of -39°C to -20°C, (ISO, 2010).

Arctic shipping applies to all shipping activity within the Arctic or polar region (PAME, 2009).

• Destination transport, in which a ship goes to the Arctic, engages in some Arctic activity, and then travels south.

• Intra-Arctic transport is a trip or maritime activity that takes place within the Arctic area and connects two or more Arctic countries.

• Trans-Arctic transport or navigation refers to trips that traverse the Arctic Ocean from the Pacific to the Atlantic Oceans or the other way around.

• Cabotage, which is the practice of trading or transporting goods through coastal waterways between ports within an Arc (PAME, 2009).

2.1.2 Arctic Ships

Ships sailing in the arctic region are designed especially for icebreaking and cold regions. These vessels must operate in both ice and open waters, the hull of these vessels are designed for minimal ice resistance and maximum maneuverability. Defining the duties that the ship must do is the first step in ship design (Riska, 2011). DNV-GL's polar code categorizes ice-class ships into three categories, categories A, are ships built to operate in polar waters in at least medium first-year ice with older ice inclusions. Vessels built to the IACS Polar ice classes PC1 to PC5 fall within this category (DNV-GL). While category B these are ships that are not included in Category A but built to operate in thin first-year ice in polar waters, these are vessels built to the IACS Polar ice-class PC6 and PC7 (DNV-GL). Category C are ships meant to operate in open waters and in conditions less than that of Category A and B, these are mostly ships without any ice strength (DNV-GL). The structural integrity and strength of the Ice class vessels hulls are high in the scale of importance, in the design and construction phase of these vessels, to meet the classification society requirements.

The bow of an ice-class vessel is important, as it determines the resistance and performance in both ice and open water because the bow for breaking the ice and the bow for sailing in open water are very different, so they are designed in such a way that weighs the ice features against open water features (Lamb, 2004).

2.2 Hazard Analysis

Hazard is always related to what can happen in the future. Hazard is an inherent physical or chemical characteristic that has the potential to cause harm to people, property, or the environment (Macdonald. 2004). The likelihood that something can go wrong in the future, if it is in the past then it is a consequence. In the hostile conditions of the arctic, the performance of vessel systems decreases, which increases the likelihood of accidents, (Khan, 2014). What can go wrong what is the likelihood of this happening and what are the consequences if things go wrong, (Kaplan, 1997)?

The main purpose of hazard identification is to first estimate how often an incident or hazardous event is likely to occur, secondly to estimate the effects on life, the environment, and property, and finally to determine the best level of risk reduction methods to mitigate the risk (Haugen, 2020).

Quantitative risk assessment is used to determine the frequency of an event likely to occur, and it makes it easy to present and rank in order of severity the frequency of hazards or hazardous events in a risk matric chart (Macdonald, 2004).

2.2.1 How are hazards identified?

There are various ways to identify hazards in a system, one is by looking at current systems that are comparable, considering interactions between two systems, and identifying potential hazardous events that could occur. By reviewing previous hazard analysis or hazard checklist, thinking about worst-case scenarios, etc.

The Polar Code (MSC, 2014) identifies 10 potential hazards for marine operations in polar waters, which are grouped into three categories:

• Environmental factors include ice, freezing temperatures, lengthy periods of darkness or daylight, high latitude, remoteness the likelihood for an absence of reliable and full hydrographic data and information, constantly changing and severe weather conditions, and a sensitive environment

• Ship-related factors: ice on the weather deck, an absence of adequate emergency response equipment

• Human and organizational factors: a shortage of experienced Arctic operations crew, (Shanshan, 2021).

The Safety of Life at Sea (SOLAS, 1974) is the most significant convention with regards to the international safety of merchant ships. The goal of the SOLAS convention is to define the minimum standard for the buildings, equipment, and running of ships, and the flag-states ensure compliance to these standards. SOLAS applies to international shipping, but it is limited to additional requirements needed for the construction, equipment, and vessel operations required for the Arctic region. IMO recognized the limitation of the SOLAS after the Exxon Valdez incident in 1989 and in 2002 the Guideline for Ships Operating in Arctic Ice-Covered Water, (IMO, 2002).

There are several classifications for hazards. Although there is no widely acknowledged classification system for hazards, it can be claimed that different classification systems are beneficial for different uses (Rausand, 2020). According to Marvin Haugen, in the Risk assessment book, the following are a few classifications adopted based on the primary causes of accident scenarios. (Schubach, 1997).

