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Dynamic cruise ship contingency monitoring and risk assessment based on a fuzzy logic approach using AIS data

Master's thesis in Marine Technology
Supervisor: Ingrid Bouwer Utne
June 2020

Master's thesis

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Preface

Dear reader.

I would like to start this Master's thesis by including a note on several contributors that have been important throughout the five year period as a Marine Technology student at NTNU in Trondheim. Firstly, an appreciation and gratitude to NTNU and the Department of Marine Technology must be given. Also, the student must mention the University of Auckland, New Zealand, which served not only as a year of exotic adventures, but also introduced the student to the world of risk assessment.

Further the author wants to recognise a few selected people that have been important contributors in the presented Master's thesis. First and foremost, I would like to thank my supervisor, professor Ingrid Bouwer Utne for her guidance and expertise. The frequent supervisor meetings have proved valuable throughout the thesis period, even through digital meetings as a consequence of the Covid-19 lock down.

Appreciations must be given to the Norwegian Coastal Administration for access to AIS data on short notice. Further, Bjørnar Brende Smestad have provided valuable insight, guidance and motivational discussions regarding the usage and implementation of AIS data which have been very valuable in the conducted thesis.

Gratitude is directed to my family who have been motivational as always. The mates at the office is given a special thanks, and last but not least; a big thanks is directed to my flatmates Andreas and Jon Kristian for magical moments and academic discussions in this special period.

Emil Carlsson
Trondheim, June 2020

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Abstract

The purpose of this Master's thesis is to develop a model for dynamic cruise ship contingency monitoring. *Ship contingency monitoring* is understood as a mean of observing a specific ship and its surroundings, further evaluating the severity of a potential accident involving the observed ship. The developed model is based on risk assessment methodology developed to fit a *dynamic* environment, that is to track a ship along its route and account for the continuous change in parameters serving as inputs to the model. A *cruise ship* is defined as a large ship carrying people for pleasure purposes, thus not being exclusively limited to the typical perception of a cruise ship. The motivation for this Master's thesis emerged from the recent Viking Sky accident 23 March 2019, which served as evidence of how cruise ships present in Norwegian waters, for certain situations, might be exposed to an unacceptable risk. Hence, the author has been focused on emphasising key issues when developing such a model and how a similar model can contribute to mitigate a potential future cruise ship accident.

The developed model is based on knowledge from relevant literature also including information obtained from previous ship incidents. The evaluation of how a cruise ship in distress can be assisted by nearby ships have been of particular focus. Thus, the model is developed to reflect factors observed to have influenced a cruise ship's risk level, emphasising how nearby ships can be of assistance. The model combines input parameters to assess the cruise ship's risk level based on a *fuzzy logic approach.* The model's architecture is further developed in a hierarchical and modular structure shown to provide transparent and understandable results.

Obtained results prove how the developed model perform well in terms of continuously evaluating and updating a cruise ship's risk level. This is derived from a detailed analysis of the Viking Sky accident based on the developed model, also comparing the acquired results with a case study of different ships sailing over Hustadvika on the west coast of Norway, the same location as where the Viking Sky accident occurred. The model utilise AIS data to provide a resulting risk level for the ships, integrating nearby ship resources and meteorological conditions. It has proved challenging to evaluate how ships can or cannot assist a cruise ship in distress, which is an important limitation to the developed model. Nevertheless, the final results show how different events will be assigned to different degrees of risk levels thus effectively separating them, which further prove how a similar model could serve as a mean to ensure that a certain risk level is not exceeded. This could be used as an important input for decision makers to re-route one or several ships, prohibit certain sailings or implement other risk reducing measures. The author recognise the importance of a further assessment on *how* ships can assist a cruise ship in distress, providing a better foundation of knowledge increasing the robustness of a similar model. Nonetheless, this Master's thesis has shown the feasibility of a cruise ship contingency monitoring methodology through a dynamic risk assessment integrating nearby ship resources, also providing insight into the complexity of such a task.

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Sammendrag

Hensikten med denne masteroppgaven er å utvikle en modell for dynamisk beredskapsovervåkning av cruiseskip. *Beredskapsovervåkning av skip* forstås som en måte å observere et spesifikt skip og dens omgivelser, for å videre evaluere alvorlighetsgraden av en potensiell ulykke som involverer det observerte skipet. Den utviklede modellen er basert på risikovalueringsmetodikk utformet for et *dynamisk* miljø, det vil si å følge et skip langs en rute og ta hensyn til den kontinuerlige endringen i parametere som fungerer som inputverdier til modellen. Et *cruiseskip* er definert som et stort skip som frakter mennesker på en nytelsesreise, dermed ikke utelukkende definert gjennom den typiske oppfatningen av et cruiseskip. Motivasjonen for denne masteroppgaven kommer fra den nylige Viking Sky-ulykken 23 mars 2019, som var et bevis på at cruiseskip i norske farvann, i visse situasjoner, kan være utsatt for en uakseptabel risiko. Som følge av dette har forfatteren vært opptatt av å fremheve viktige problemer når man utvikler en slik modell, og hvordan en lignende modell kan bidra til å forhindre en mulig fremtidig cruiseskip-ulykke.

Den utviklede modellen er basert på kunnskap fra relevant litteratur som også inkluderer informasjon hentet fra nylige skipshendelser. Evalueringen av hvordan et cruiseskip i nød kan bli assistert av nærliggende skip har vært et spesielt fokusområde. Derfor er modellen utviklet for å gjenspeile faktorer som har blitt observert å påvirke risikonivået til et cruiseskip, der det er lagt vekt på hvordan nærliggende skip kan være behjelpelige. Modellen kombinerer inputparametere for å vurdere cruiseskipets risikonivå gjennom en tilnærming basert på *fuzzy-logikk*. Modellens oppbygning er utviklet i en hierarkisk og modulær struktur som har vist seg å gi gjennomsiktige og forståelige resultater.

Produserte resultater har vist hvordan den utviklede modellen presterer godt med tanke på en kontinuerlig evaluering av et cruiseskips risikonivå. Dette er avledet fra en detaljert analyse av Viking Sky-analysen basert på den utviklede modellen, ved også å sammenligne resultatene med en «case study» av ulike skip som seiler over Hustadvika på vestkysten av Norge, samme sted som Viking Sky-ulykken fant sted. Modellen benytter seg av AIS-data for å beregne et resulterende risikonivå for skipene, ved å også ta hensyn til nærliggende skipsressurser og meteorologiske forhold. Det har vist seg å være utfordrende å evaluere om skip kan eller ikke kan hjelpe et cruiseskip i nød, noe som er en viktig begrensing ved den utviklede modellen. Til tross for dette viser de endelige resultatene at ulike seilaser vil bli tildelt ulike risikonivåer og dermed effektivt vil skilles fra hverandre, som videre viser hvordan en lignende modell kan benyttes for å forsikre seg om at et gitt risikonivå ikke overstiges. Dette kan bli brukt som en viktig input til beslutningstagere for å endre seilingsruten til et eller flere skip, forby visse seilaser eller innføre andre risikoreduserende tiltak. Forfatteren erkjenner viktigheten av en videre vurdering av *hvordan* skip kan assistere et cruiseskip i nød, for å danne et bedre kunnskapsgrunnlag for å øke robustheten til en lignende modell. Denne masteroppgaven har allikevel vist at det er mulig å formulere en metode for beredskapsovervåkning av cruiseskip gjennom en dynamisk risikoevaluering som tar høyde for nærliggende skipsressurser, samt har gitt innsikt i kompleksiteten av en slik oppgave.

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Nomenclature

General Abbreviations	
AIS	Automatic Identification System
BPP	Bollard Pull Power
MoU	Memorandum of Understanding
MRO	Mass Rescue Operation
PSC	Port State Control
SAR	Search and Rescue
swh	Significant Wave Height
Organisations and conventions	
IMO	The International Maritime Organisation
NCA	The Norwegian Coastal Administration
NMA	The Norwegian Maritime Authority
NSRS	The Norwegian Sea Rescue Society
Ship particulars	
DWT	Dead Weight Tonnage
GT	Gross Tonnage

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Chapter 1

Introduction

1.1 Background and motivation

The raw nature and magnificent views found in Norway is a popular and growing cruise ship destination. As described by Visit Norway; "You won't find a more relaxing way to see and experience coastal Norway than on board a cruise ship. It's a hotel room on the move, giving you all the comforts of home, while at the same time letting you take in the joys of Norway's long coastline." (Visit Norway, 2020)

This might have been the intention of the 915 passengers on board Viking Sky sailing down the Norwegian coast in March 2019. However, their *joys of Norway's long coastline* came to an abrupt halt March 23, when the 282 meters long top modern cruise ship experienced a total black out in severe weather conditions just five kilometres off the coastline at Hustadvika. The ship lost all means of propulsion and drifted helplessly towards shore. Just 100 meters from shore Viking Sky regained limited propulsion and was able to battle the waves for more than 19 hours whilst evacuating passengers through a large-scale rescue operation. All evacuated passengers were evacuated by helicopter whilst several nearby ships could do nothing but watch.

In the wake of the Viking Sky accident many have asked questions relating to whether the safety of passenger ships exposed to harsh conditions is acceptable or not, and if actions are required to prevent similar events from occurring in the future ("The Viking Sky incident – A wake-up call for the Arctic cruise industry?", 2019). Questions arise relating to how one might improve the risk level of cruise ships sailing in Norwegian waters where Utne and Vinnem (2019) presents several alternatives for reducing risks such as the refusal of cruise ships to sail in severe weather conditions or by enforcing cruise ships to bring sufficient towing assistance when sailing in remote areas where no immediate towing assistance is available.

As recent cruise ships are being built to accommodate more than 6,000 passengers, the potential consequence of a major cruise ship accident could prove to be disastrous. This forms the basis of how cruise ships should be given more attention to prevent fatal accidents in the future. This Master's thesis will hence evaluate how a contingency monitoring method through dynamic risk assessment can be established and how this can be used to monitor and evaluate the continuous risk level of a cruise ship along its route integrating nearby ship resources.

1.2 Scope and objective

This Master's thesis will investigate aspects relating to cruise ship incidents to establish a method for cruise ship contingency monitoring through a dynamic risk assessment. This is performed to provide a tool aiding decision-makers to circumvent potential high-risk situations.

Ship contingency monitoring is understood as a mean of observing a specific ship and its surroundings to further evaluate the potential severity of an accident involving the observed ship. Throughout the thesis a *cruise ship* is defined as a large ship carrying people for pleasure purposes, thus not being exclusively limited to the typical perception of a cruise ship.

The work will in particular focus on how the availability of relevant ships, hereby referred to as *ship resources*, in the vicinity of a cruise ship may contribute as a risk reducing factor, also including other important aspects such as meteorological factors and shore distance. The methodology of the contingency monitoring model, hereby referred to as *the model*, will be developed to prove how it is possible to obtain a real-time risk level for a cruise ship by using available AIS (Automatic Identification System) and weather data which can be used to monitor cruise ships and thus make pro-active strategic decisions to obtain acceptable risk levels. This methodology will be evaluated by using historical AIS and weather data to analyse a real-time scenario for cruise ships sailing along the Norwegian coast integrating nearby ship resources.

The model will be developed based on risk assessment knowledge and methodology to combine risk influencing factors into a total risk level. Thus, an investigation on cruise ship accident statistics and individual events will be performed to understand how factors influence accidents to establish which factors to implement into the model. This will also include an investigation on different ship categories' potential to assist in a cruise ship accident. The work will also focus on understanding existing safety regulations relating to the cruise ship industry as well as how cruise ship accidents are being planned for today to evaluate how this could affect the proposed model.

1.3 Limitations to the proposed objective

The model will be developed to provide a risk level for cruise ships thus limiting the work to focus on cruise ship accidents and relevant theory. in addition, the model will, with certain exceptions, only evaluate environmental and geographical variations that apply to Norwegian conditions, thus no work will be performed to evaluate how the model performs in other geographical conditions.

1.4 Confidentiality note on AIS data

This thesis will use AIS data acquired from the Norwegian Coastal Administration (NCA) which will be handled according to the Norwegian licence for public data 2.0 (NO: Norsk lisens for offentlige data 2.0) as well as through a confidentiality agreement between the student and the Department of Marine Technology, NTNU. As a consequence, AIS data presented will not contain information that identifies individual ships, and if ship particulars are presented, they will be approximate values to safeguard a ships identity.

With that said, the author has no intention of deliberately target any ship or in any way blemish the reputation of a specific ship. Ship identities will be presented in the following work if the ship is not presented through AIS data alone, that is if the author recognise the importance of including a ship name from accident investigations to enhance the ability to reproduce the work and to increase the credibility of the performed work.

1.5 Structure of the report

The report is divided into 9 chapters. After the introduction in chapter 1, chapter 2, 3 and 4 will present relevant theory for the proposed contingency model development. Selected theory will further be used to develop a risk model in chapter 5 which is validated from different scenarios in chapter 6. Chapter 7 will then develop a program to process and present AIS data in combination with the developed risk model. The results from the developed cruise ship contingency monitoring model is then presented and discussed in chapter 8 before a final discussion and conclusion of the presented results is performed in chapter 9. A short discussion on further work will also be presented in chapter 9.

Chapter 2

Risk assessment and dynamic risk modelling

The following chapter will introduce some risk concepts to provide a basis of knowledge used throughout the thesis. A number of risk assessment methods will be presented and discussed based on relevant theory further evaluated against the proposed risk model. Eventually a risk assessment methodology will be chosen that will be used for the following model development.

2.1 General risk theory and concepts

Rausand (2013) describes risk as something relating to that can occur in the future, and how the use of correct methods allows one to analyse and manage risk. A general definition of risk is often defined as the probability of an event multiplied with the consequences of said event, and a risk analysis seeks to derive a quantitative or qualitative risk measure by answering three questions; 1. What can go wrong?; 2. what is the likelihood of that happening?, and; 3. what are the consequences? (Kaplan & Garrick, 1981).

Risk assessment is the combined analysis and evaluation of available information in which the risk can be managed to be within an acceptable limit. A commonly used model to visualise the relationship between hazards/threats, an hazardous event and its consequences is the *bow-tie diagram*, as represented in Figure 2.1. The bow-tie diagram is also presented with barriers, which is a representation of controls that will stop either an hazardous event from occurring in the first place, or to limit the consequences of said event.

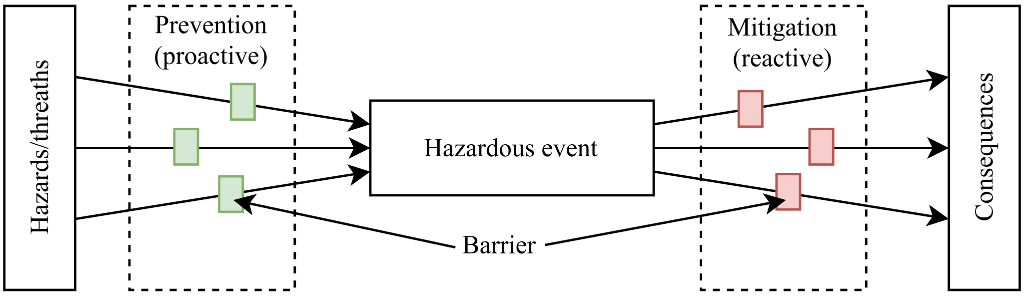

Figure 2.1: Illustration of the bow-tie diagram with barriers.

The idea of the work conducted in the following thesis is to develop a model which will have the potential to act as a barrier on both the proactive and reactive side of an hazardous event focused on preventing and mitigating a major cruise ship accident.

2.2 Risk assessment

Within risk management a number of different methods exist to assess risks in complex systems, both for qualitative, quantitative and semi-quantitative purposes (Mentes & Helvacioglu, 2011). The most commonly used methods to assess the safety of marine systems are presented in the below list;

- Preliminary Hazard Analysis
- Failure Modes and Effects Analysis
- Fault Tree Analysis
- Event Tree Analysis
- Hazard Operability Studies
- Artificial neural networks
- Markov Analysis
- Bayesian Belief Network
- Monte Carlo Simulation
- Dempster-Shafer Theory
- Fuzzy Logic Approach

Some of the above methods are commonly used for qualitative and early analyses, such as Preliminary Hazard Analyses and Failure Modes and Effects Analyses. Bayesian Belief Networks and Fault Tree Analyses have been used extensively for maritime quantitative analyses to assess complex systems and are well suited to determine the root causes and the probabilities of an undesired event (Rausand, 2013). Artificial neural networks and Monte Carlo simulations can provide very good results but are subject to advanced knowledge within fields of computer science and mathematics.

Other methods exist like that of Eide et al. (2008) which combine accident frequencies with consequence modelling for a number of input variables to achieve a total risk picture.

A downside with many of the mentioned methods, such as Bayesian Belief Networks and Fault tree analyses is their need for input values supported by precise statistical information thus, they do not easily incorporate subjective and vague terms. An alternative solution to this is the fuzzy logic approach, also called the approximate reasoning approach which is described by Sii et al. (2001) as an alternative approach to risk modelling using a fuzzy inference system.

2.3 Managing input uncertainties

Within the maritime domain, many systems will have a high level of uncertainty rooted in the nature of their complexity hence they need special consideration. A modelling approach well-fit to manage such uncertainties is the fuzzy logic-based approach. Zadeh (1988) discuss how fuzzy logic not only utilise classical two-valued and multi-valued logical systems but how it also integrates probability theory and probabilistic logic. In essence, this can be understood as the methods ability to represent values in terms of 'degrees of truth' such as by low, medium, high, very high and so on. The idea is that fuzzy logic is closely related to the human ability to make rational decisions in an uncertain and imprecise environment. As an example, Hegde et al. (2018) presented a method to develop a safety envelope around an underwater remotely operated vehicle based on a fuzzy logic interpretation of imprecise inputs through a human preference model. The result proved the functionality of the concept but also emphasised how the method development could prove challenging in terms of defining a valid rule set that gives reasonable output values.