Technological hazards refer to equipment, software, structures, as well as transportation (Haugen, 2020).

Natural or environmental hazards could be flooding, earthquake, acts of God, hurricanes, as well as low temperatures in the arctic (Rausand, 2020).

Organizational hazards, for example, extended watch hours, incompetence, lack of proper maintenance, and poor safety culture.

Behavioral hazards include drugs and alcohol onboard, inability to concentrate.

The Arctic is a region that is hash and unpredictable, covered in various sizes of icebergs rocks and many uncharted areas, the possibilities for accidents are enormous from a collision with icebergs to running aground, to being trapped in ice, ice buildup on deck equipment, rapid temperature drops, etc. (Rausand, 2020). The likelihood of things going wrong is always high. Given the nature of things according to Maslow's law what can go wrong will go wrong, even vessels operating in regions with fewer environmental challenges and complications as the arctic region, still experience equipment failure, incidents, and accidents.

Hazard analysis tools or methods help in answering the first question in the Risk assessment, relevant papers, articles, and journals regarding maritime shipping hazard and risk assessment relating to Arctic shipping guided this study. To answer this, we must identify the possible accident scenario that may harm the asset we want to keep protected.

The primary objectives in a hazard identification process aim to first Identify all hazards and hazardous events that may occur throughout all planned and anticipated use and abuse of the research object, as well as any interactions with it. It also helps in the describing of each hazard's features, as well as the form of hazard and quantity (Rausand, 2020).

Hazard identification indicates when and where the hazard is present, it Identifies the potential enabling events and conditions for each hazard (Haugen, 2020). It identifies probable initiating hazardous events that the hazard or in conjunction with other hazards might cause, an example in the scenario of a tanker collision with an iceberg in the Arctic, this could compromise the hull integrity of the tanker's cargo holds resulting in an oil spill, which in turn leads to a very dangerous environmental pollution and the destruction of the very sensitive ecosystem.

2.2.1 What can go wrong.

To answer the first question, hazard analysis is classified into external and internal hazards. The external being hazards that are external to the ship such examples are the weather, poor visibility, tide, temperature, storms, sinking, grounding, etc. While the internal hazards include incidents that could occur inside the tanker these are fire in the accommodation area, machinery failure on deck, or slippery deck to due oil spill or ice cover, fire in the machinery space, fire in the cargo space, etc.

These are machinery failure, collision, grounding, fire, man overboard, environmental pollution. The consequence of things going wrong in the Arctic region for a tanker ship could lead to accidents ending with serious consequences. An accident scenario is a sequence of events, that starts with an initiating event and ends with an end state that affects and causes harm to the assets (Haugen, 2020). These assets could include people, ships, or the environment. accidents happen in the Arctic region this could be fatal as the region is inhospitable cold and treacherous. The consequences for accidents here are pretty steep and could lead to loss of lives property and damage to the environment. The environment is a specially protected area, unspoiled by human exploration and exploitation could be severely damaged.

The hazard triangle is made up of three essential and connected components, each of which constitutes one side of the triangle. In order for a hazard to exist, all three sides of the hazard triangle must be present (Ericson, 2015). If any side of the triangle is removed the hazard is eliminated as it can no longer cause an accident, and if we reduce the likelihood of the Initiating mechanism happening, then the likelihood of an accident decreases. To reduce the severity of an accident we remove one element from the Hazard source or Threat or target Outcome. This feature of a hazard is important in identifying where to reduce a hazard (Ericson, 2015).

2.2.2 Hazard analysis methods

This answers the first research question What are the widely used hazard analysis methods in the maritime industry? The following are the hazard identification methods recognized in the industry.

The checklist method for hazard analysis is a written list of potential hazards or hazardous events based on previous experiences (Rausand, 2020). The use of the basic checklists and thinking method is also referred to as process review. In many instances, the checklist just starts with a basic list of general hazards or general hazardous events and determines whether, where, and how these events could happen (Haugen, 2020). The items on the lists might be examples of hazards and incidents, or they can be framed as questions to assist in pointing out all factors of the safety check. Checklists are created for certain purposes, for the offshore oil and gas industry, the ISO 17776 (2016) is utilized (ISO, 2016), HSE is also used for accident and safety (Rausand, 2020). For machinery safety, ISO 12100 (2010). IMO (2015) provides a hazard list for the shipping industry (Rausand, 2020).