On the other hand, if the uncertainty of the model inputs is quantifiable, Baraldi et al. (2015) discuss how methods based on BBN are well suited to provide a satisfactory representation of the output uncertainty. However, it is emphasised that for a case characterised by limited knowledge a fuzzy inference system often proves to give a more transparent representation of the input and output uncertainty. Models exist that combine the two approaches which have been proven to provide good results (Eleye-Datubo et al., 2008).

2.4 Previous work on dynamic risk models

Much work exists on the application of fuzzy logic to the maritime domain, such as the study on a ship-bridge collision alert system (Wu et al., 2019) and the determination of a ferry operation safety criteria (Priadi et al., 2013). Their common issue is the development of a precise model within an uncertain environment.

Machine learning models have recently been developed that use AIS data to monitor ship traffic for anomaly detection, which is thought valuable to mitigate groundings, navigational mistakes, terrorism and other unwanted events (Norconsult, 2018; The Norwegian Coastal Administration, 2020a).

MAROFF (The Norwegian Innovation Programme for Maritime Activities and Offshore Operations) initiated the project *Enhanced Surveillance and Decision Support*, which worked towards the development of a preventive risk based ship prioritisation model with the goal of preventing oil spill accidents by identifying and monitor high risk ships. In relation to the MAROFF-project Eide et al. (2008) presents a methodology towards the development of a dynamic environmental risk model for tankers along the Norwegian coast which includes ship drift models, vulnerability data and AIS-data. This also integrates accident frequency and consequence modelling and is based on a spatial and time dependent risk definition, which explores how AIS-data can help position tugs in the most risk-effective locations.

A similar study is presented by Balmat et al. (2011) which developed a decision-making system to maritime environmental risk assessment based on a ship's characteristics, position, and the prevailing weather conditions. The study presents how the use of fuzzy logic proves valuable to obtain a flexible decision-making tool by developing a modular and hierarchically fuzzy logic structure that accounts for both static and dynamic factors, see Figure 2.2.

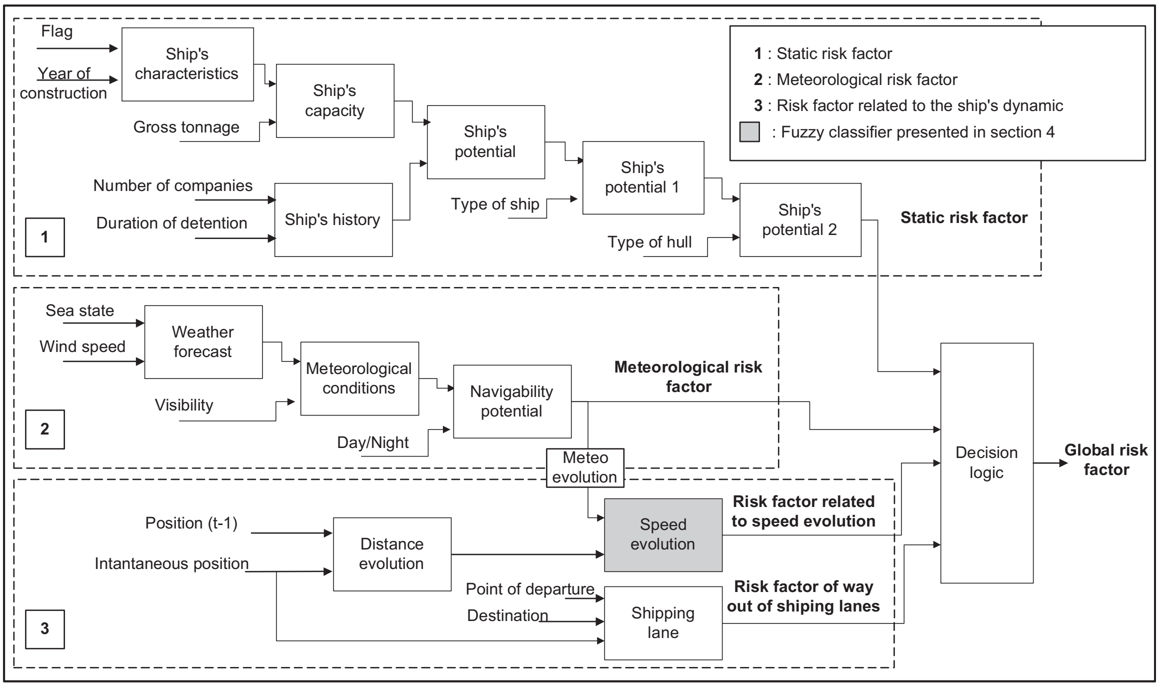

Figure 2.2: The general design of the risk model developed by Balmat et al. (2011) combining risk assessment and the fuzzy logic approach.

The methodology presents a model architecture which incorporates ship specific parameters of ship age, size, flag, etc., with meteorological parameters such as sea state and visibility which are further combined with a ship's dynamics such as speed evolution. This is all combined to establish a global risk factor.

2.5 Summary and final choice of dynamic risk model method

A number of different methods have been presented as candidates well-fit to suit the intended model description. The author has ultimately decided to move forward with the fuzzy logic methodology based on a number of findings. First of all, this method have been proved to provide good result based on input values based on vague and/or imprecise knowledge which is often the case for cruise ship accidents as will be explored further. Secondly, the fuzzy logic methodology is well described in a number of papers which will ease the work to integrate the theory also using the previously presented work by Balmat et al. (2011) which gives a good indication on how such a model can be developed for maritime risk assessment purposes.

Thus, the fuzzy logic methodology is chosen as a basis to develop a risk level for cruise ships given a set of input values similar to that seen in Figure 2.2. Hence the following chapters will focus on understanding which factors that are important to include in such a model, and how they should be combined to provide the best possible total risk level.

Chapter 3

Cruise ship safety

The following chapter will firstly introduce the work performed in the previously conducted project thesis, which serves as an initial basis for the proposed model development. Further, general literature relating to the safety of cruise ships will be presented to gain insight into the current areas of concern. This will also include an overview of important regulations relating to cruise ship accidents and cruise ship operation. Finally, a brief statistical analysis will be performed to support the presented literature and investigate *why* cruise ship accidents occur.

3.1 Project thesis summary

As an introduction to the master thesis work, a project thesis was produced to extract and understand information relating to the proposed master thesis objectives (Carlsson, 2019). The project thesis was titled *An investigation on cruise accidents and mishaps focused on the development and quantification of major risk contributing factors*, and hence focused on answering three questions; 1. What is the current status and outlook on the cruise industry; 2. Which factors are the most important to consider when evaluating the operational risk of a cruise ship, and; 3. How can this information be used towards the development of a dynamic risk model for cruise ships along the Norwegian coast?

Four cruise ship accidents were analysed using the man, technology and organisation (MTO) accident investigation model to deduce major risk influencing factors. A statistical analysis was also performed to better understand how weather, ship age and ship size seems to influence an accident. The main conclusions of the conducted work will be presented along with important works performed to establish the presented conclusions, however the full analysis is not presented in this report.

Table Table 3.1 shows the main findings from the four selected accidents. Each factor has been ranked from -3 to +3 according to their how they influenced the accident, 0 being no observed influence and -3 or +3 being a major negative or positive influence, respectfully. A copy of the factor definitions and discussions supporting the quantified factors can be found in Appendix section A.2.

Table 3.1: A summary of risk contributing factors showing how they contributed positively or negatively in the total assessment of the respective incidents analysed. Factors are evaluated between -3 and 3, -3 being maximum negative influence, +3 being maximum positive influence and 0 meaning it did not influence the incident. Explanations, comments and definitions of all factors can be seen in section A.2.

	Analysed incident			
Factor	Viking Sky	Carnival Triumph	Costa Concordia	Star Princess
Weather	-3	+1	+1	+1
Emergency preparedness	+1	+2	-2	+3
Maintenance	-3	-3	0	-1
Navigation	-2	0	-3	0
Communication	+2	-1	-3	+2
Geographical location	-3	-2	+2	+1
Passengers	-1	0	-1	-2
Ship design	-1	-2	-2	-2

Similarly, the results from the statistical analysis is presented in Table 3.2. The analysis is based on a ship accident database and consequentially factors was evaluated on how present they seemed to be in different accident categories. The presented factors were ranked ranging from a value of 0 to 3 representing their degree on negative influence on the different accident categories. A value of 0 means that the factor did not seem to affect the different accident categories, 3 implied that the factor seemed to be a present factor in the reviewed data, and thus having a negative influence on the given cruise ship accident categories, whilst 1 and 2 is something in between. A copy of the conducted project thesis work showing a detailed discussion on the development of the values representing the different factors can be seen in Appendix section A.2.

Table 3.2: Result from the statistical analyses, showing how different factors seem to contribute negatively to the different accident classes. The factors are rated from 0 to 3, 0 meaning that they are not thought to be a of any significant influence, whilst 3 being that they do influence a risk factor in a significantly negative way. A full explanation of the rated factors can be found in Appendix section A.3. *Hull/Machinery*^{1} is referring to the accident class of *Hull/Machinery damage*.

Factor		**Accident class**				
		Hull/Machinery^1	Fire/Explosion	Contact	Collisions	Stranded
Weather	Heavy weather	3	0	3	3	3
	Good weather	0	0	0	1	2
	Poor visibility	0	0	0	2	0
Ship age	<5 years	3	1	0	0	0
	5-15 years	2	2	0	0	0
	15-25 years	1	1	0	0	0
	>25 year	2	2	0	0	0
Ship size	<100,000 GT	0	0	0	0	0
	>100,000 GT	1	1	0	0	0

The main takeaways from the project thesis was as follows. Firstly, the work emphasised how the cruise industry is a growing industry and that the safety of cruise ships must be carefully considered as the potential consequences of an accident could prove to be severe. Further the work proved as evidence towards how cruise ship accidents comprise complex combination of factors which will influence an accident in both positive and negative ways. The prior work from the project thesis have been an important basis in the further work.

3.2 Current challenges within the safety domain of the cruise ship industry

The following section will further describe recent work done within the cruise ship safety domain, to further develop a basis of knowledge for the proposed model. Literature related to cruise ship safety and relevant regulations will be presented followed by available theory on mass rescue operations. This will include the presentation of state-of-the-art research and development within ship safety, especially cruise safety on a global basis.

3.2.1 Relevant literature and recent trends

It is important to understand how recent research concerning cruise ship safety can aid in the development of the proposed dynamic risk model. The literature search has been focused on exploring which areas of research that exists and how they are relevant for the intended model development.

From the statistical safety review of cruise ship accidents by Mileski et al. (2014) it is shown that the dominant cause of cruise ship accidents is the lack of maintenance of important ship systems (60.52 %) and the second largest being human errors by the crew (26.21 %). Mileski et al. (2014) further discuss how there seems to be a paucity in academic research assessing the causes of cruise ship accidents. Some recent literature of relevance does however exist and is presented as follows.

Lois et al. (2004) introduce a formal safety assessment of cruise ships discussing the complex nature of accidents, and how simple countermeasures can contribute positively, such as proper training of crew and improved operational procedures.

The study by Talley et al. (2008) discuss the severity of cruise ship accidents, and how ocean-going cruises seem to have the highest probability of incurring nonfatal and fatal injuries compared to other types of cruises.

Mileski et al. (2014) discuss how the paucity in cruise ship accident research could be caused by the rarity of major cruise ship accidents where, from 2005 to 2012, there was in fact only 16 fatalities out of more than 100 million cruise ship passengers carried worldwide.

Further, Eliopoulou et al. (2016) presents a recent statistical analysis of cruise ship accidents and review of cruise ship safety level. They present how statistics reveal an exceptional standard of safety on cruise ships and how hull and machinery damage-accidents are the dominating accident type for cruise ships.

3.2.2 IMO on cruise ship safety

IMO is especially concerned of the safety regarding passenger ships, usually defined as a ship carrying more than 12 passengers (The International Maritime Organization, 2020), which includes the category of cruise ships. Cruise ships must comply with all relevant IMO regulations, often adapted or improved in the wake of serious ship accidents like that of the 1992 fire safety amendments being adapted after the Scandinavian Star fire in 1990 (“History of fire protection requirements”, 2020).

3.2.3 Recent work and current cruise ship safety framework

A special ISM Code for passenger ships also came into force in 1998, which provided international standards to ensure safe management and operations of passenger ships, and also to prevent pollution.

In the years following 2000, as cruise ships increased in size, the Maritime Safety Committee which deals with all matters related to maritime safety and security within the scope of IMO, reviewed regulations concerning passenger ship safety to assess whether or not they were adequate.

The philosophy of the work was to emphasise the importance within the two following main areas:

1. the importance of preventing casualties from ever occurring in the first place; and
2. to design future ships for improved survivability so that, in the case of a casualty, people can stay safely on board as the ship sails to port. This is the concept of that the ship is its own best lifeboat.

The revised passenger ship regulations entered into force in 2010, and included the following amendments which affects passenger ships built after 1 July 2010 ("New international passenger ship safety regulations enter into force", 2020):

- alternative designs and arrangements;
- safe areas and the essential systems to be maintained while a ship proceeds to port after a casualty, which will require redundancy of propulsion and other essential systems;
- on-board safety centres, from where safety systems can be controlled, operated and monitored;
- fixed fire detection and alarm systems, including requirements for fire detectors and manually operated call points to be capable of being remotely and individually identified;
- fire prevention, including amendments aimed at enhancing the fire safety of atriums, the means of escape in case of fire and ventilation systems; and
- time for orderly evacuation and abandonment, including requirements for the essential systems that must remain operational in case any one main vertical zone is unserviceable due to fire.

The adapted amendments can be summarised into five main categories, which all relates to passenger ship safety:

Prevention

Focus on fire prevention, navigation safety, training and contingency planning;

Improved survivability

Focus on essential system redundancy, emergency management and casualty mitigation;

Regulatory flexibility

Promote the regulatory approval of new safety technologies and arrangements;

Operations in areas remote from SAR facilities

Guidelines focused on reducing passenger recovery time from survival crafts and water, as well as external SAR support, and;

Health safety and medical care

Focus on medical safety programmes and cold-water survival.

Cruise ship voyage planning

IMO's resolution A.893(21) adopted 1999 facilitates guidelines on ship voyage planning, which was supplemented with resolution A.999(25) adopted in 2007 which gives guidelines on voyage planning for passenger ships operating in remote areas (IMO, 1999, 2007).

The prior resolution address the importance of adequate planning to ensure the safety of life and property, and the latter highlights the importance of geographic limitations of remote areas especially relating to ice and the availability of search and rescue (SAR) resources.

However, there seems to be a lack of explicit rules and regulations covering how ships carrying a large number of people, such as cruise ships, should take extra precautions in their voyage planning.

Contingency planning and SAR research

In relation to cruise ship contingency planning and external SAR support, IMO's Maritime Safety's Sub-Committee on Radiocommunications and Search and Rescue (COMSAR), formulated in 2003 a project with an initial objective to collect SAR research information relating to passenger ships ("Report to COMSAR", 2010). The limited amount of existing SAR research proved to be a difficulty, and it was evident that the existing research focused on design issues rather than the topics of search and rescue.

The committee have over the years prepared a number of guidelines relating to developing robust plans for cooperation between search and rescue services and passenger ships. Amongst others, these guidelines accentuate the importance of the following four topics (IMO, 2017):

1. to link the SAR response plans of the company, the passenger ship, and relevant SAR services so that these plans complement each other;
2. to enable the early and efficient establishment of contact in the event of emergency between the passenger ship, the company's shore-based emergency response system and the SAR services. The SAR plan for cooperation should ensure that all relevant contact details are known to each of the three parties beforehand and that these details are kept up-to-date;
3. to provide the SAR services with easily accessible and up-to-date information about the ship – in particular the intended voyage and onboard communications and emergency response systems; and
4. to provide the ship and the company with easily accessible information about SAR and other emergency services available in the ship's area of operation, to assist in decision-making and in contingency planning.

Summary of the IMO cruise ship safety framework

Recent developments within IMO concerning cruise ship contingency planning and availability of search and rescue-resources show how this is an area that needs careful consideration.

Firstly, cruise ships are larger than ever before, and even though the probability of an accident from historical records is exceptionally low, an accident with a large cruise ship could prove to be disastrous for the thousands of people on board. Secondly, there is a lack of regulations on how cruise ships plan their voyage, especially for different geographical areas which might require alternative and more strict regulations.

Finally there seems to be a vacuum within the regulatory literature on how cruise ship voyage planning is prepared and executed with respect to local geographic and oceanographic conditions and how these should be included in a voyage planning phase to account for any possible unwanted scenario.

3.2.4 Mass Evacuation Theory

From the presented literature it is evident that cruise ship accidents do occur and that one must prepare for such events. Hence the following section will focus on understanding existing literature on mass evacuation theory, and how this can be integrated into the proposed model.

IMO define a mass rescue operation (MRO) as ”one that involves the need for immediate assistance to large numbers of persons in distress such that capabilities normally available to search and rescue authorities are inadequate” (International Maritime Organisation, 2003). IMO further emphasise that events of mass evacuations on a global scale are rare but not infrequent, hence are often poorly understood due to their rarity.

IMO urge companies that operate ships carrying a large number of people to work towards minimising the chances that MROs will be needed, and ensure their success if they are. The MRO guidance provides several recommendations on how a sudden accident requiring a MRO should be handled. The most relevant general guidance is summarised in the following list;

- It is advisable to stay on board the ship for as long as it is safe to do so;
- Acknowledge the importance of continuous accounting of all people on board and lifesaving equipment;
- Deck space should be available to ease a helicopter landing or hoisting operations;
- Minimise unnecessary communications with the master of a ship in distress;
- During certain circumstances it might be better to tow survival crafts with occupants to shore rather than removing them at sea.

Apart from that of IMO, very little information exists on MROs. Bureau Veritas have presented some thoughts and statistics relating to MROs stating how cruise ships might be a concern, as they comprise only 12 % of the passenger ship fleet but account for 22 % of the passenger capacity (Corrignan et al., 2011). Further they present a case study analysing the time frame of an MRO-event occurring in the Dover Strait. The rescue resources included 3 helicopters and 11 ships. The rescue operations time frame is illustrated in Figure 3.1.

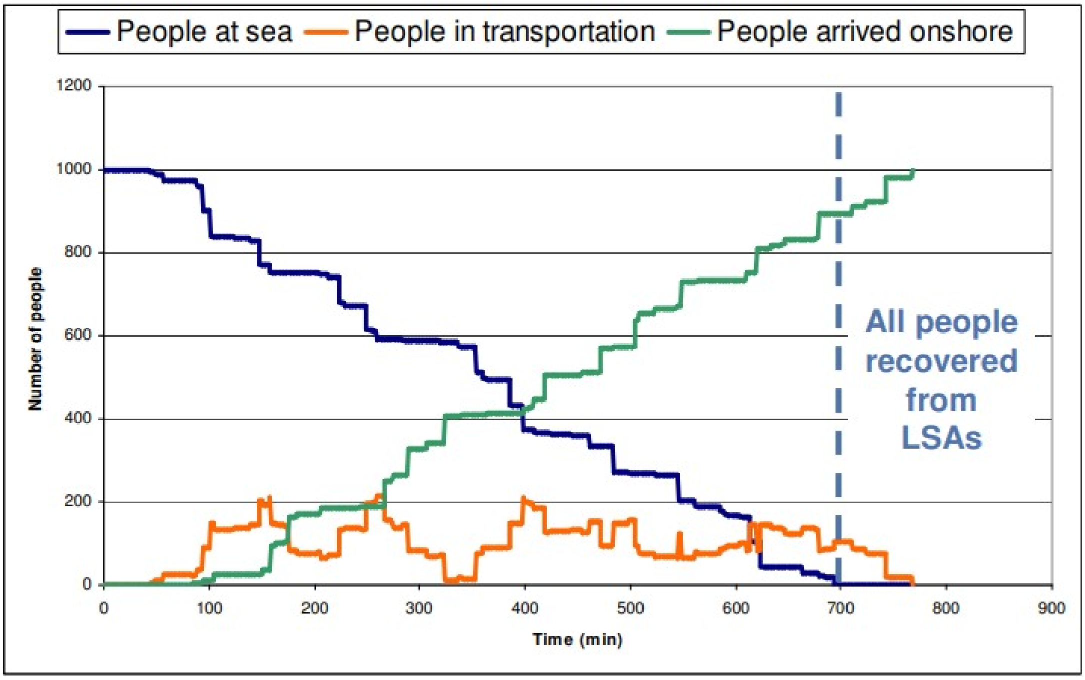

Figure 3.1: Figure adapted from the Bureau Veritas analysis of the time-dependent development on passenger recovery from life-saving appliances (LCAs) for the evacuation of a ship in distress with 1,000 people on board (Corrignan et al., 2011).

It can be seen that the total time before evacuation is complete is approximately 11-12 hours. It is important to remember that this is a case study under ideal conditions, and that the evacuation of passengers in a real-life scenario might be prone to unavailability of rescue resources or that standard rescue procedures are encumbered due to shore proximity, weather conditions etc.

Further, Corrignan et al. (2011) presents important findings from casualty statistics from year 2001-2011 on passenger ship accidents and evacuation;

- 50 % of casualties leading to an abandonment are related to fire or grounding events
- 50 % of casualties lead to disembarkation at sea
- 50 % of fire events lead to disembarkation at sea
- 70 % of grounding events lead to disembarkation at sea
- 70 % of collision, steering and machinery events lead to disembarkation in port

Other work includes that of Pospolicki (2017) who presents a study on how to improve mass evacuation, with several relevant case studies and interviews. He describes the four main phases of a ship evacuation with two steps;

1. On board; Assembly ⟶ Abandon

↓

2. At sea; Clearing of vessel and waiting for rescue ⟶ Rescue

Pospolicki (2017) further describes how the *Rescue*-phase have no standardised procedures, but commonly consist of three standard means of rescue-resources;

- Re-routed ships (e.g. other passenger ships, cargo ships etc.);
- Maritime rescue boats, and;
- Helicopters.

The study presents in detail studies and discussions of evacuation theory relating to the Norman Atlantic fire in 2014, the Sorrento fire in 2015 and also what is referred to as minor incidents. The main conclusions of interest are summarised as the following;

- Survival craft embarkation tends to be impeded by fire or smoke
- Evacuation systems may not perform well in high wind speeds
- Hypothermia are seen to affect passengers during prolonged evacuations
- The transferring system from survival crafts to rescue units is problematic, especially during high seas

Summary of Mass Evacuation Theory

With the presented literature several important aspects are being mentioned. First it is noted how a large percentage of maritime casualties for passenger ships leads to a disembarkation at sea, and that MROs does occur and need to be prepared for. Secondly, the time needed for an evacuation of a large passenger vessel is substantial, which can lead to passenger hypothermia if life-saving appliances, clothing etc. are not adequate. This seems to be closely related with the number of available ship evacuation/assistance resources. Thirdly, high seas and high wind speeds are emphasised to make ship disembarkation and evacuation particularly difficult.

The author recognise how the presented literature seem to emphasise the importance of having rescue resources in immediately vicinity should a cruise ship accident occur.

3.3 Statistic review of recent cruise ship and passenger ship accidents in Norway

The following statistical overview is meant to provide statistical arguments as to why it seems advantageous to develop a model evaluating the risk of cruise ships emphasised on the presence of nearby ship resources. Thus, the following chapter will present statistics revealing which accidents that are most frequent amongst cruise ships and passenger ships and what their causes are. The reason to include passenger ships in the analysis is the scarcity of data from cruise ship accidents and that the two ship categories are often combined into a single category.

Data used in the following analysis is extracted from the Norwegian Maritime Authority's (NMA's) accident database from year 2000 to late 2019.

Figure 3.2 shows the accident types of registered accidents for cruise ships.

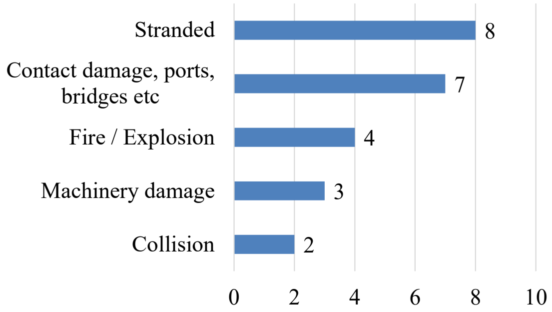

Figure 3.2: The figure show the distribution of accident categories for cruise ships from the NMA accident database.

It can be seen how over the course of 19 years, only 24 accidents are registered for cruise ships. This can be compared with the fact that in the same period, the Norwegian institute of transport ecomonics (2018) cruise ship berthed more than 30,000 times in Norwegian ports, it seems to confirm the work presented by Eliopoulou et al. (2016) stating how cruise ships have an exceptional statistical standard of safety.

It is of interest to analyse the probable causes of the accidents. An in-depth analysis of accident causes will not be performed. However, a presentation of the available accident statistics will be briefly discussed.

There is a limited amount of information registered per accident, and the available information includes amongst others, ship ID, date of event, location of the accident, rough ship damage consequence and the involved equipment. Of these, it is assumed that the equipment involved in the accident, often involved as in being dysfunctional to its intended purpose, should be given further attention. See Figure 3.5 which shows the equipment involved in the different cruise ship accident classes.

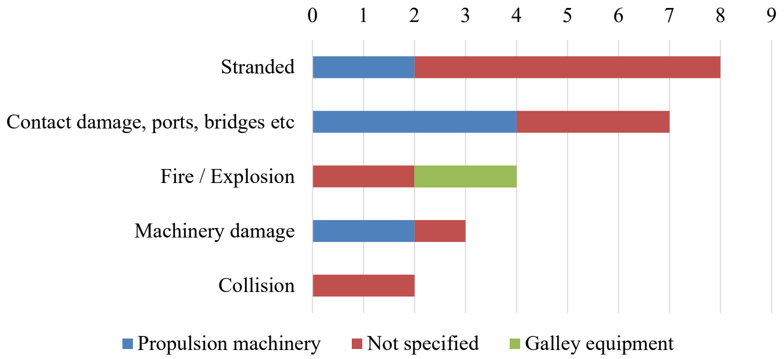

Figure 3.3: The figure shows the ship equipment involved in the different cruise ship accident categories.

It is hard to deduce information from the somewhat vague and limited amount of data presented in Figure 3.5. However, it is noted how the presence of propulsion machinery equipment seems to be dominant along with the non-specified equipment-category.

Due to the limited amount of accident statistics relating to that of cruise ships, it is thought to be advantageous to include data from all passenger ship accidents. This will, apart from cruise ships, also include other passenger ships like RoRo-ships and passenger car ferries.

Figure 3.4 shows the different accident types of all registered passenger ship accidents in the data base.

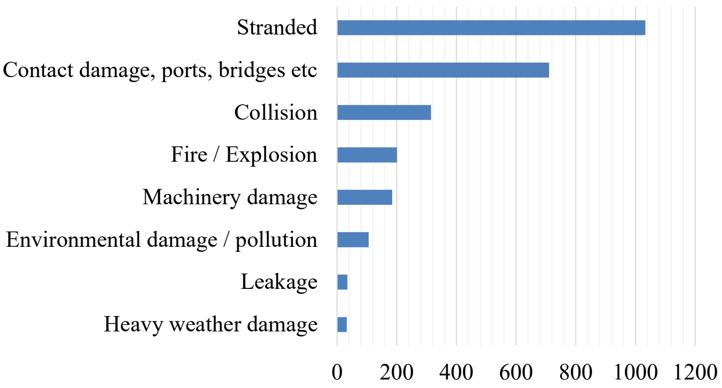

Figure 3.4: The figure presents the distribution of accident categories for ships registered in the NMA's accident database as passenger ships.

Figure 3.5 shows the equipment involved in the four main contributing accident classes from Figure 3.4, represented as pie charts.

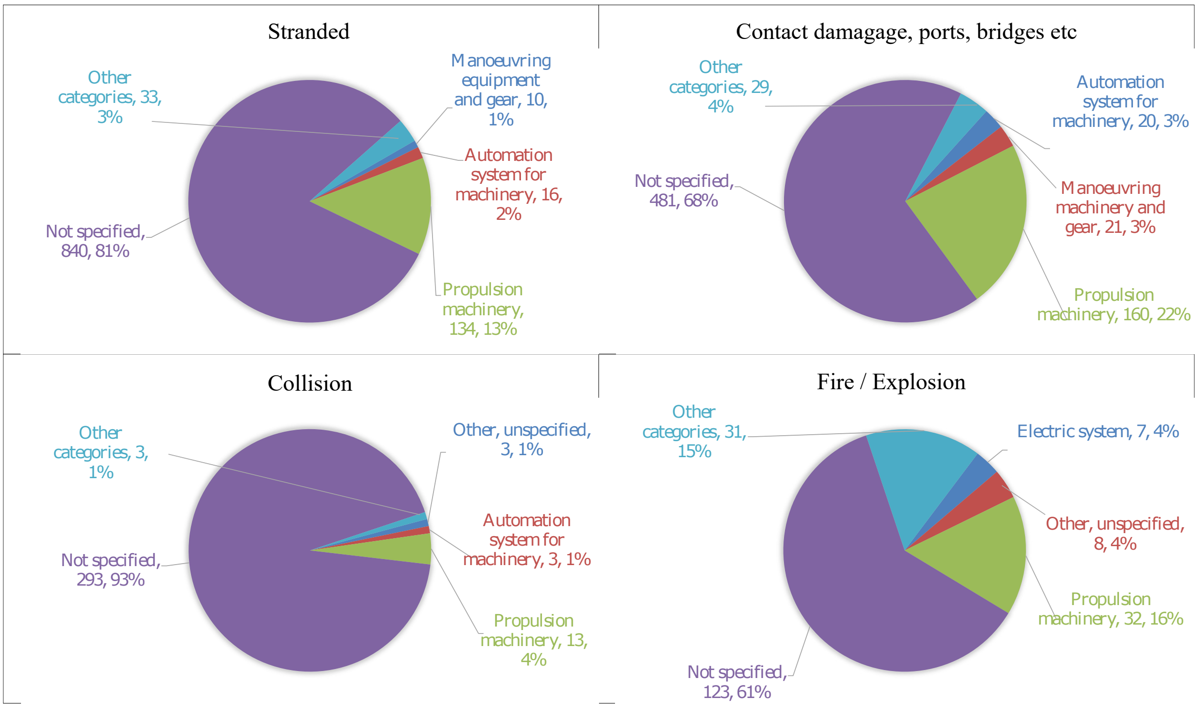

Figure 3.5: The figure shows the main equipment involved in the four main contributing accident classes for passenger ships.

It can be seen how for all four accident categories of the observed accidents, the specific equipment involved is not always specified, which can relate to other accident causes, e.g. human errors. It can be seen how the failure of propulsion machinery dominates all four main accident classes, similar to that seen for cruise ships in Figure 3.3.

To further investigate the presence of the propulsion machinery equipment failure class, Figure 3.6 shows a pie chart of the equipment failure categories for all passenger ships. The four most contributing accident classes for both non-specified equipment and the propulsion machinery equipment is shown as bar charts.

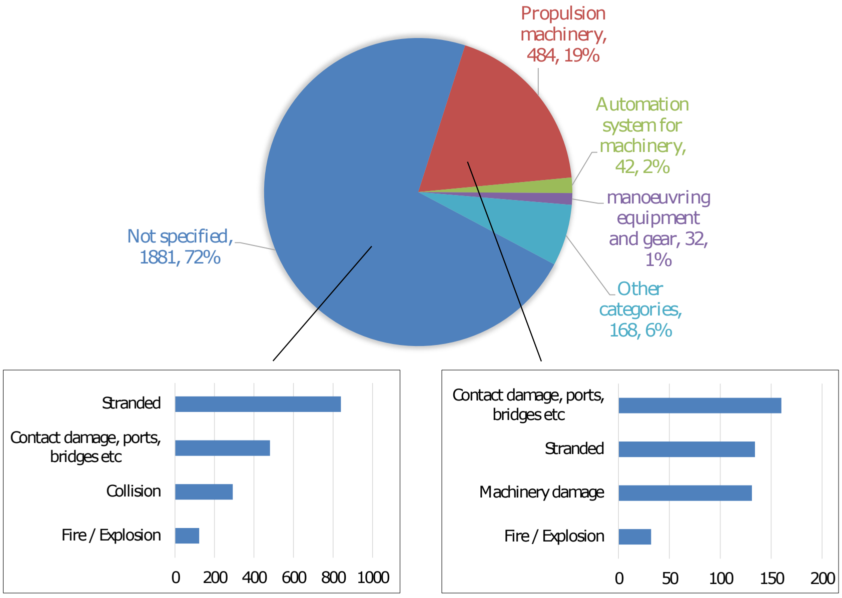

Figure 3.6: The figure shows a pie chart of the equipment involved for all passenger ship accidents, as well as the main contributing accident categories for the *not specified*-category and the *propulsion machinery*-category.

Most of the registered accidents' involved equipment is seen to be *not specified*. There could be several reasons for this, one being how the literature emphasise how accidents are dominated by human errors, which was one of the two main causes for cruise ship accidents presented by Mileski et al. (2014). The other main cause presented was the *lack of maintenance on of important ship systems* which seems to be coherent with the presented statistics.

3.3.1 Summary of the presented statistical ship accident overview

Through the conducted statistical analysis, the author recognises that information relating to individual accidents are vaguely formulated in the accident statistics. To fully understand the development of an event, time consuming individual assessments must be performed which makes it hard to easily assess both the causal and consequential side of an event. For instance, the presented statistics reveal how propulsion machinery is a dominant part of passenger ship accidents, but does not specify further how the event evolved, i.e. if a ship was towed to safety, managed to fix the problem themselves or if any other outcome was the case. It is also hard to evaluate the seriousness and potential consequence of the events from the accident database.

The data presented from the NMA ship accident database seems to emphasise how cruise ships and passenger ships in general are prone to accidents that demobilise the ship. This further shows how it is thought important to analyse how nearby ship resources can assist a cruise ship in distress and how the cruise ships' risk level can be both positively and negatively affected by including nearby ship resources into a total risk level evaluation.

In the next chapter, the model will be further developed by investigating how different factors influence a cruise ships dynamic risk level.

Chapter 4

Model theory

To obtain a better insight into which theory is thought to be of importance for the proposed model development, a simple flow chart describing the basic architecture of an assumed ideal ship monitoring system is presented in Figure 4.1. The model is based on the combination and simplification of existing dynamic risk models as presented in section 2.4.

Obviously, there will be many factors that must be considered in a ship monitoring system which might not have been mentioned in the above presented figure such as collision avoidance methods and similar. However, the ship monitoring system architecture provides insight into the most vital parts of such a system, especially considering the input variables.

The input variables as seen in Figure 4.1 is assumed to be important when monitoring a cruise ship's risk dynamic level, even though the ship monitoring system is generalised to apply to all ships.

Hence the following chapter will focus on the following theory; section 4.2 will firstly present how both static and dynamic ship data can be acquired and analysed from available AIS-data. Further section 4.3 will present theory on how maritime accidents are being planned for along the Norwegian coast, which will be elaborated in section 4.4. Further, an investigation into the available ship resources along the Norwegian coast is presented in section 4.5.

The chapter will eventually perform an analysis of a few selected ship incidents to gain a further insight into risk-influencing factors in section 4.6. Finally section 4.7 will discuss how environmental conditions should be implemented in the proposed model.

4.1 Ship standard and static risk evaluation

From the work performed in the project thesis it was shown how dynamic factors contribute in accidents, but also static factors such as a ship's size and age. Factors such as flag of convenience and company performance was not evaluated but should be given attention. It is thought advantageous to divide the proposed cruise ship risk model into a static and dynamic part, similar to the work presented by Balmat et al. (2011). Thus, this section will deduce how a static ship risk level can be obtained using the existing methods which are well implemented in the maritime industry.

When evaluating the standard of a ship, it is the responsibility of a flag state authority to enforce and ensure that ships registered under its flag follows required regulations. Flag state authorities operate with different rules thus attracting different ships. The reason to choose a certain flag of convenience is complex and often driven by fiscal incentives combined with less restrictive regulations (Saini, 2017).