Preliminary hazard analysis (PHA) is a basic approach for identifying risks during the design phase of any system. It is referred to as preliminary as it first identifies what needs to be protected, it identifies various hazardous that could possibly happen, it determines the primary reasons for each potentially hazardous incident. The PHA determines the frequency at which each potentially hazardous event may occur (Haugen, 2020). The results of PHA are often modified when more thorough risk analysis is conducted along the line, for simpler systems the PHA can be a comprehensive and satisfactory risk analysis (OSHA, 2002). Hazard identification (HAZID) is another name for a simpler PHA (Rausand, 2020). The PHA can be applied in both the initial design stage and at the later stage.

Job safety analysis (JSA) also known as job hazard analysis (JHA) or safe job analysis (SJA), is a basic approach used to analyze work operations and processes to identify potential hazards and decide on risk-reduction strategies (COHS, 2009). Each job is broken down into separate tasks for which hazards are identified using observation, checklist, and experience (Haugen, 2020). JSA is usually applied right before a work activity to prepare and improve the safety awareness of individuals who will be participating a good example of this is the toolbox meeting onboard ships before maintenance or any other task is carried out (OSHA, 2002). JSA is applied in three main contexts, it is used in Nonroutine jobs, dangerous routine jobs, and new work procedures (Rausand, 2020). Due to its comprehensive and exhaustive design, the JSA can identify possible hazards that might otherwise go unnoticed.

Failure modes, effects, and criticality analysis (FMECA), or FMEA was one of the earliest methods for analyzing system reliability, and the first guidelines were published in 1949 (Haugen, 2020). It's primarily a method for reliability engineering. This is the widely used hazard analysis used in the maritime industry today. The goal of a technical FMECA system is to identify all of the system's potential failure modes, determine the causes of these failure modes, and analyze the implications of each failure mode on the overall system (Schubach, S. 1997). FMECA is mostly used to identify and analyze possible failures during the design phase of a technical system and in the lifecycle of the system.

Hazard and operability (HAZOP), the HAZOP technique was created to detect deviations and dangerous conditions in process plants. The system is designed on guidewords and relies on teamwork and brainstorming (Rausand, 2020). HAZOP was developed in 1962 for the chemical industry (Kletz 1999). HAZOP has been used successfully over the years and is now a common approach for risk assessment in the design of process facilities. IEC 61882 (2016) id the international standard for HAZOP.

Structured what-if technique (SWIFT) SWIFT is conducted by a group of specialists in a brainstorming session that asks – and answers – a series of what-if questions. A specific checklist is used to organize the task. Previously, this approach was known as a what-if/checklist method. SWIFT is a simplified HAZOP that may be used in the same types of systems as HAZOP.

Fault tree analysis (FTA) is an analysis method approach for determining the root causes and likelihood of a certain unwanted event occurring. FTA is used to assess large and complicated dynamic systems to comprehend and prevent accidents. It allows the analyst to model the unique combinations of fault events that could cause an unwanted event to occur using a rigorous and systematic technique (Ericson, 2015). There are 8 steps in FTA.

2.3 What are the strengths and weaknesses of traditional hazard analysis methods?

Knowing no method can identify all potential hazardous events in a system, and it is always possible that undiscovered hazardous events may occur." A hazardous incident that is not discovered will not be managed, this could, in turn, result in a larger risk than initially assessed” (Haugen, 2020). These are a few of the strengths and weaknesses of the traditional hazard analysis methods. Starting with the checklist method then the preliminary hazard analysis method, job safety analysis, and the various strengths and weaknesses of the traditional hazard analysis methods are looked out in reference to shipping.

2.3.1 The Checklist method

In general, a generic hazard checklist is effective for most risk assessments, but it is not used as the only method for hazard identification. Except in cases onboard a ship where a checklist is used to identify and point out potential hazards and the mitigating factors to make the workplace safe. It is used to ensure the operation and running of a ship are in compliance with the industry standards and practices.

Table 1. Strengths and Weaknesses of Checklist method.