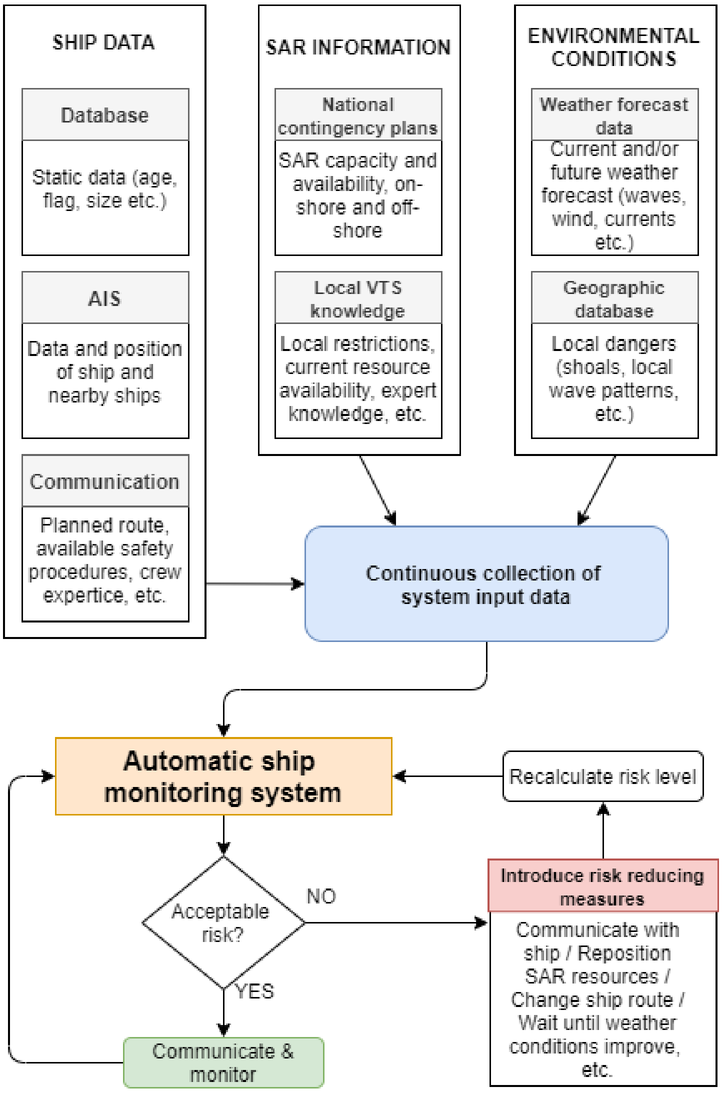

Figure 4.1: The flowchart illustrates how an ideal ship monitoring system comprise of several different input parameters.

When a foreign ship enters a national port, the Port State Control (PSC) have the authority to inspect said ship to verify that they comply with international regulations. This is meant to be an extra measurement of safety to identify substandard ships. The port state can require that defects are corrected or detain the ship.

Through encouragement from IMO, several regional organisations and agreements on PSC have been formulated through different memorandums of understanding (MoU's) covering the world's oceans. Paris MoU has 27 member states and covers waters of the European coastal states, including Canada and Russia with a mission to "eliminate the operation of sub-standard ships through a harmonised system of port State control" ("Paris MoU", 2020).

Paris MoU select ships for inspection on a regular basis, based on a weighting scheme of target factors including generic factors (shiptype, age, flag, recognised organisation and company performance) and historical factors (deficiencies and detentions). This gives the indication on the ship risk profile, given as low (LRS), standard (SRS) or high risk ships (HRS).

The ship risk profile gives indication to how often the ship should be inspected, ranging from every 5-6 months for HRS to every 24-36 months for LRS. Unexpected factors can also trigger an inspection in between the periodic inspections.

The Paris MoU have been recognised by the European Union to be one of the main pillars in terms of improving safety at sea, but have been criticised for not embracing the total concept of risk by including the product of the probability of an undesired event and the consequence of such an occurrence (Degré, 2007). Also, the author notices how ship size, or in reference to cruise ships, the total number of passengers, is not part of the Paris MoU ship risk evaluation.

The static ship risk factor obtained through the work by Balmat et al. (2011) integrated a ships flag, age, size, company performance, ship type and similar. The method was shown to efficiently give an individual ship risk assessment factor which matched that of Paris MoU. A ships' Paris MoU ship risk profile is an easily available parameter through the official website of Paris MoU[1] and will be further used in the proposed model development to assess a ships static risk factor.

However, the Paris MoU and the work presented by Balmat et al. (2011) does not discuss how the number of passengers on board affects the risk level. Obviously, this does not directly influence the static risk of the ship's performance, but the author recognise the importance of including such a factor. This will be a direct consequence of how large cruise ships can accommodate thousands of people, which from the presented MRO-theory is a cruicial factor in rescue operations. Thus, the model will combine knowledge from the ship risk profile obtained through the Paris MoU with knowledge of the total number of people on board a cruise ship to evaluate the ship's total static risk factor.

4.2 AIS - Automatic Identification System

As presented in Figure 4.1, availability of ship data is an essential part of an automatic ship monitoring system. Ship data can be obtained from static data bases, such as ship performance, ship age, flag of convenience, ship type and similar, whilst the dynamic data needs to be obtained through a continuous stream of data. The introduction of the automatic ship identification (AIS) from the Safety of Life at Sea (SOLAS) convention in 2002 have proved to be a valuable source of information for a number of applications within maritime research (Svanberg et al., 2019). As of today, a number of ships is enforced to emit AIS data which includes all tankers and passenger ships as well as ships of size over 300 GT. This also applies to European fishing vessels of lengths of 15 meters and above. Other ships may also carry AIS-transmitters if this is thought to be advantageous.

Ships will emit data relating to its identity, position, speed, navigational status and heading which is sent in different message types. The most important message types are those of message type 1-3 (MSG 1-3) containing dynamic data and those of message type 5 (MSG 5) containing static data. The Norwegian Maritime Administration provides an open AIS source for the dynamic MSG 1 type at https://ais-public.kystverket.no/ais-download/ and does provide more detailed data on request.

A ship will emit data every 2 - 10 seconds depending on the its speed, and every 3 minutes while being at anchor (MarineTraffic, 2018). Essentially this will provide a continuous flow of spatio-temperal data i.e. information related to both time and space. Some of the available data from AIS thought to be useful in the proposed model is presented in Table 4.1, categorised in dynamic data received from message type 1-3 and static data received from message type 5.

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[1] https://www.parismou.org/

Table 4.1: Non-exhaustive list of the data available from AIS data

Available AIS data (Non-exhaustive)	
Dynamic data (MSG1-3)	**Static data (MSG5)**
Timestamp	Timestamp
MMSI	MMSI
Navigational status	IMO
Speed Over Ground (SOG)	Name
Longitude	Ship type
Latitude	Ship dimensions

Both MMSI and IMO serves as an identification number, but not all AIS messages will originate from ships as several other devices emits AIS-data such as buoys, emergency beacons and other miscellaneous objects (National Oceanic {and} Atmospheric Administration, 2017).

Svanberg et al. (2019) presents a state-of-the-art literature review on the usage of AIS within maritime research, providing an overview of in total 189 quality assured published papers that concerns AIS. These papers are categorised in different categories, with two being of especial interest, namely papers concerned with *collisions and navigational safety* and *oil spill*.

A total of 40 articles were related to *collisions and navigational safety* where most of these use AIS to calculate the probability of accidents in various ways. The *oil spill*-category accounts for 8 of the total presented papers and studies oil discharge from ships. One of these papers is the previously discussed paper from the introduction on dynamic risk models, the work conducted by Eide et al. (2007) on the development of a dynamic risk model for intelligent ship traffic monitoring for oil spill prevention.

To effectively separate ships in the proposed model formulation, the AIS data containing information on ship type will be further explored. The ship type contains a number ID which is associated with a specific ship type which can also imply if a ship is carrying a specific type of cargo. In essence, the number ID consist of two digits which is combined to provide information on the type of ship. There is a vast variety of ship types, and the author have used available information from two different sources[2] to produce a simplified presentation of the available ship types as presented in Table 4.2, showing the most relevant ship details.

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[2] https://www.navcen.uscg.gov/?pageName=AISMessagesAStatic & https://help.marinetraffic.com/hc/en-us/articles/205579997-What-is-the-significance-of-the-AIS-Shiptype-number-

Table 4.2: The description of selected ship types obtained from AIS data. Irrelevant ship types (air crafts and unknowns) have been removed from the list.

Shiptype	**Ship details**	**Shiptype**	**Ship details**
0	MSG5 unavailable	40-49	High-Speed Craft
10-19	Unspecified	50	Pilot Vessel
20-28	Wing in Ground	51	Search and Rescue
29	Search and Rescue	52	Tug
30	Fishing	53-54	Special Craft
31-32	Tug	55	Patrol Vessel
33	Dredger	56-58	Special Craft
34	Dive Vessel	59	Multi Purpose Vessel, Etc.
35	Military Ops	60-69	Passenger
36	Sailing Vessel	70-79	Cargo
37	Pleasure Craft	80-89	Tanker
38-39	Unspecified	90-99	Other

Special consideration is made towards the category of tugs. It can be seen from Table 8.3 that the ship types of tugs are spread over three different categories. These categories are seen in detail in Table 4.3.

Table 4.3: Detailed description of the different tug ship types.

Shiptype	**Ship type details**	**Shiptype**	**Ship type details**
31	Towing Vessel	31	Tug/Ice Breaker
31	Tug/Tender	31	Tractor Tug
31	Tug/Supply Vessel	31	Tug/Support
31	Tug/Fire Fighting Vessel	31	Articulated Pusher Tug
31	Tug	32	(No information)
31	Tug/Pilot Ship	52	Icebreaker
31	Anchor Handling Salvage Tug	52	Inland Tug
31	Towing/Pushing	52	Pusher Tug

The ship type data from AIS is somewhat imprecise, as ships within the same category can be very different. This is exemplified by ship type No. 59 which includes offshore supply ships and multipurpose offshore vessels whilst also including radio ships, floating cranes, nuclear fuel carriers and more than 60 other ships.

4.2.1 AIS data challenges

AIS data is thought to be a very powerful tool to obtain both static and dynamic ship data but is also associated with some difficulties. Most importantly is how AIS will produce a vast amount of data for even a confined area at sea. From online AIS services such as that of the Norwegian Maritime Authority[3] it can be estimated that approximately 1,000 ships are present within a confined area of 200x200 km. Assuming that the majority of these ships are sailing, meaning they will emit an AIS signal every 2-10 seconds, it is obvious that this produce a large amount of data that must be handled with appropriate data management tools.

Furthermore, AIS data is not ”perfect” meaning the data will be prone to errors. A typical erroneous occurrence is how a particular ship's position might fluctuate within a limited area which is typically a ”ship-to-receiver” data transmission consequence. From https://ais-public.kystverket.no/faq/ it is emphasised how the AIS data might show a ship moving forth and back when it is actually sailing in a straight line with steady speed.

Other data errors known to occur is data subject to inputs from the ship's crew which is typically the static data. This could give an erroneous ship dimension from MSG 5. However, Smestad (2015) discuss how this erroneous data can be easily removed and thus how the erroneous data can be managed in an analysis utilising AIS data.

4.3 Introduction on contingency planning for maritime accidents in Norway

The responsibility of maritime infrastructure and preventive measures related to safety at sea in Norway is delegated by the Norwegian Government to be developed and maintained by the Norwegian Coastal Administration (NCA). NCA is responsible for the contingency planning of environmental pollution and also to ensure the implementation of the regulatory framework of IMO and the EU (Ministry of Transport, 2020).

The following section will describe the most important risk reducing measures implemented in Norwegian waters, and how they might influence the proposed model development.

4.3.1 Fairways and traffic separation scheme

Fairways and traffic separation schemes have been introduced to implement a road-network at sea, which improves ship safety by providing safe paths for ship to travel.

The fairways can be divided into three main leads for passing traffic, the outer main lead and the inner main lead. An example of the inner lead is shown in Figure 4.2.

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[3] https://kart.kystverket.no//share/9220e0e277e4

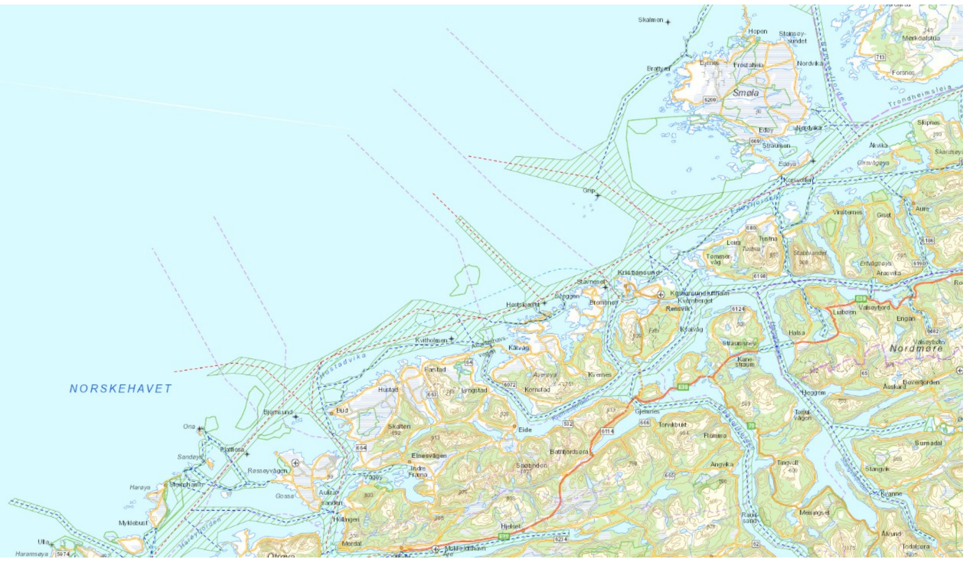

Figure 4.2: Example of navigational fairway on the west coast of Norway.

Ships tend to choose the shortest possible route, meaning they often navigate close to shore. It could be of interest to investigate how cruise ships navigate in different conditions, for instance if it chooses a different fairway depending on the current weather conditions, which can be implemented into the proposed model to evaluate the ship risk based on its distance from shore.

4.3.2 Vessel Traffic Service centres and maritime pilots

As of 2020, the Norwegian Coastal Administration operates five VTS centres, see Table 4.4. These monitor and regulate the ship traffic along the Norwegian coast which are each assigned to a special area of responsibility.

Table 4.4: Norway's five VTS centres and their areas of responsibility (The Norwegian Coastal Administration, 2020b).

VTS centre	**Main area of responsibility**
Fedje VTS	Oil shipments from the Sture and Mongstad terminals and; ship traffic to and from Bergen
Kvitsøy VTS	Gas shipments from theterminal at Kårstø and; general ship traffic surveillance in the area
Brevik VTS	Monitoring of shipments to the industrial area in Grenland
Horten VTS	Monitor ship traffic from Færder to Oslo
Vardø VTS	Monitor traffic in the northern areas and; organise the state tugboat emergency preparedness scheme

Maritime pilots have been introduced as a risk reducing measure for ships sailing in Norwegian waters. All cruise ships larger than 50 meters sailing within the Norwegian maritime baseline is enforced to have a maritime pilot on duty on board at all times.

The above is not thought to directly influence the model but could prove useful to gain understanding of different maritime factors and how cruise ships are being monitored and operated.

4.3.3 Emergency ports and beaching areas

As part of the Norwegian Coastal Administrations contingency plan, several locations have been established as emergency ports and beaching areas. Emergency ports are designated areas where ships in distress can visit to correct its condition to to maintain life, environment, and property. Ships can be forced to enter these ports if the Coastal Administration evaluates the ships condition to be a threat to the environment or cause any other immediate negative impact. A beaching area acts as a location where a ship can be moved if it poses an immediate risk of sinking.

More than 400 unique locations are defined as emergency ports which can be found in the NCA's digital map solution[4]. These are spread along the Norwegian coast. Some emergency ports doubles as beaching areas, whilst several other beaching areas also exists for that sole purpose.

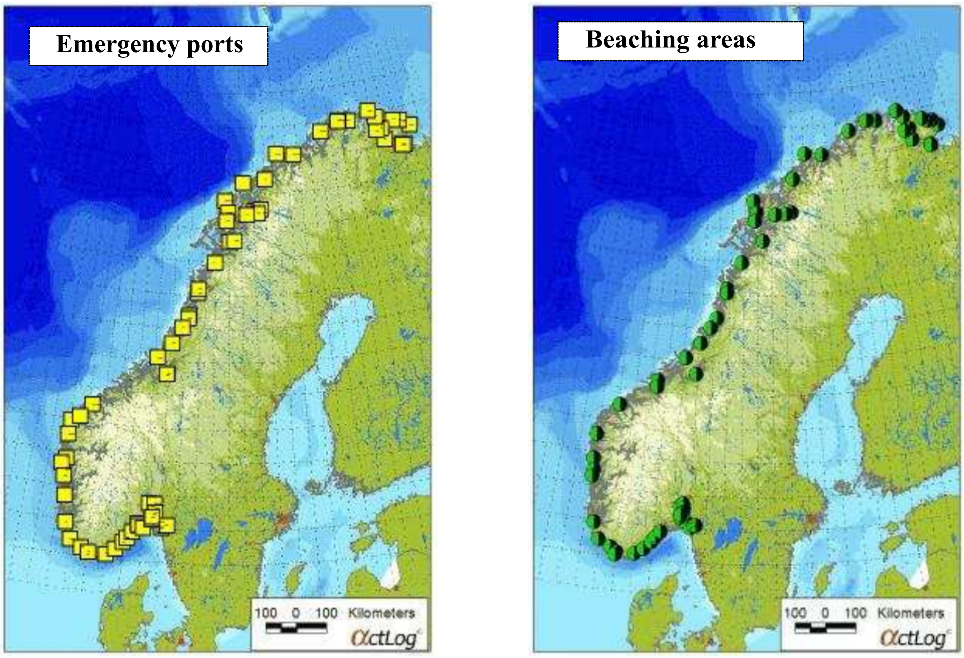

Figure 4.3: Emergency ports and beaching areas along the Norwegian coast. Figure adapted from NCA.