Strengths	Weaknesses.
People without a background in risk analysis can readily apply the checklist method	Because the checklist technique is restricted to previous experience, it may not predict risks in new designs or unique accidents from current designs.
takes advantage of prior risk assessments knowledge	It may overlook hazards that have not been encountered before.
The checklist method guarantees that problems that are more prevalent and evident are not neglected	it provides limited understanding into the nature of the hazard
is useful in the design phase for identifying hazards that may otherwise go unnoticed	

In general, a generic hazard checklist is effective for most risk assessments, but it should not be used as the sole way of hazard identification unless the dangers of conventional installations have been explored in greater depth elsewhere (Rausand, 2020).

2.3.2 Preliminary hazard analysis (PHA)

It can be used as part of a more detailed analysis method, or it can be used solely. PHA is carried out in 7 steps distinctive steps

Table 2 Strengths and Weaknesses of PHA

Strengths	Weaknesses
It helps in ensuring the system is safe	"Primarily, PHA is challenging to use to depict events with widely varied outcomes.
Early in the design process, modifications are less expensive and quicker to execute making PHA a first step in most risk analysis.	The analysts must be aware of potential dangers.
People without a background in risk analysis can readily apply the preliminary hazard analysis method.	Connections between hazards are difficult to recognize.
PHA identifies and provides hazard logs and their associated risk.	It fails in assessing risk of combined hazards or already existing system failure modes
PHA is a flexible method that can address a variety of challenges.	

2.3.3 Job safety analysis JSA

Detailed understanding of the job is required, and unless the participants have prior work experience to utilize this method. A JSA requires a substantial amount of data collecting. This contains information needed to understand the duties as well as to detect potential hazards.

Table 3 Strengths and Weaknesses of

Strengths	Weaknesses
it teaches the employees safe and efficient work procedures.	it is too time consuming for complicated jobs
It raises workers awareness of potential safety issues.	it is not suitable for identifying potential problems if substantial coordination is necessary
JSA introduces new workers to the job and safe working practices.	and it is not a structured process.
gives guidance for nonroutine jobs	

2.3.4 Failure modes, effects, and criticality analysis (FMECA) or FMEA

First used by the military in the 1940s this is the hazard analysis method adopted in shipping, FMEA identifies and describes the failure modes, failure causes, and failure effects that may occur (Haugen, 2020). FMECA is also known as the bottom-up approach is when the analysis describes or ranks the magnitude of the various failure modes. To carry out failure modes, causes, and impacts of such failures, FMECA analysis is carried out by analyzing as many components, assemblies, and subsystems as possible (Macdonald. 2004).

Table 4 Strengths and Weaknesses of FMEA

Strengths	Weaknesses
It is widely used and simple to comprehend	Its advantages are dependent on the users experience
It offers a full hardware evaluation and is suited for complex systems	it analyzes hazards originating from single-point failures and will typically fail to identify hazards created by various faults.
It has a certain amount of flexibility that allows the adjustment of information to meet any objective.	It is expensive and time-consuming
It is systematic and thorough	

2.3.5 Hazard and operability HAZOP

Hazard and operability HAZOP analysis is done in a guided brainstorming meeting, carried out by a group of specialists, the HAZOP team investigates how a system or a plant may deviate from the original purpose, resulting in hazards and operability issues (Macdonald. 2004). HAZOP is used to identify any deviations from how a system is meant to operate, the causes of the deviations, as well as the hazards and operability that arise.

Table 5 Strengths and Weaknesses of HAZOP

Strengths	Weaknesses
"It's widely used, and its benefits and weaknesses are well known.	It is heavily dependent on the leader's engagement and the analyzing team's expertise.
It is structured, methodical and thorough, and it identifies all potentially hazardous process variations.	It is optimized for process hazard and has to be modified to address other kinds of hazards.
HAZOP is efficient for both human and technological errors.	It requires the creation of procedural descriptions, which are frequently lacking in sufficient detail.
HAZOP is suitable for systems requiring interaction between multiple disciplines or organizations.	It creates a lot of paperwork.
HAZOP identifies existing safeguards, and aids in the recommendations of new safeguards.	It requires skills and experience to design the control structure hierarchy to be used.

2.4. New hazard analysis methods

2.4.1 Systems-theoretic process analysis (STPA)

Systems-theoretic process analysis (STPA), designed to tackle some of the flaws and limitations in previous hazard analysis approaches methods, particularly those involving complex software systems (Haugen, 2020). Proposed by Leveson in 2011, STPA is built on a systems theoretic accident model and processes (STAMP) (Leveson, 2011). STPA takes into account potentially dangerous interactions between system components, it is founded on the idea that accidents occur as a result of insufficient control of the research object (Dakwat, 2018). There is no industry standardized STPA analysis process. In STPA study a hierarchical control system is required. (Dakwat, 2018).

2.4.2 The functional resonance analysis method (FRAM)

FRAM hazard analysis is based on the assumption that accidents occur as a result of a function variation rather than component failure (Tian, 2020). FRAM is a system-based analysis approach that evaluates the entire system and focuses on how it works rather than the structure of its individual components (Tian, 2020). Established in 2004 by Hollnagel, for accident and incident investigations in complex social-technical systems, in recent times, FRAM has evolved from an accident model to a more general analysis method (Caponecchia, 2020). Performed based on these four keywords, not providing, "providing creates a hazard, "too early/too late," and "Stop too soon/Applying too late (Toda, 2018). FRAM shares many similarities with the STPA method. FRAM can give a clearer and more in-depth knowledge of how complicated systems interact. The dynamic and nonlinear characteristics of a complex system failure may be captured using FRAM (Costantino, 2018). FRAM analysis can identify the key variabilities that developed in the dynamic system by monitoring how component variabilities reverberate.

2.5. What are the strengths and weaknesses of modern hazard analysis methods?

Table 6 Strengths and Weaknesses of S

Strengths	Weaknesses
it is beneficial for complex systems comprising automation, software, and people.	One of the most significant disadvantages is that a STPA research cannot prioritize hazardous events.
Compared to other methodologies, it uses a different approach.	It is expensive and time consuming
STPA detect system flaws that other approaches have trouble detecting.	

Table 7 Strengths and Weaknesses of (FRA

Strengths	**Weaknesses**
FRAM detects system flaws that other approaches have trouble detecting.	Its advantages are dependent on the user's experience
It is systematic and thorough	FRAM is expensive and time consuming
Able to handle complex system analysis.	**It is considered new and no industry standard approach**
	Still untested in other relevant industries.

2.6 What hazard analysis method is best suited for arctic operations?

The hazard analysis method for the arctic must take into consideration the hazardous nature of the Arctic region, the inhospitable climate, and the remoteness of the region. Hazard analysis for the Arctic is paramount as it is the first step to safeguarding life, property, and the environment, identifying potential hazards and hazardous events is the best way to prevent or lessen the effects of accidents. This is helpful in breaking the accident chain.

A hazard analysis method suitable for the Arctic should take into consideration the following factors listed in Table 7. With the natures of the hazards varying but all related to maritime, The FMEA method cannot be excluded in the analysis methods to be considered as this is the industry standard for shipping and shipbuilding (Haugen, 2020).

Table 8 External and internal hazard.

External	Internal
Grounding	Machinery equipment failure on deck
Weather	Machinery failure of the engine room
Collision with ice	Fire in the accommodation or machinery space
Freezing temperatures	Cargo
poor visibility	Ice cover
sinking	Crew onboard familiarization, training, and the human element
Tides and current	Oil Spill
Hull structure, bow and propeller damage	Garbage
storms	Sewage
Underwater radiated noise	Air pollution
Ballast	

2.6.1 External hazards

Grounding or running aground is when a vessel comes in contact with the seabed or a reef, this could be as a result of incomplete hydrographic charts of the arctic region and human error.

Weather in the arctic is very unpredictable and is known to change unexpectedly. Throughout history, many ships have been lost due to bad weather, and this poses a potential danger for ships caught out in remote regions of the arctic.

Collision with ice, most vessels that sail in the arctic regions are designed for icebreaking; these are known as category A ice-class and are suited for all-year ice, but not all vessels share this rugged hull structure to withstand a collision with every ice formation. In addition, ice collisions could be detrimental to tankers not designed with specially strengthened hulls, which could lead to the sinking of the vessels. Reversing in icy waters should be done slowly and cautiously to avoid damage to the rudder and propeller blades.

Freezing temperatures are to be expected as this region is known for its freezing temperature. This drop in temperature could affect the performance of certain machinery equipment or compromise to hull integrity of the vessels leading to accidents sinking coalition and damage to brittle metals.