Though rare, cruise ships have used emergency ports for different reasons, exemplified by the large wave hitting the cruise ship Norwegian Dawn in 2005 forcing it to use a nearby emergency port for immediate repairs and to disembark passengers in Florida, see news article at https://eu.floridatoday.com/story/news/2019/03/05/cruise-ship-tilts/3064213002/.

The implementation of emergency port's positions relative to the cruise ships position could be of relevance to implement into the proposed risk model, however this is only discussed at this stage.

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[4] https://kart.kystverket.no/

4.3.4 National tug readiness scheme

The first Norwegian tug readiness program was established in 2003 as a supplement to the existing private tugs operating in Norwegian waters (National tug readiness concept study, 2006). The program was initiated to fill the gaps of commercial tugs in remote non-profitable areas, which led to the stationing of governmental operated and funded tugs. These were located in the northern part of Norway, two during the summer period and three during winter.

In the following years, a conceptual study group was established to review the need for a national tug readiness programme covering the Norwegian coast. The work included an investigation into the availability of tug resources and how these related to mishaps with ships requiring emergency tows. Other works included an evaluation of ship drift models, legal matters and technical requirements for tugs.

It is emphasised in the report that the two main reasons to acquire an emergency tow of a ship is;

1. to prevent SAR-situations that could result in loss of lives, and;
2. to prevent or limit an event that could cause environmental damage as a result of oil- or chemical pollution.

The report was finalised in 2006 and recommended the establishment of a state-run tug readiness programme in high risk environmental areas.

A second report was finalised in 2012, providing an updated version of the state tugboat emergency preparedness scheme. This report had the recommendations as follows:

1. Improve the data used in the drifting models
    (a) Accident statistics used does not cover which events that leads to a ship drifting;
    (b) The private tugboat capacities and availabilities needs to be evaluated and included in a national tug readiness plan
2. Optimisation of the chosen alternative
    (a) Perform a detailed analysis to optimise the total number of tug boats, and where the tug boats should be located;
    (b) Evaluate how the tug boats should be equipped to provide the best possible coastal contingency scheme;
    (c) It is recommended that the acquired tug boats are state owned

In the preparation of the national tug boat readiness scheme the capacity was designed to cover those events, ships and coastal segments associated with a high environmental risk. However, cruise ships were only briefly discussed during the process, and might need more consideration.

The current scheme for positioning of tug resources along the coast is performed through a risk based approach, which is based on a analysis tool developed in combination between NCA and the Coastguard. In particular this tool analyses and predict wind strength and direction, which in turn highlights exposed areas that should be given attention.

It is important to note how the National Tug Contingency Scheme is dimensioned for ships sailing in the outer fairways, that is not fairways close to shore, as is often the case for cruise ships.

4.3.5 Interim discussion

When deciding upon the dynamic risk level of a cruise ship, especially considering accidents leading to uncontrolled drifting of the ship, the availability of ship resources is considered to be important, and this area should thus be given extra attention.

It is stated how the main focus through the process of establishing a national tug readiness scheme was to prevent environmental damage, and how ships sailing in fairways close to shore have not been considered when developing the scheme. From experience cruise ships tend to sail close to shore which should be given attention when developing the proposed model.

For a cruise ship in distress, the availability of ship resources in a given proximity is thought to be of importance and should thus be carefully considered. The national tug readiness scheme, general ship assistance availability and its relevance to the model development is further discussed and analysed in section 4.4.

4.4 Evaluation and presentation of the national tug readiness scheme

The following sections will give a summary and discussion of the most important aspects of tug readiness theory extracted from the presented literature, where most of the conducted work is from the 2006 analysis if not stated otherwise (National tug readiness concept study, 2006). The presented literature will be discussed relating to how it will fit into the model development.

4.4.1 Evaluation of high-risk ships

The foundation of the tug readiness scheme is to evaluate which ships and areas along the Norwegian coast that are most prone to environmental accidents. In the analysis, ships with a capacity of 300 metric tonnes of oil and above has been included, which comprises both bunker oil and cargo. This yields that large cruise ships have also been included even though tankers represent the majority of ships carrying large quantities of oil. As the high-risk ships have been established from an environmental point of view, and thereby mostly considered accidents with tankers, it is interesting to see how tanker accidents compare to other ship types, especially that of cruise ships.

Machinery damage is the dominating contributor for ships in need of tug assistance as this often leads to the ships drifting helplessly at sea (National tug readiness concept study, 2006). Thus, this accident category have been plotted for different ship types, see Figure 4.4. Note how machinery damage was not included in the accident database until 2012.

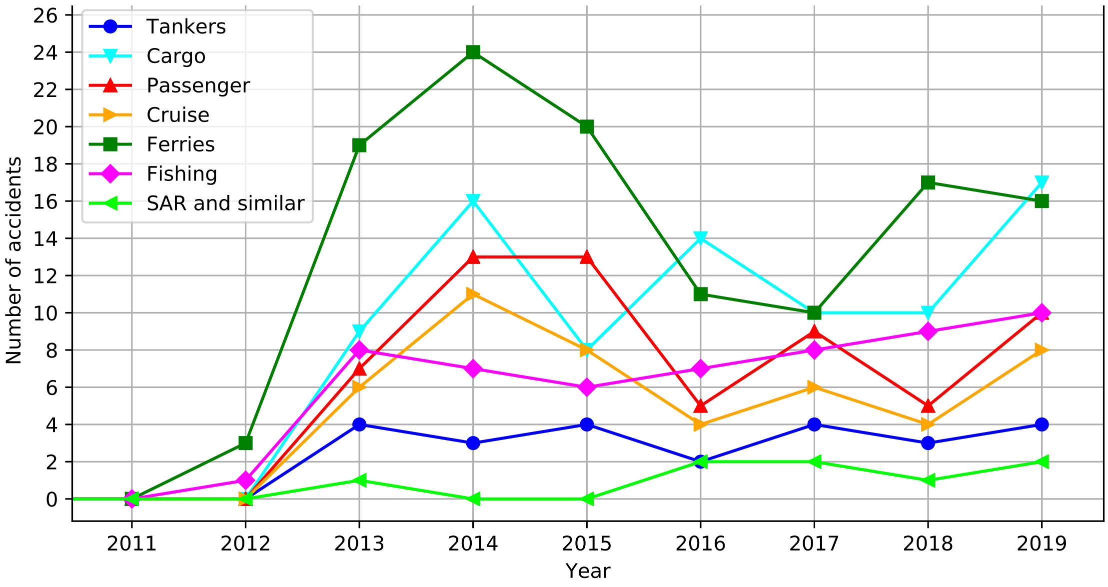


Figure 4.4: The graph shows the development of number of registered machinery damage accidents for different ship types. Please note how the machinery damage category did not exist before 2012. The data is extracted from the NMA accident database.

It is seen how ferries are the main contributor to the machinery damage-category. It can be further seen how the tankers have a relatively low frequency of machinery failures ranging from two to four registered accidents each year.

Cargo ships are seen to be a major contributor to machinery damage-related accidents. In terms of number of occurrences per year, cruise ships, which is a sub-category of passenger ships (not mutually exclusive), are seen to experience machinery damage approximately as often as tankers.

Machinery damage can ultimately lead to stranding if a ship is drifting towards shore and cannot regain power or get assistance in time. Given this, and that the existing tug boat readiness scheme have been focused on environmental damage by which is most often caused by tankers, cruise ship stranding and machinery damage accidents can be plotted against the same accident categories for tankers, see Figure 4.7.

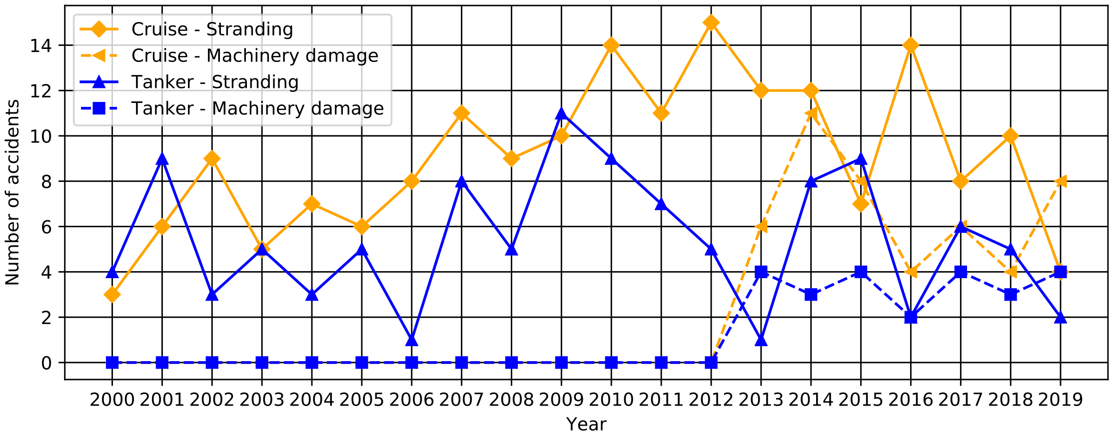


Figure 4.5: The graph shows the development of number of registered stranding and machinery damage accidents for cruise ships and tankers. Please note how the machinery damage accident category did not exist before 2012. The data is extracted from the NMA accident database.

It is seen from Figure 4.7 how cruise ships and tankers seem to be equally exposed to machinery damage, with cruise ships being more prone to stranding. This could be explained as cruise ships often operate closer to shore and in fjords, being more exposed to stranding.

It would have been of interest to evaluate statistics directly relating to which situation that needed the assistance of a tug but it have proved to be a difficult task to gather information on tug-related statistical data, even through direct contact with NCA. However, knowing how Vardø VTS is the responsible for tug related operations, some statistics does exist which gives some information on the 1,759 incidents Vardø VTS was involved with from 2012 until today. This is seen in Figure 4.6.

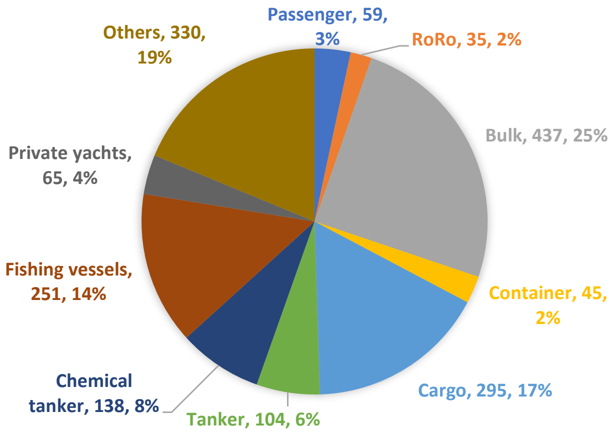


Figure 4.6: The diagram shows the ship categories for the incidents available from the Vardø VTS event log from 2012-2020 with a total number of 1,759 registered incidents.

It can be seen how passenger and RORO-ships account for only 5 % of the incidents over a period of 8 years, where most incidents are marked with incidents of drifting or groundings and how they request assistance or merely monitoring of the situation. Cruise ships will be a subgroup of the *passenger*-category. The majority of events logged from Vardø VTS relates to various cargo- and tank ships with a total of 58 %.

To further evaluate cruise ships' potential need for ship assistance, data have been extracted from the NCA's online ship traffic tool (https://kystdatahuset.no/) to evaluate the presence of different ship types close to shore. The data does not differ cruise ships from passenger ships thus cruise ship information is not explicitly presented.

Figure 4.7 shows the mean gross tonnage (GT) for the 100 largest ships within the categories of tankers, cargo ships and passengers ships crossing Hustadvika within a distance from shore of less than 30 km over a period of seven years, categorised for winter and summer season. The reason to choose only the 100 largest ships of each ship category is to obtain a better insight into the size difference of the larger vessels within the three different ship categories.

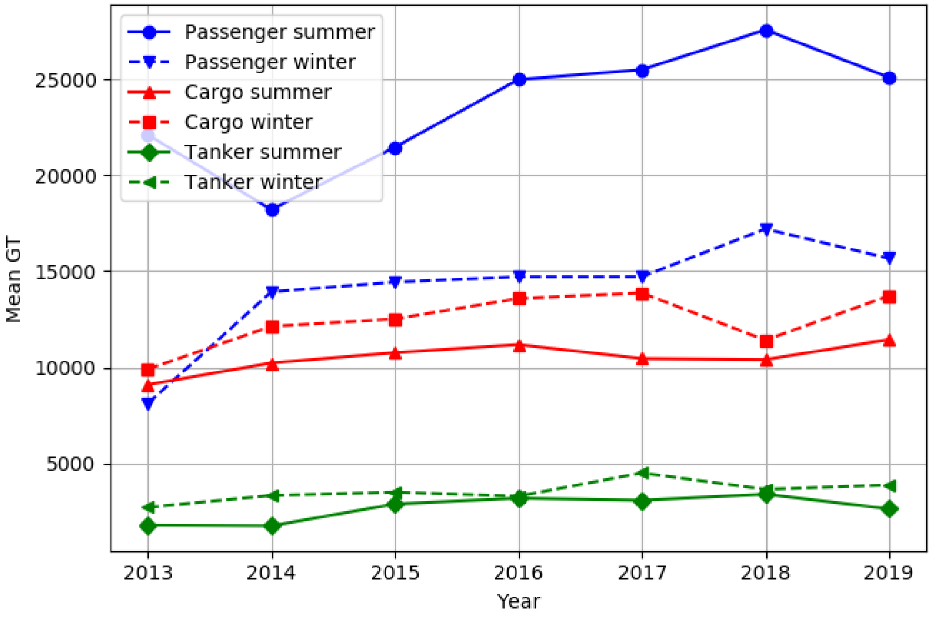


Figure 4.7: The figure shows the number of different ship categories passing Hustadvika, regardless of direction, in the summer and winter period from 2013 until 2019. The data is extracted from the NCA's digital map solution at https://kystdatahuset.no/, with the oldest publicly available data being from 2013.

The graph presents how passenger ships account for the majority of large ship crossings in the fairways close to shore at Hustadvika. It is seen how larger tankers and cargo ships seems to travel with a further distance to shore, whilst large passenger ships, that is in many occasions cruise ships, tends to sail close to shore.

Figure 4.7 also presents how the general size of both cargo ships and passenger ships have increased over the past few years, whilst the largest tankers passing close to shore seem to be of somewhat similar sizes. Large passenger ships in the summer season for this particular coastal segment are seen to have an accumulated increased size of approximately 25 % GT over the last seven years.

Limitations to the analysis

The reader should be aware of a number of factors that have influenced the statistics represented.

Firstly, the information presented is strongly affected by which ships one defines to be within the different categories. In the performed data analysis, the harmonisation of ship types is based on codes and directions from the Norwegian Maritime Directorate, Eurostat and Lloyd's, see https://www.ssb.no/klass/klassifikasjoner/76. The classification of cruise ships have been altered to also include ships from Hurtigruten.

Secondly, the reader is further advised to be aware of how under-reporting of accidents, as described by Hassel et al. (2011), might affect the outcome of statistical analyses. For instance, examples have been found through the conducted work where a drifting passenger ships have been identified and contacted by Vardø VTS, but which have never been reported in any accident database.

Thirdly, the data used does include faulty and vague information, exemplified by how it is hard to acquire information on drifting incidents. This is further exemplified from a drifting ship 14 December 2003 which was found to be subject to a machinery failure and drifted towards shore in heavy weather. The ship managed to connect a tow in harsh conditions just before the ship hit shore and the ship never did strand, but the accident is reported as stranding.

Despite some uncertainty rising from the statistical data, there seems to be evidence of how cruise ships indeed should be given more attention when it comes to the national tug readiness scheme, and how tug boats seem to be important risk mitigating measure that should be included in the development of the proposed model.

4.4.2 Emergency tow theory on cruise ships

The prior presented national tug readiness scheme is mostly limited to tankers, and it is of interest to discuss the significance of emergency towing for cruise ships.

From the accident statistics presented in Figure 4.7 it was seen that cruise ship stranding and machinery damage incidents are more prone to occur than for tankers. As presented in subsection 4.5.1, the only registered case in Norwegian waters of a cruise ship in immediate distress requiring an emergency tow have been that of Viking Sky 23 March, 2019, which is confirmed by conversations with Vardø VTS (Vessel Traffic Operator at Vardø TCC, phone interview, April 17, 2020).

Further conversations with the VTO's at Vardø TCC also acknowledged the difficulties of securing a towline to cruise ships, as they often do not have a large open deck area where crew can receive and secure a tow line compared to typical tankers and cargo ships. It was however stated that the general consensus amongst the vessel traffic operators was that cruise ships are not of especial concern, and that the current emergency towing scheme seemed to perform well overall.

Despite this, Berglihn (2019) discuss how even with the appropriate initiatives, recent cruise ship mishaps show how lack of regional or international regulations could prove fatal, and that emergency towing gear should be mandatory for cruise ships to ease the process of securing a tow.

Summarising, it seems that the current tug-availability situation in Norway is not too concerned with cruise ships, even though statistics show how cruise ship drifting accidents and other mishaps requiring tug assistance does occur.

4.5 Availability of ship resources along the Norwegian coast

The following section will evaluate how ships in proximity to a cruise ship can be off assistance. The reason a cruise ship might need assistance can be one of many, in different degrees of seriousness. A scenario could be associated with a ship having to perform a mass-evacuation of all passengers and crew, that is evacuating a few hundreds to several thousand people. Another scenario is that the ship has lost all means of propulsion and need immediate towing assistance to drift ashore. A third scenario is that a ship is drifting helplessly with no immediate risk of stranding. How different ships can assist a cruise ship in distress will be discussed in the following sections.

4.5.1 Bollard pull power

An introduction on the bollard pull power (BPP), that is the pulling strength of a ship, necessary to pull ships of different sizes will be introduced. Figure 4.8 presents the various requirements for tug boats for different sized ships in various significant wave heights as presented in the concept study from 2006 (National tug readiness concept study, 2006).

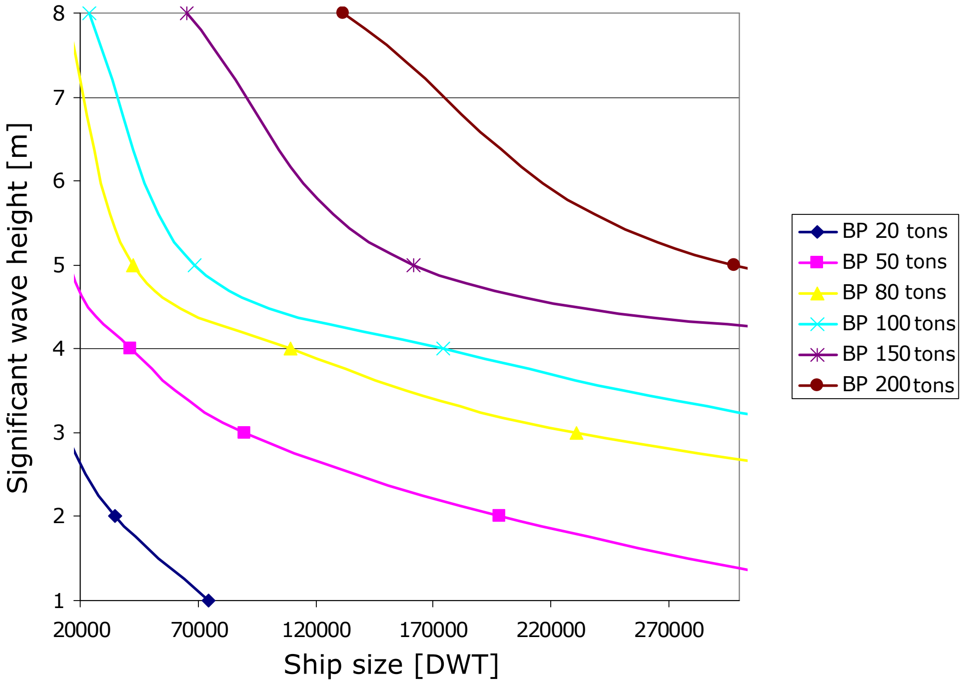


Figure 4.8: Required bollard pull for different dead weigh tonnage in various significant wave heights. The figure is adapted from the concept study of tug boat readiness from 2006 (National tug readiness concept study, 2006).

The graph displays the required bollard pull power to assist a ship of a certain dead weight tonnage (DWT) in a certain wave height. It is important to note that the graph does not directly apply to cruise ships as the data used to produce the graph was based on tankers. The graph does however give insight to how ships with a relatively low BPP can assist most ships in fine weather, whilst an increased sea state requires powerful ships to tow large ships.

Little data is available to further evaluate requirements used when deciding how a ship can be of assistance to another ship in distress. Conversations with a vessel traffic operator (VTO) at Vardø TCC is meant to clarify the process of obtaining tug assistance, explained as follows. When a ship is in distress, the VTOs will use AIS-tools to find ships nearby the ship in distress that are equipped to secure a tow or be of assistance, and the VTOs know by heart and experience which requirements the assisting ships must fulfil, thus not following a specific list. Ships are then contacted directly to clarify whether they can help or not and if they are currently busy with other tasks (Vessel Traffic Operator at Vardø TCC, phone interview, April 17, 2020).

When asked directly, it was stated that the maritime traffic controllers do not use any other kind of aid but their own experience and direct conversations with the ship itself when deciding if a ship have the required bollard pull power and equipment to secure a tow.

Hence, it is difficult to obtain an absolute conclusion as to which ships that can assist another ship in distress. Time have been spent to evaluate which ships that could indeed assist a cruise ship in distress, which is presented in the following section.

4.5.2 The Norwegian Sea Rescue Society

The Norwegian Sea Rescue Society (NSRS) operates 33 rescue boats, of small to medium size. Six of these rescue ships have a bollard pull power of 23 tons and can assist ships of 20,000-70,000 DWT in calm weather (The Norwegian Sea Rescue Society, 2018). A typical rescue ship can be seen in Figure 4.9.

Figure 4.9: The rescue ship "RS 125 DNV" which is one out of six ships in the ship class "Fosen", providing the largest bollard pull power of 23 tonnes. Picture courtesy of https://www.redningsselskapet.no/.

The NSRS operates in total 66 ships, where a summary of the capacity of all ships with a bollard pull power of 10 tonnes or more is summarised in Table 4.5.

Table 4.5: The Norwegian Sea Rescue society's rescue ship fleet with a towing capacity of 10 tons or more as of 2018. Data extracted from the annual report of 2018, (The Norwegian Sea Rescue Society, 2018).

Ship class	**BPP**	**LOA**	**Max speed**	**Number of ships**
Fosen	23 tonnes	24.7 m	29 kn	6
Von Koss	16 tonnes	23 m	28 kn	2
Ulstein	12 tonnes	22 m	38 kn	2
Emmy Dyvi	10 tonnes	20.4 m	25 kn	3

Even though the ships operated by NSRS are limited in their ability to assist a cruise ship by their relatively low BPP they have a high maximum speed compared to many other ships and can reach a ship in distress in a short amount of time.

4.5.3 The Coastguard

From 1 January 2020, the Coastguard will have the primary responsibility of executions of emergency tow operations. The coast guard operates 15 ships, six of these being assigned to the national tug readiness scheme. All of the ships and ship details can are presented in Table 4.6. Ships that are assigned to the tug readiness scheme's names are marked with a star (*).

Table 4.6: Coast guard ship details.

Ship class/name	BPP	LOA	Top speed	Build year	Number of ships
Barentshav*	100 tonnes	93	18 knots	2009-2010	3
Nordkapp	100 tonnes	105 m	21 knots	1980	3
Nornen	20 tonnes	47 m	18 knots	2006-2008	5
KV Svalbard	100 tonnes	103 m	18 knots	2002	1
KV Harstad*	100 tonnes	83 m	18 knots	2005	1
KV Jarl*	270 tonnes	91 m	7 knots	2014	1
KV Bison*	270 tonnes	91 m	7 knots	2015	1

It can be seen how the presented vessels, excluding the Nornen ship class, have a high BPP and thus are well equipped to handle emergency tow operations even in relatively high seas. Due to the ships' large sizes they are also well equipped relating to mass-evacuations of ships.

4.5.4 Fishing vessels

Fishing vessels are known to be present along the whole Norwegian coast and could have the potential to assist a ship in distress. Large fishing vessels are described to have an approximate BPP of 50-100 tonnes and capable of towing ships in calm seas. Fishing vessels does however not satisfy the technical demands required to be part of a planned and organised tug readiness scheme but are said to be well equipped to tow smaller ships.

Obviously, there are limitations to how well a fishing vessel can assist a large cruise ship in distress. They often have a limited capability of rescuing people, say if a cruise ship is to evacuate. There exists a vast number of different configurations and designs for fishing vessels, and its search and rescue/towing-limitations have not been explored in detail.

It seems though as fishing vessels could be a valuable ship resource within its limitations, and thus they will be given further attention in the following chapters.

4.5.5 Offshore supply vessels

Offshore supply vessels, especially anchor handling vessels, are described to be well equipped to assist drifting ships. They often have a BPP of 100-300 tonnes, good manoeuvrability and are often stable in rough seas due to their large size. They often have large open deck areas, well suited to accommodate a number of people in an emergency situation. Two anchor handling vessels have in fact been part of the prior tug readiness scheme fleet, showing their capability.

A drawback of offshore supply vessels are how they are often occupied with indispensable tasks for specific oil fields and their availability is thus often limited. However, the ships have at several occasions assisted drifting ships after being contacted by the NCA. They are thus believed to be a valuable ship resource to be included in further research.

4.5.6 Tug boats

Obviously, conventional tug boats are considered to be well equipped to assist ships. However, they are often limited in size and have a typical towing capacity of about 95 BPP. A positive side is how they operate with professional crews well-mastered within the art of towing. As they are commercially driven, they operate from customer demand, and are mostly present where ship in need of tug-assistance are located. This is typically in the most ship dense areas, which largely comprise the waters south of Trondheim.

It is described how tug boats are often not well-suited for challenging operations in open seas over a longer period of time. Also, a typical tug boat often have a limited free deck area, and are believed to be better at towing ships than rescuing large crowds of passengers in distress.

The conclusion of how well-suited tug boats are to assist cruise ships in distress tends to be how they are well suited for relatively large towing operations, and less suited as a mass-evacuation resource. They are thus a valuable resource and will be given further attention.

4.5.7 Other ships

Other ships such as RoRo-ships, passenger ships, cargo ships and tank ships have been briefly assessed on their rescue and towing capacity, as very little information exists on this matter. The ships have not been observed to tow other ships in distress and are therefore not evaluated as being of interest to include in the model relating to their towing capacity.

Their mass-evacuation capacity is however of interest as the ship classes often comprise large vessels that can potentially extract life rafts from the water and accommodate a large number of people in an emergency situation.

4.5.8 Ship resource summary

Based on the the introduced ship types, Table 4.7 presents a summary of the presented information. Each ship has been given a numerical factor ranging from 0, zero relevance, to 5, high relevance, indicating it's assumed relevance for the given category. The table is divided into the two main categories of assistance, that is assistance relating to towing and mass-evacuation.

Table 4.7: The figure shows a summary of the ships available along the Norwegian coast and how they are evaluated as a resource in case of a cruise ship emergency. Each ship has been given a numerical factor ranging from 0, zero relevance, to 5, high relevance, indicating it's assumed relevance for the given category.

	Ship assistance capacities				
	Good weather		Bad Weather		Max
Ship type	Towing	Mass-evacuation	Towing	Mass-evacuation	speed factor
NSRS	2	1	0	0	5
Coast Guard Ships	5	5	5	5	5
Fishing Vessels	3	2	1	1	3
Offshore Supply Vessels	5	4	5	4	3
Tug Boats	4	1	2	0	3
RoRo/Passenger ships	1	4	0	2	4
Cargo Ships	2	4	1	2	3
Tank Ships	2	3	1	1	3

From the table it can be seen that only a few of ships categories are evaluated to be appropriate as towing resources, especially in poor weather conditions. On the other hand, most ships are thought to be of relevance for mass-evacuations in good weather, however some ship categories are given a low factor of relevance based on their limited size. It can be seen that the most appropriate ship categories to assist for any given situation is coast guard ships and offshore supply vessels.

This information will be used directly as an input to the proposed cruise ship risk model to evaluate which ships that should be introduced as a risk influencing factor.

4.6 Analysis of risk influential factors from historical events

An analysis of selected cruise ship events has been performed to further investigate how important factors influenced a certain incident. The work has proved to be a tedious and challenging task. Information is not easily acquired, and accidents and events are vaguely described. In the performed accident review and factor influence analysis five different tools have been used in a combination to produce results, which are listed below;

1. NCA accident database;
2. Vardø VTS event log;
3. AIS data from https://kystdatahuset.no/;
4. Weather information from https://klimaservicesenter.no/observations/, and;
5. Web-searches of accident details from online articles, news etc.

All of the information from the above list is combined to see how different influential factors described in the prior theory sections ultimately affected an event. Five unique events have been analysed which all were subject to drifting. They are all listed in the Vardø VTS event log. The selected accidents with relevant information can be seen in Table 4.8. A low drift speed implies a drifting speed of 0-2 knots, medium being 2-5 and high being 5 and above. The events have been evaluated based on their *severity potential*, that is the presumed worst-case consequences of the event, had they not regained propulsion.

Table 4.8: Table showing relevant details of the reviewed ship accidents. *General Cargo; **Response Time.

Accident type	Machinery	Machinery	Unknown	Other	Machinery
Date	24.06.2019	23.03.2019	01.09.2018	26.06.2018	03.04.2018
Time	09:00	13:00	23:00	20:00	22:00
Ship name	Finnmarken	Viking Sky	Marco Polo	Mein Shiff 3	AIDAcara
Paris MoU risk profile	LRS	LRS	LRS	LRS	LRS
Ship size [GT]	15,690	47,842	22,080	99,526	38,557
Pass. capacity	1,000	1,300	820	2,790	1,186
Shore dist. [km]	0.5	5	50	At port	25
Drift speed	Low	High	Low	Medium	Low
Wind [m/s]	5	20	10	12	10
Closest ship [km]	10	10	25	1	15
Closest shiptype	Tug	Reefer	Trawler	Tug	GC*
RT [min]**	20	60	-	30	-
Tow connected	N	Y	N	N	N
Ship evacuated	N	Partly	N	N	N
Severity potential	Med	High	Low	Medium	Medium

A quick summary of the chosen accidents will follow;

24.06.2019 Finnmarken drifting event

Hurtigrutens ship Finnmarken experienced machinery shutdown only 500 meters from shore while sailing towards Honningsvåg. The ship immediately notified Vardø VTS as they drifted slowly towards shore in wind conditions of about 5 m/s. A tug was available 10 km off Finnmarken's location and was on scene only 20 minutes later.

A SAR-ship arrived on the scene few minutes later and they were both on standby. Finnmarken managed to regain power and was followed by the two assisting ships to the port of Honningsvåg.

Event remarks

It is the authors impression that the event is not insignificant, even though the accident is not described as a dramatic event. The machinery damage and drifting seem to have occurred unexpectedly and lasted for about an hour. The event is thus described with a medium accident potential and several factors seems to have influenced the situation positively. Two ships equipped to assist were immediately available and the weather was calm with a slight wind strength of 5 m/s. The ship managed to regain power by itself after approximately an hour and did not require a tow to be connected.

The event shows the importance of having adequate ship resources in vicinity, even though they did not intervene in this particular event.

23.03.2019 Viking Sky black-out event

A detailed analyses of the Viking Sky accident was performed in the previously introduced project thesis, describing how different factors influenced the accident. A short summary of the accident and influential factors follows.

Viking Sky experienced a total blackout just five km off Hustadvika in severe weather conditions. The wind was 20 m/s westerly and raising with significant wave heights of 6-8 meters. Viking Sky started drifting at a speed of 5-10 knots towards shore and managed to regain some propulsion just 100 meters from shore after approximately 40 minutes off drifting. There was an immediate danger of drifting on dangerous shoals, but evacuation of the ship by life rafts was not considered safe in the deteriorating weather conditions.

Ships in the immediate vicinity of Viking Sky was a reefer and a tank ship arriving at scene approximately an hour after Viking Sky's black out, which assistance was encumbered by the severe weather conditions. Tugs later arrived but could not safely secure a tow. Evacuation by helicopter was performed, and tugs managed to secure a towline 18 hours after the initial black-out when the weather conditions had improved. Viking Sky was finally assisted to the port of Molde.

Event remarks

The Viking Sky incident is, from the authors knowledge, the only recent large passenger ship accident of this scale in Norway and is thus important to evaluate which factors that are of importance. Obviously, the weather conditions were severe rendering the incoming tugs and other ship resources unable to assist, and the large windage area of Viking Sky contributed to a high drift speed from the westerly wind. This combined with the fact that Viking Sky was positioned only five km from the shore was not a good combination, and the event is classified with a high severity potential.

The accident proved how vulnerable cruise ships can be should they experience a black out in severe weather positioned close to shore. Also, the event showed how the connection of a tow line is not easily performed in heavy weather, even with the appropriate vessels.

The Viking Sky event will be used as a reference in the model as to which events should be given a high risk level, which will comprise a combination of a low availability of ship resources in immediate vicinity in combination with poor weather conditions. Hence the incident will be evaluated further with the developed model to evaluate the model's performance.

01.09.2018 Marco Polo drifting event

Not much information is available on the Marco Polo drifting accident. The only information available is that of the Vardø VTS event log, stating how they observed Marco Polo drift approximately 50 km off the coast south-west of Tromsø. Vardø VTS contacted the ship which would not state why they were drifting. The ship was observed to drift for about an hour and did not request any help. The event is not included in the NCA accident database.

The wind strength was observed to be approximately 10 m/s southerly, and from the AIS data the ship was seen to drift slowly towards the north. The closest ship is seen to be a trawler 25 km from Marco Polo.

Event remarks

There is a lot of uncertainty related to the described event. It is unknown whether the ship was drifting due to machinery trouble or other causes. It can though be seen that the ships position 50 km off the coast in combination with southerly winds affected the situation positively, as there was no immediate threat of grounding. Thus, the event is thought to be have a low severity potential.

Final remarks on the Marco Polo drifting event is how the accident is evaluated with a low severity potential, partly due to the northerly drifting and partly due to the ships large distance from shore. The VTS operator describes the event as non-dramatic, which is assumed to be partly as the ship did not express any need for assistance, and partly as the ship was in no immediate danger of drifting ashore. Hence the author recognises the large shore distance as the main contributing factor proving the situation to have a low severity potential.

26.06.2018 Mein Schiff 3 drifting event

Mein Schiff 3, a large cruise ship capable of carrying close to 3000 passengers and a crew of 1000 was docked in Honningsvåg when their mooring failed caused by a powerful wind gust. The wind in the area was southerly 12 m/s. The ship drifted close to shore and caused damage to the port areas and the ship itself. From AIS-data it is seen that tugs and the coast guard were readily available and could assist the ship within a short response time of 30 minutes. The ship managed to regain control by itself when the ship resources arrived, and the situation was under control.

Event remarks

The Mein Schiff 3 drifting event shows how a ship is not safe even when docked. The wind was a major factor ripping the mooring lines. The short response time of 30 minutes by several ship resources would have contributed positively to the incident had the ship not regained control by itself. The event is categorised with a medium severity potential.

04.04.2018 Aicacara drifting event

The cruise ship Aidacara was sailing towards Trondheim north-east of the Halten lighthouse 25 km off the shore when it experienced an engine failure and started drifting. The wind speed was 10 m/s south-east and the ship drifted slowly away from shore hence the captain decided they did not need immediate assistance. Vardø VTS followed the situation closely and the ship managed to regain propulsion after two hours of drifting. Several ships were seen to be nearby, the closest being a general cargo ship 25 km away.