Poor visibility could result from dense fog, excessive snowing, or darkness long darkness, as this region is known to experience such. This could lead to accidents, such as collision, grounding or

The sinking of the vessels entails the vessel going under as a result of the vessel, and this could be caused by various incidence such as capsizing, taking in water, or damage to the hull of the ship due to a collision with ice or rocks.

Tides could pose a threat to the vessel's safety as being trapped in an area of the low tide could lead to the grounding of the ship, or trap the ship in ice. An unfavorable current can expose the vessel to collision, grounding, or other types of structural damage.

The hull structure bow and propeller the bow of an ice-class ship are strengthened to withstand forces, the stresses, and the strain of the ice acting on the vessels and for icebreaking. If this hull's integrity is compromised this would have a devastating effect that could lead to the hull breaking and the vessel sinking. Ice damage to the vessel's hull could result in oil spills.

Storms sailing through storms are challenging with high winds and towering waves battering ships, storms have been responsible for the disappearance of ships in the past. is much better to avoid storms than to sail through them, and given the nature of the Arctic

Underwater radiated noise

Ballast adopted in 2004 the ballast water and sediment convention entered into force in 2017, but ballast water discharge in the arctic is prohibited and vessels are expected to manage their ballast water. Even after the treatment of said ballast water, it cannot be discharged in the arctic protected regions.

Underwater radiated noise from commercial ships can harm marine life, particularly marine mammals, in the short and long term. Underwater noise and its influence on marine animals was first brought up at the International Maritime Organization (IMO) in 2004. It was found that shipping was the primary source of continuous anthropogenic noise in the ocean.

2.6.2 Internal hazards

Machinery equipment failure on the weather deck could occur as a result of ice cover or extreme cold. Pipelines are usually exposed to damage when the appropriate precautions are not taken to mitigate this. Fire hoses and couplings, purging or venting air manifolds, freshwater pipes, winches, and ropes are to be protected from freezing.

Machinery failure in the engine room, freezing could occur in the engine room affecting the performance of certain types of equipment, and damages to brittle metals, freezing of cooling tanks and sea chest.

Fire in the accommodation or machinery space could be challenging as the fire suppression system could experience freezing or clogged piping due to ice.

Ice cover could lead to the ingress of moisture into cargo space or machinery and electrical space. Snow and moist cold air could cause condensation cargo holds. Snow build-up must be dealt with and hatches must be sealed and cleared of snow.

Crew onboard familiarization, training, and the human element, Extreme cold reduces the crew's efficiency considerably, and physical abilities and performance and their ability to make decisions as long-term exposure leads to hyperthermia. Crews onboard arctic going vessels are expected to have special knowledge on survival in extreme cold and competence for ice-class ships

Oil spill on the weather deck ice damage to the vessel's hull could result in oil spills. Likewise, collision or grounding could result in an oil spill. MARPOL Annex I is the main international convention covering the prevention of oil pollution of the marine environment by ships.

Garbage MARPOL Annex V is the main international convention covering the prevention of garbage waste. Waste management in the arctic region of critical importance as no form of waste is thrown overboard.

Sewage MARPOL Annex IV is the main international convention covering the prevention of sewage.

Given the severity of the potential hazards for tankers in the arctic region, the technology and design phase of an ice-class tanker is the first phase the most important phase of any hazard analysis, this part lays the foundation for the tanker's safety, functionality, and durability throughout its life cycle.

At the early stages of the technology and design phase, methods like preliminary hazard analysis or SWIFT, brainstorming, and guided questions could be used and along the line more advanced methods like FMEA should be introduced. When external hazard analysis is carried out it is recommended that the method employed should take into consideration the constantly shifting nature of the region the vessel is to operate, depending on the ice-class notation of the vessel each factor listed in Table 7, relating to external hazard should be tackled, and a satisfactory hazard identification result must be achieved. The analysis method should also identify potential hazardous events and measures to mitigate these hazardous events should be provided.

Chapter 3: Methodology

3.1 Research method

There are three widely used research methodology, the quantitative, the qualitative, and the combination of both qualitative and quantitative often referred to as the mix-method (Choy. L, 2014). The methodology used is dependent on the data type collected and how best to answer the research question. For this thesis paper, the qualitative approach was used to analyze relevant data collected for this thesis paper. The research methodology used is based on the data type, the qualitative methodology is best employed on literary data collections and analysis, and the quantitative methodology is employed for numeric data collection and analysis (Bell, 2018).