Event remarks

The favourable wind direction and the distance from shore influenced the Aicacara event positively. The ship is a large cruise ship capable of carrying 1,186 passengers and 360 crew members. The fact that the ship was drifting for more than two hours is significant, and the accident is thought to be serious even though the incident is not found in the NMA accident database.

The ship is considered to have a medium severity potential. The drifting seemed to appear unexpectedly and had the wind blown towards shore the situation could have been more severe. AIDAcara's relatively large distance from shore is thought to have had a positive influence on the event.

4.6.1 Summary of analysis

From the analysis, the findings will be summarised relating to how a factor is thought to influence an event positively or negatively relating to the severity potential of an event. Six main factors are presented evaluated to be the most important factors to be considered, as seen in Table 4.9.

Further, the analysed events are summarised by introducing a quantified evaluation value ranging between -3 and +3. A factor value of -3 refers to how a factor only influenced the event negatively, whilst a value of +3 refers to the opposite, that is how the factor contributed only positively. Numbers ranging in between is a weighting of the negative or positive effects of the factor and 0 represents how it is hard to justify how the factor influenced the event.

The ship condition for all ships is given a value of negative one as all of the analysed ship accidents were chosen based on how they seemed to experience an unexpected drift, even though all ships are seen to have low Paris MoU ship risk profile.

Table 4.9: Table summarising how different factors in a ship accident influenced the severity potential. A factor value of -3 refers to how a factor only influenced the event negatively, whilst a value of +3 refers to the opposite, that is how the factor contributed only positively. Numbers ranging in between is a weighting of the negative or positive effects of the factor and 0 represents how it is hard to justify how the factor influenced the event.

	Analysed incident				
Factor	Finnmarken	Viking Sky	Marco Polo	Mein Schiff 3	Aidacara
Ship condition	-1	-1	-1	-1	-1
Wind	+2	-3	+1	-3	+2
Waves	0	-3	0	0	0
Location	-1	-3	+2	-1	+2
Shore distance	-3	-3	+2	0	+2
Ship resource availability	+3	+1	0	+2	0
Severity potential	**Medium**	**High**	**Low**	**Medium**	**Low**

Information on how wave heights affected the different incidents is only mentioned in the information available from the Viking Sky-incident, thus this factor is seen as a value of zero for all other incidents. The findings represent how weather can influence an event positively or negatively depending on the ships location. Also, severe weather is seen to halt attempts to secure tows through the Viking Sky incident. Furthermore, the proximity of ships that can assist is evaluated to reduce the severity potential, but a in-depth analysis of this cannot be performed with the available data and tools at this stage.

4.7 Weather influence

Previous work conducted in the project thesis as presented in section 3.1 showed how weather is observed to be a dominating factor in all accident categories except those relating to fire and explosions. The results also showed that good weather is seen to be present for the stranding of cruise ships, whilst poor visibility seemed to be mostly present for collisions.

Hence, it is assumed important to include a factor describing the weather conditions in the model. The influence of visibility for a given situation have not been evaluated in detail and will therefore not be included in the further work.

4.7.1 Drifting consideration

As larger cruise ships are in general more seaworthy than smaller cruise ships it is thought important to include a parameter into the model describing the manoeuvrability potential of the cruise ship being analysed. This will be advantageous as larger ships tend to sail in weather not suitable for smaller ships, and thus allowing the risk model to account for this.

Furthermore, it has been seen from the presented theory how drifting cruise ships is of concern thus should be given special consideration in the developed model. The combination of an immobile cruise ship and unfortunate weather conditions can lead to drifting which in a worst-case scenario will cause a cruise ship to drift on shore. Thus, a short summary of the drift analysis conducted in the previously presented National tug readiness concept study (2006) will be discussed.

The tug readiness scheme's presented work included the use of SHIPDRIFT, a model developed in 1996 by DNV that was used to estate drift trajectories for drifting ships at various strategic locations. The model calculates drift velocities based on wind and wave generated currents, also including climatological currents. Wave induced forces on ships are calculated based on the ship's geometry, and the wind-induced forces are based on the geometry of the ship above the waterline. The ships used in the model were large oil tankers.

In the conducted work in the tug readiness evaluation, tankers were especially considered. It is of interest to compare the results for the tankers with the recent incident with Viking Sky in March 2019, where the drift speed was observed to be ranging from 5-10 knots for a significant wave height of approximately 8 m. As a modest assumpton a speed of 6 knots is included in the further analysis. The drift times observed from the assessed SHIPDRIFT model have been plotted in a scatter plot with the corresponding significant wave height, also including information from the Viking Sky incident, see Figure 4.10.

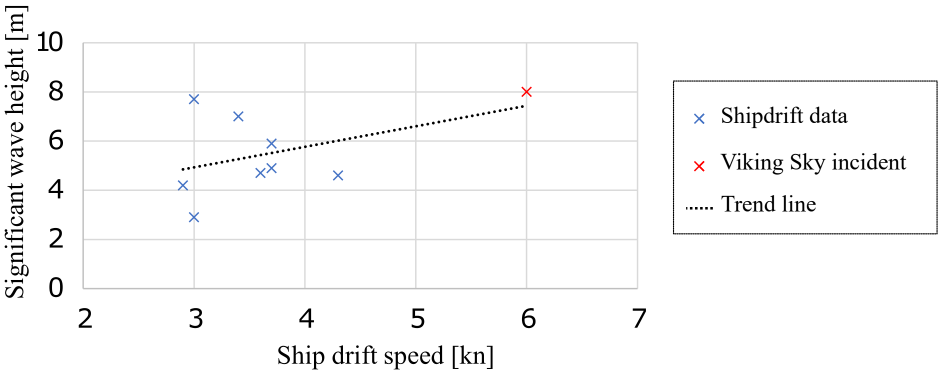


Figure 4.10: A scatter plot showing the ship drift speed and the corresponding significant wave heights used in the SHIPDRIFT model also including that of the Viking Sky incident.

It is stated in the drift model sensitivity analysis of the drift modelling results that the wind induced drift is a dominant contributor compared to currents and wave heights which can explain how the drift speeds from SHIPDRIFT does not correlate well with the significant wave height. As cruise ships are known for their large height to depth ratios, with approximately 80-90% of the ship's structure being above the waterline this would suggest how cruise ships are subject to an increased drifting speed compared to that of tank ships.

Nevertheless, Figure 4.10 with the addition of the situation of the Viking Sky accident does give an approximate knowledge of how fast cruise ship drifts, at least in a modest worst case scenario with on shore wind and large waves such as that of Viking Sky. This will be used in the further model development.

4.8 Summary of important factors and further model limitations

In the previous chapters, theory have been discussed relating to important aspects of cruise ship rescue operations and how this theory can be used in the proposed model. Theory have been assessed based on the "ideal" ship monitoring system presented in Figure 4.1 as well through information acquired in the process. The Paris MoU was introduced as an appropriate way of measuring static ship risk in the proposed model, with the addition of total number of people on board. AIS data was discussed to be a powerful tool to obtain spatio-temperal data ship data, which can be utilised in the model. From the knowledge obtained on how cruise ships tend to follow certain fairways close to shore, it will be advantageous to use the AIS-data to evaluate a cruise ships distance from shore. This again can be combined with weather data and hence a cruise ships drift speed can be evaluated.

Information relating to ship assistance resources have been evaluated in the previous chapters and will hence be implemented in the model formulation. Other means of emergency resources such as helicopters and on-shore facilities is not included in the further model formulation, which also disregards emergency ports and beaching areas.

Furthermore, information relating to the cruise ship such as its position, drift speed and prevailing weather conditions can be combined with information of nearby ships, also provided by AIS-data. This can be further used to evaluate if a potential cruise ship accident would have necessary means of emergency resources in terms of ships in reasonable vicinity to minimise accident consequences should an accident occur.

Even though the above-mentioned factors are limited, the combination of the factors to produce a meaningful risk level has been a tedious task. As mentioned in the prior statistical analyses it is hard to extract explicit information from accidents without individual assessment. Therefore, an evaluation and discussion of five unique accidents that required the attention of the Vardø VTS operators have been evaluated to further understand how different factors were involved in the accidents and how they influenced the outcome. The analysis includes the Viking Sky accident.

Chapter 5

Risk model development

The following chapter will describe the development of the risk model. First, the model architecture for the intended risk model will be presented. Further the reader will be introduced to how the risk model will utilise the concept of fuzzy logic combined with risk assessment theory and a simple example showing the methodology of the fuzzy risk concept will be presented.

Further, a detailed presentation of the development of each step in the presented model architecture will be presented along with a discussion and evaluation of the presented steps.

5.1 Model architecture

The approach to create a risk model based on fuzzy logic is visualised by Sii et al. (2001) as presented in Figure 5.1.

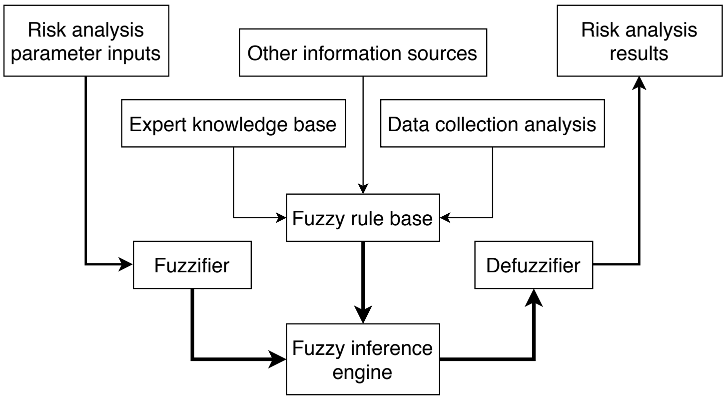


Figure 5.1: The figure shows the methodology of performing a risk analysis based on fuzzy logic. The figure is adapted from Sii et al. (2001).

In the previous chapters a foundation of knowledge have been developed that will be used to create risk a model using the approach shown in Figure 5.1.

For the risk model to be easily interpretable, manageable and changeable, a modular and hierarchical structure integrating fuzzy logic will be developed, as suggested by Balmat et al. (2009) in their work on a fuzzy approach to define an individual ship factor which was further discussed in chapter 2.

Previously evaluated theory assumed important when evaluating the risk level of a cruise ship have been carefully assessed to develop the architecture of the risk model. A modular and hierarchical risk model structure is chosen due to the users enhanced ability to control the results by defining a well-fit fuzzy rule base controlling the behaviour of the model, as seen in Figure 5.1.

The model calculate the static and dynamic risk factors individually from a set of input values $\boldsymbol{X}$ being a vector containing static and dynamic risk factor input values respectively denoted as $\boldsymbol{X_S}$ and $\boldsymbol{X_D}$. The static and dynamic risk factor will be combined into a total risk factor. Thus the proposed model can be simplified to a function with two dependencies, seen in Equation 5.1 as

$$R_{Total}(\boldsymbol{X}) = R(R_{Static}(\boldsymbol{X_S}), R_{Dynamic}(\boldsymbol{X_D})) \in [R_{max}, R_{min}], \tag{5.1}$$

where

$$\boldsymbol{X} = \{\boldsymbol{X_S}, \boldsymbol{X_D}\}. \tag{5.2}$$

This gives the model input values as presented in Equation 5.3.

$$\boldsymbol{X} = \left\{ \overbrace{\begin{bmatrix} \\ \\ \text{Paris MoU ship risk factor} \\ \text{No. of people on board} \\ \\ \\ \end{bmatrix}}^{\boldsymbol{X_S}}, \overbrace{\begin{bmatrix} \text{Ship size} \\ \text{Sea state} \\ \text{Distance from shore} \\ \text{Distance to closest vessel} \\ \text{Number of vessels in proximity} \\ \text{Night or day} \end{bmatrix}}^{\boldsymbol{X_D}} \right\} \tag{5.3}$$

The proposed risk model architecture is presented in Figure 5.2. As discussed in the theory evaluation of chapter 3 the static risk factor will include the well-known Paris MoU ship risk profile in combination with the total number of people on board, whilst the dynamic risk factor will include meteorology data and data based on AIS data. The static and dynamic risk factor will further be combined into a total risk factor. Note how the *Paris MoU ship risk profile* implicitly includes several ship specific static factors.

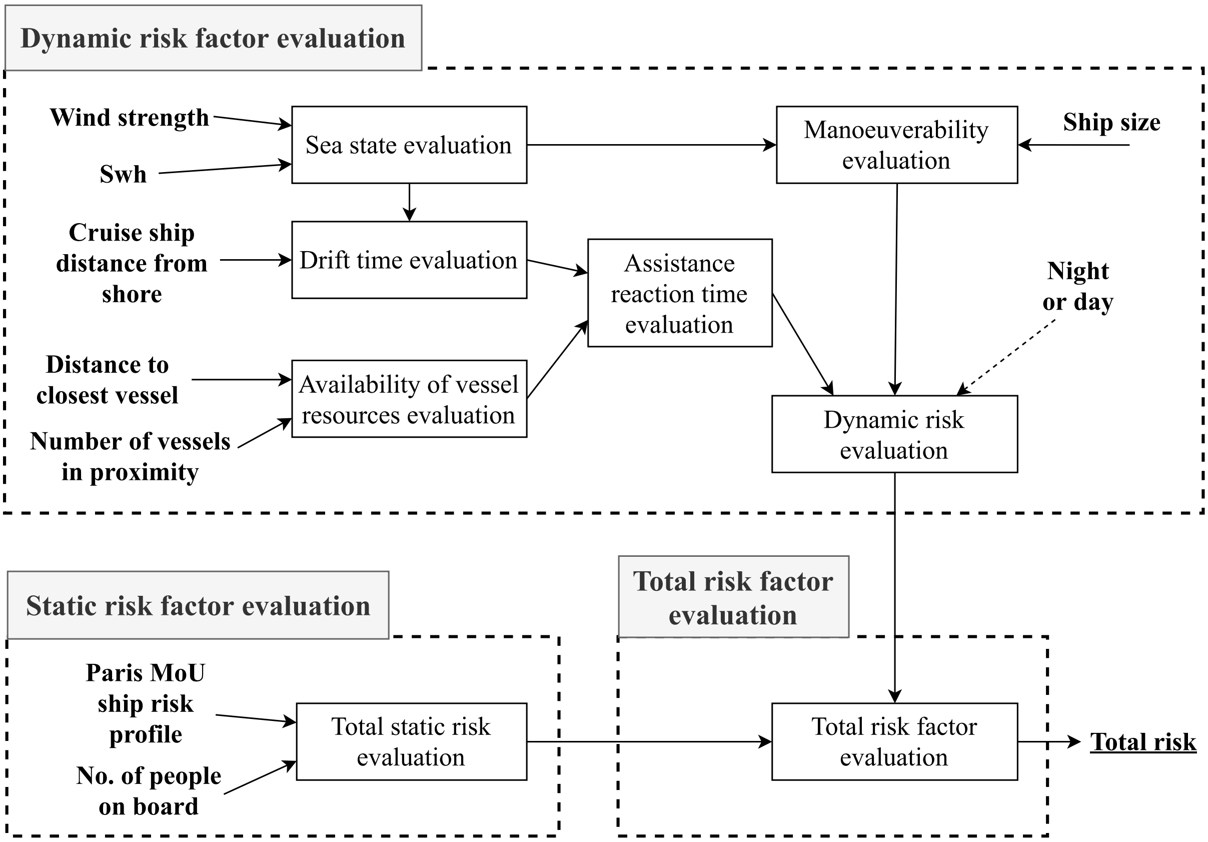


Figure 5.2: The figure presents the developed modular and hierarchical risk model which integrates parameters relating to the ship's static and dynamic risk. All parameters acting as input variables are seen in bold text with arrows pointing towards a modular "box". The input parameter of *Night or day* is seen as a dotted arrow as this parameter is a non-fuzzy parameter. The final output is the underlined *total risk* in the bottom right corner.

The modular and hierarchical fuzzy logic model presented in Figure 5.2 have been the favourable choice after careful consideration of different architectural structures. All fuzzy logic boxes will consist of two input variables and one output variable, which despite many different input variables gives an easily interpretable and flexible model. This eases the process of evaluating and calibrate how the model will respond to different sets of input values, as will be further described.

5.2 Fuzzy logic methodology

To better grasp how the risk analysis and fuzzy logic concepts will be combined, the methodology will be presented followed by a simple example.

To implement the factors in the proposed model, the fuzzy logic controllers will be developed to fit the hierarchical and modular structure. Consequently, each fuzzy logic controller will receive two input values, which through the fuzzy logic controller will be transformed into a single linguistic output value. This is exemplified by the sea state evaluation seen in Figure 5.3.

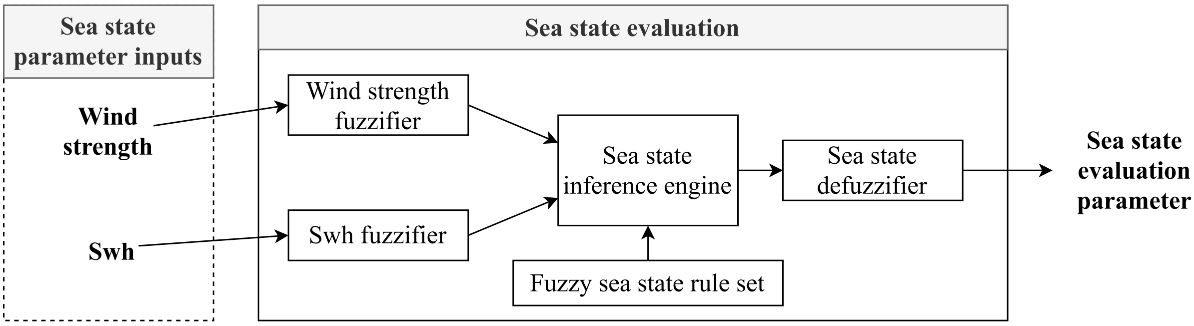


Figure 5.3: The figure shows the details of how the sea state will be evaluated from the input parameters comprised of wind strength and swh.

The evaluation of all parameter inputs is performed similarly to the sea state parameter, which will be explained in detail.