3.2 Research design.

Using the qualitative method for this paper, data was sourced from articles and books this paper aim is to understand and explore hazard analysis in the context of ice-class tankers and the hazard analysis methods used in the maritime industry today,

3.3 Sample and population

To understand the hazard and the hazard analysis methods used in general, different research materials, textbooks, journals, and articles had to be analyzed and studied, taking an explorative approach relevant information came from papers and lectures on hazard analysis methods. In other to understand the arctic region and ice-class shipping, relevant paper on arctic shipping and the requirements for ice-class ships were sourced from the classification society.

Preliminary searches revealed that searching for hazard analysis methods alone yielded thousands of documents from scientific journals and other sources majority of the results obtained were risk analysis based. In subsequent searches for modern hazard analysis methods, results were mostly health-based. Redefining the search for hazard analysis for accidents prevention and accident investigation resulted in hundreds of documents for various journals and databases. The search for hazard analysis identified over 120,000 existing hazards and related studies from 1970 to 2021 and further analyzed those applied in the maritime industry. For the FRAM analysis over 98,000 results, for FMEA over 100,00 results.

3.4 Ethical considerations

Research ethical considerations are principles that guide a researcher's research designs and practices. When gathering data from individuals, or scientists, researchers must always adhere to this set of rules (Bhandari. 2018). These principles protect participants in the study's rights, promote research validity, and preserve scientific integrity. This master's thesis was written in conformity with the University of Southeast Norway's research ethics guidelines. Abiding by the ethical principles, the data sourced and collected for this master's thesis was done ethically and with respect to the authors cited. The author of this thesis has no conflict of interest with the results of this body of work.

Chapter 4: Findings

The goal of this chapter is to answer the questions posed in this master's thesis by analyzing the data gathered based on the qualitative research carried out, and the results obtained. This chapter discusses the findings from the exploratory analysis of books, journals, and articles conducted to better understand hazard analysis and the various approaches used in the industry. This research was conducted by analyzing the data collected from various sources, Oria, ScienceDirect, OnePetro, and Elsevier. It is noteworthy that a great deal of research and academic papers have been written on hazard and hazard analysis methods. This cuts across various industries and fields of study, from healthcare to nuclear plants, to the aviation industry, space satellites and rockets industry, the military, and the maritime industry. Hazard is related to what can happen in the future. Hazard is an inherent physical or chemical characteristic that has the potential to cause harm to people, property, or the environment (Macdonald. 2004).

Hazard analysis as an accident prevention and investigation method was first used by the military and later adopted by other industries is prevalent in every aspect of life. The objective of hazard identification is to estimate how often an incident or hazardous event is likely to occur, secondly to estimate the effects on life, the environment, and property, and finally to determine the best level of risk reduction methods to mitigate the risk (Haugen, 2020). What can go wrong, and what is the likelihood of this happening, and what are the consequences if things go wrong, (Kaplan, 1997). Even in mundane daily activities such as crossing a street, hazards are identified and prevented against accidents. This same principle applies to more complex systems and in various industries. The method of hazard analysis used is determined by the complexity of the system being analyzed. There are various methods to analyze hazards and identify potential hazardous events in systems to prevent accidents. The rule of thumb in the all-hazard analysis is to identify the hazard initialing event and put systems in place to stop it or mitigate its effect on the system, as stated in the hazard triangle by Ericson et al "reducing the likelihood of the initiating mechanism from happening, decreases the likelihood of an accident", and removing one element from the Hazard source or Threat or target reduces the severity of an accident.

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Chapter 5: Discussion

The main objective of this study was to find, and understand, hazard analysis, identify traditional hazard analysis methods, understand their strengths and weaknesses, identify new hazard analysis methods, and understand their strengths and weaknesses, and find which method is best suited for Arctic shipping for Ice-class tankers. With several hazard analysis methods available today, these are the following relevant to this study.

The checklist method for hazard analysis is suitable for identifying potential hazards or hazardous events based on previous experiences, but in the larger context for ice-class tankers, this method should be used for basic safety checks and routine operational tasks. As it lacks the complexity and the analytic techniques to deal with more advanced systems.

A checklists method can be created to meet specific safety goals or assist in pointing out all factors of the safety check. The use of Job safety analysis (JSA) combined with the checklist method for routine work onboard the vessel is possible as these methods are similar

Preliminary hazard analysis (PHA) is a basic approach for identifying risks during the design phase of a ship. It is used to identify what needs to be protected and identifies various hazardous that could possibly happen, it is also used to determine the primary reasons for each potentially hazardous incident. this method is updated alone the line. It's can be only in the initial design stage of the vessel and not in the operating phase of an ice-class tanker as this method lacks the complexity to handle hazard analysis in the arctic.

Failure modes, effects, and criticality analysis (FMECA), or FMEA one of the earliest methods for analyzing system reliability; first used by the military, the first guidelines were published in 1949 (Haugen, 2020). It has been the predominant method used for reliability engineering. FMEA is internationally used and recognized. In the maritime industry, FMEA is used in every aspect of the lifecycle of the ship. Excellent in identifying potential failure modes and determining the root causes of such failures and their implications. This is the recommended method of choice for the Ice class vessels and arctic operation, as it is complete to handle and identify complex potential hazardous events. A mixed system or hybrid method of FRAM and FMEA could certify both the external and internal hazards in Table 8.

Hazard and operability (HAZOP) analysis was created to detect deviations and dangerous conditions in process plants. Developed in 1962 for the chemical industry (Kletz 1999). The HAZOP is used to handle chemicals and hazardous cargo on board ships. This method does not satisfy the external and internal hazards in Table 8. The structured what-if technique (SWIFT) is a hazard analysis method used by a group of specialists in a brainstorming session that asks – and answers – a series of what-if questions. This could be used to ascertain the severity of the actions in an unlikely hazardous event.

Fault tree analysis (FTA) is an analysis method for determining the root causes and likelihood of a certain unwanted event occurring. Used mainly in risk analysis, its process touches on the identification of hazards and potential hazardous events but it does not satisfy the external and internal hazards in Table 8 and should be used strictly to determine the root cause of accidents.

Systems-theoretic process analysis (STPA) is designed to tackle some of the flaws and limitations in previous methods of hazard analysis, particularly those involving complex software systems (Haugen, 2020). Built on a systems theoretic accident model and processes (STAMP). There is currently no industry standardized STPA analysis process used in the maritime industry. It satisfies most of the external and internal hazards in Table 8

FRAM hazard analysis is based on the assumption that accidents occur as a result of a function variation rather than component failure (Tian, 2020).

FRAM is a system-based analysis approach that evaluates the entire system and focuses on how it works rather than the structure of its individual components (Tian, 2020). This modern method was first introduced in 2004 by Hollnagel and has been used in various industries. Designed for complex technical systems and FRAM has evolved from an accident model to being used as a more hazard analysis method. This method shows great promise for use in ice-class ships as it can be structured to meet the hazard identification needs of any system.

Given that no hazard analysis method is without its weaknesses, the ideal hazard analysis method for the arctic should satisfy the external and internal hazards listed in Table 8. Is proposed that a combination of systems that applies to different aspects be used when and where it is needed as seen fit by the analyst. A recommendation of a mixed-method approach combining the functional resonance analysis method FRAM and the failure modes, effects, and analysis FMEA as these methods can handle the technical nature of the ice-class ships and the operation aspects.

Chapter 6: Conclusion

This research described the hazard analysis methods generally used in the industry. The papers that guided this study were of industry relevance and broadened the context of hazard and analysis methods predominant in the industry. The findings added to the understanding of the different methods of hazard identification and how they had been employed in the past, and the potential use of an ice-class tanker. Given the nature of the arctic, just one hazard analysis method would not suffice as the external and internal challenges vary and are unpredictable. It is safe to say a flexible approach to hazard identification and analysis should be considered for operations in the arctic.

6.1 Limitation and suggestions for further research

This section of the master's thesis discusses a few limitations that deserve further study.

Because the samples for the analysis were taken from two textbooks and an internet database, the study was is considered constrained.

The selected documents for this research are not the only relevant data published in this study.

The database utilized to obtain data for this thesis is not the only database in the field.

Not every relevant hazard and hazard analysis document was reviewed.

For further studies, I recommend that researchers consider the use of Failure modes, effects, and analysis FMEA and functional resonance analysis method FRAM hazard analysis in long-term effects on the Arctic environment and wildlife.

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