Fuzzification

For each parameter input a fuzzification of the input values must be performed. This fuzzifying process will transform the input values to a certain degree of truth between 0 and 1 of a corresponding membership function within a linguistic set representing that factor. For the wind strength the linguistic set is defined to comprise five membership functions named *low*, *low-medium*, *medium*, *high* and *very high* that will be related to a certain range of the wind speed input values.

To illustrate the example, a wind strength of 6 m/s is used as a input value to the wind strength fuzzifier, which provides the result shown in Figure 5.4.

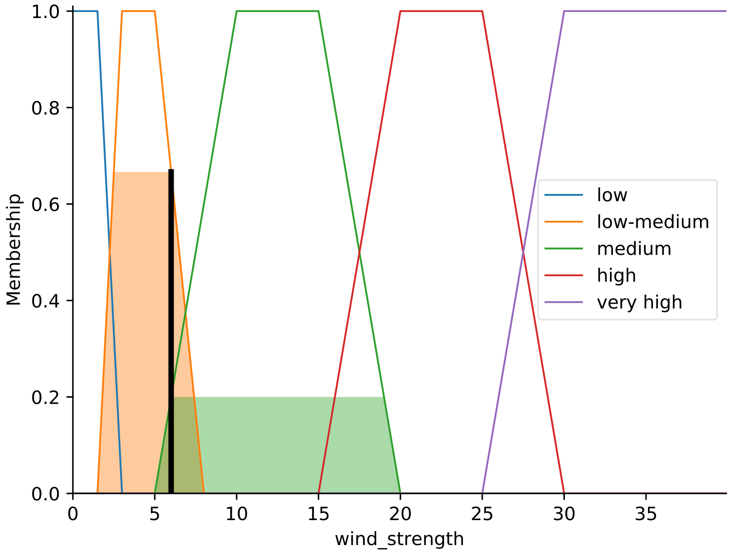


Figure 5.4: The figure shows the fuzzification of the wind strength input parameter with an input value of 6 m/s and how the input value gives a degree of truth of the two membership functions *low-medium* and *medium*.

It can be seen from the vertical black line in Figure 5.4 how a wind strength of 6 m/s gives a fuzzified wind strength of the *low-medium* membership function equal to 68 % and a resulting *medium* membership function wind strength of 19 % by evaluating where the black line crosses the membership functions. In other words, the wind strength is dominated by the *low-medium* membership function.

Further the swh fuzzifier can be evaluated. The linguistic set of the swh fuzzifier also comprise five membership functions, namely *calm*, *slight*, *rough*, *high* and *very high*. Using a swh of 3 m as the parameter input, the resulting fuzzification is seen in Figure 5.5.

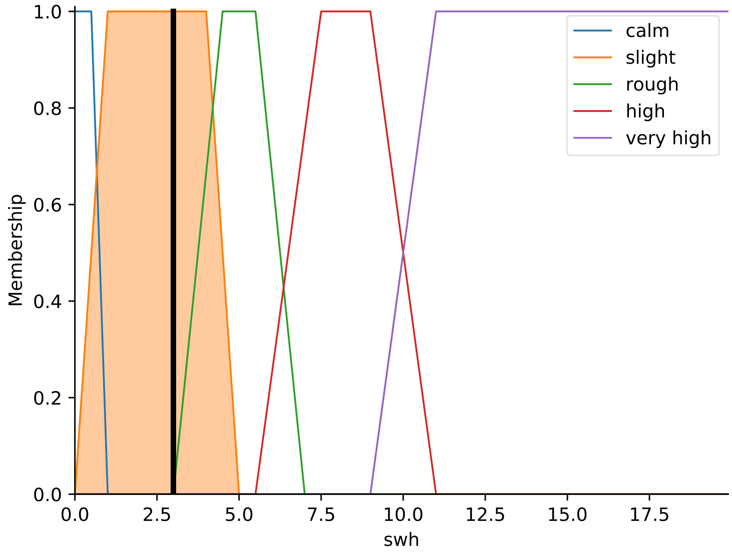


Figure 5.5: The figure shows the fuzzification of the swh input parameter with an input value of 3 metres and how the input value corresponds to the *slight* membership function.

Figure 5.5 shows how a swh input parameter of 3 metres results in 100 % correspondence to the *slight* membership function.

Fuzzy rule set

To further evaluate the fuzzified input parameters, a rule set for the sea state inference engine have to be defined. The rule set seen in Table 5.1 shows the specific rules used with the produced results from the fuzzification process which comprise an AND-rule set e.g. if the wind strength is *low-medium* AND the swh is *slight* the sea state parameter is *slight*.

Table 5.1: A non-exhaustive fuzzy rule set for the sea state evaluation example.

Wind strength	**Swh**	**Sea state parameter**
Low-medium	Slight	Slight
Medium	Slight	Rough

Inference engine and defuzzifier

The results from the wind strength and swh fuzzification process is combined with the rule set in the sea state inference engine into a crisp sea state result, as seen in Figure 5.6.

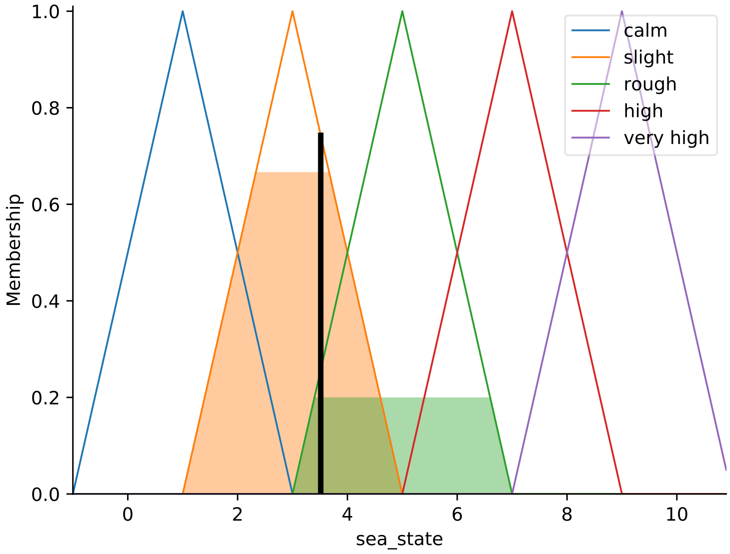


Figure 5.6: The figure shows the process of the sea state's interference engine and how a crisp sea state value is extracted through defuzzification.

Firstly it can be seen how the sea state's linguistic sets is divided into the five membership functions of *calm*, *slight*, *rough*, *high* and *very high*. Furthermore Figure 5.6 shows how the resulting sea state will be somewhere in between the membership functions of *slight* and a *rough* sea state parameter value represented by the vertical black line.

To obtain the crisp output value represented by the vertical black line in Figure 5.6 the results have to be defuzzified by specifying a defuzzifying method. Balmat et al. (2011) recommends what is called the *centre-of-gravity*-defuzzification method, which use a weighted relationship of the obtained membership functions to provide a crisp output value. Hence the *centre-of-gravity*-defuzzification method will be used throughout the model development. It can be seen from Figure 5.6 how the black line crosses the sea state's x-axis in 3.5, thus obtaining a sea state parameter value of 3.5.

In other words, a wind strength of 6 m/s combined with a swh of 3 metres gives a fuzzy sea state parameter value of 3.5, that is a sea state parameter value dominated by the *low-medium* membership function.

5.3 Model parameter estimation

When evaluating the different parameter modules shown in Figure 5.2 all defuzzification processes will use the same membership functions, similar to that shown in the example for the sea state parameter inFigure 5.6. That is five membership functions which comprise values between -1 and 11, where the leftmost triangle have a maximum membership function value for a sea state parameter value of 1, followed by the next triangle having a maximum function value for a sea state parameter of 3 and so up to the fifth triangular membership function value having a maximum membership function value for a sea state parameter of 9.

5.3.1 Static risk evaluation

The static factors will comprise the factors that are fixed whilst a ship is underway, as seen in the leftmost part of Equation 5.3.

When evaluating the static factors for a ship, Balmat et al. (2011) showed how static risk analyses using fuzzy logic by the implementation of a large number of static inputs (age, flag, ship history, company performance etc.) in a fuzzy relationship was coherent with that of the target factor used by the Paris MoU. In other words, they obtained a similar static risk level with both approaches.

The Paris MoU ship risk profile is well-established, and its implementation directly into the model is assumed to minimise model uncertainty on the static risk factor. The alternative would be to recreate a similar fuzzy environment as presented in Balmat et al. (2011).

Further, the model should thrive to give extra attention to the number of passengers on board, which is not a criterion from the Paris MoU target factor. Thus, a factor of close relevance is the total number of passengers on board a ship, including crew. Ship size could also be a factor of interest for the static factor, but as the passenger-to-space ratio for a typical cruise ship can range from less than 20 to more than 50 passengers per GT it is assumed that the total number of people on board the ship is the better input to affect a cruise ship's static risk index. ("Cruise Ship Passenger Capacity", 2015). Also, the number of passengers on board a ship relates directly to the time it takes to evacuate a ship, thus this is considered to be an important inclusion.

Hence the membership functions of the total amount of people on board the ship is seen in Figure 5.7. The membership functions are based on the capacity of the current fleet of cruise ships, also integrating how ships carrying fewer passengers should be categorised in finer categories to make the model more sensitive to smaller ships.

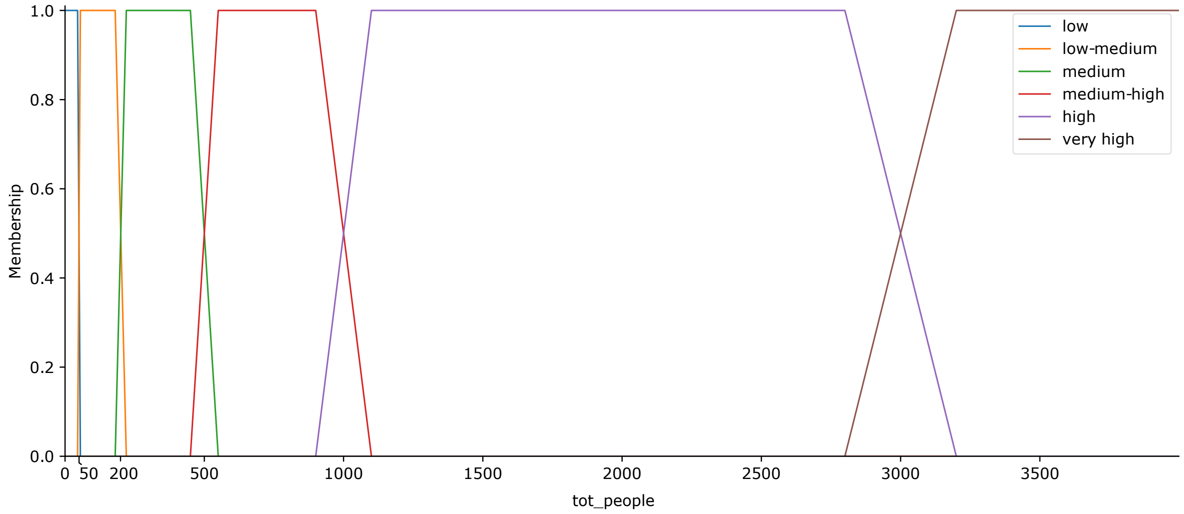


Figure 5.7: Fuzzification logic of the total number of people on board. The membership functions' linguistic name represents the ship's capacity.

The rule set for the static risk will be evaluated based on the five different degrees of risk as seen in Table 5.2. The risk level will comprise how severe a potential accident could become based on the ship's static performance. The number of passengers on board will be a large contribution to the severity potential, thus a large ship even with a low Paris MoU ship risk profile will be given a relatively high static risk level.

Table 5.2: Static risk definitions.

Static risk level	**Definition**
Low	The low static risk potential of the cruise ship is not evaluated to pose any immediate concerns.
Low-medium	The cruise ship should be given some attention but does not pose any immediate concern.
Medium	The cruise ship should be given some attention and will have a potential of severity in case of an accident.
Medium-high	The ship needs to be given attention and will have a high severity potential in case of an accident.
High	The ship is of especial concern and needs porter attention. The ship will have a large severity potential in case of an accident.

Further the definition of the fuzzy rule set shown in Table 5.3.

Table 5.3: The fuzzy rules set of the static risk factor.

Paris MoU ship risk factor	**No. of passengers**	**Static risk parameter**
low risk ship	low	low
low risk ship	low-medium	low
low risk ship	medium	low-standard
low risk ship	medium-high	standard
low risk ship	high	standard
low risk ship	very high	standard-high
standard risk ship	low	standard
standard risk ship	low-medium	standard
standard risk ship	medium	standard-high
standard risk ship	medium-high	standard-high
standard risk ship	high	high
standard risk ship	very high	high
high risk ship	low	high
high risk ship	low-medium	high
high risk ship	medium	high
high risk ship	medium-high	high
high risk ship	high	high
high risk ship	very high	high

5.4 Dynamic factors

The dynamic factors will include all factors that are thought to change often for a cruise ship under way, as seen in the rightmost part of Equation 5.3.

The fuzzification process of each of the dynamic input parameters corresponding to the modular evaluation boxes as presented in Figure 5.2 will in the following section be described in detail.

5.4.1 Sea state evaluation

The wind strength fuzzification process have been developed with a basis in the Beaufort scale, divided into five membership functions as seen in Figure 5.8. It can be seen how winds stronger than 30 m/s will obtain the highest possible degree of wind speed as *very high*. The direction of the wind is not implemented directly into the model formulation but is obtainable from the weather data.

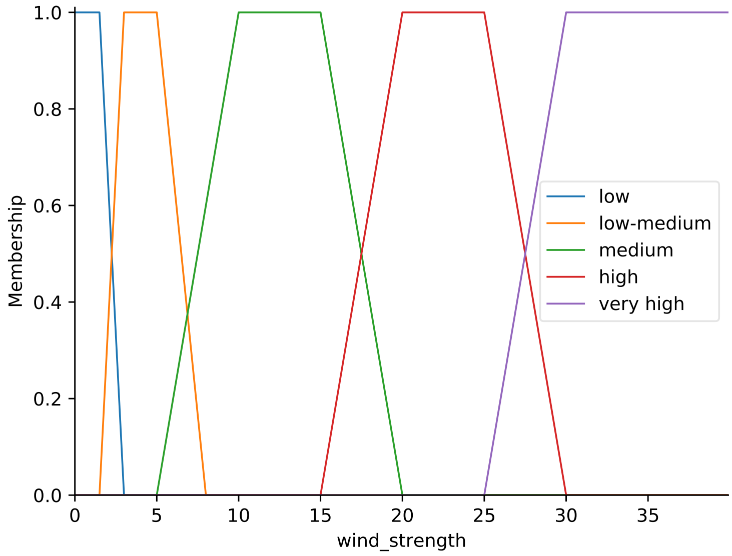


Figure 5.8: Fuzzification process of the wind strength input parameter.

For the wave heights the Douglas sea scale (https://en.wikipedia.org/wiki/Douglas_sea_scale) have been used to categorise the input variables of the significant wave height into five membership functions as seen in Figure 5.9.

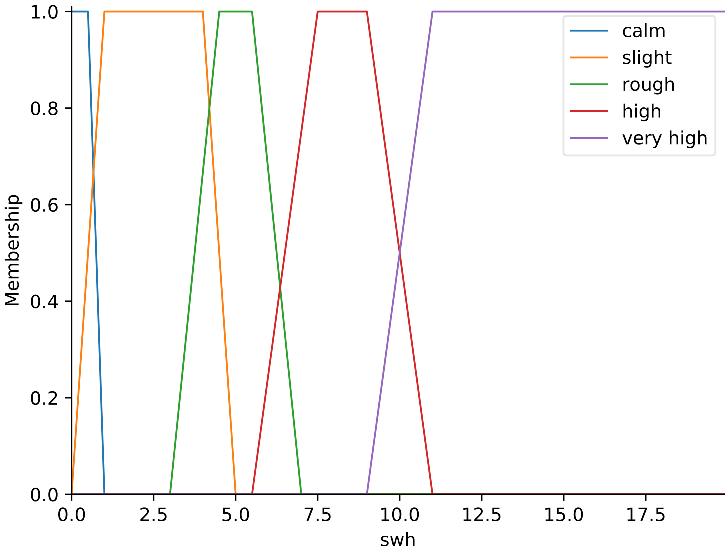


Figure 5.9: Fuzzification process of the significant wave height input parameter.

The fuzzy rule set relating to the sea state evaluation can be seen in Table 5.4. The rules have been defined through a combination of the Beaufort scale and Douglas sea scale definitions to obtain a overall sea state defining the condition of the sea. All possible combinations of the two input parameters are defined, however in most situations the wind strength and swh will correlate strongly.

Table 5.4: The fuzzy rule set of the sea state parameter.

wind strength	swh	Sea state parameter
low	calm	calm
low	slight	calm
low	rough	slight
low	high	rough
low	very high	high
low-medium	calm	calm
low-medium	slight	slight
low-medium	rough	slight
low-medium	high	rough
low-medium	very high	high
medium	calm	slight
medium	slight	rough
medium	rough	rough
medium	high	high
medium	very high	very high
high	calm	rough
high	slight	rough
high	rough	high
high	high	high
high	very high	very high
very high	calm	rough
very high	slight	high
very high	rough	very high
very high	high	very high
very high	very high	very high

5.4.2 Manoeuvrability evaluation

It is advantageous that the model can receive a weather input and evaluate the current manoeuvrability of the ship, thus evaluating whether a ship is equipped to handle the prevailing weather conditions. It is expected that larger ships are less susceptible to adverse weather than ships of smaller size, thus it is assumed that a factor representing the ship size should be combined with a factor representing the current weather conditions to evaluate the manoeuvrability of the cruise ship. The current weather conditions are simplified to comprise a single input variable shown as the developed *sea state*-parameter.

As described in section 4.2 the ship length in meters is an easily available ship factor obtained from the ship dimensions in the AIS data. Figure 5.10 illustrates the fuzzifiation of the ship size input.

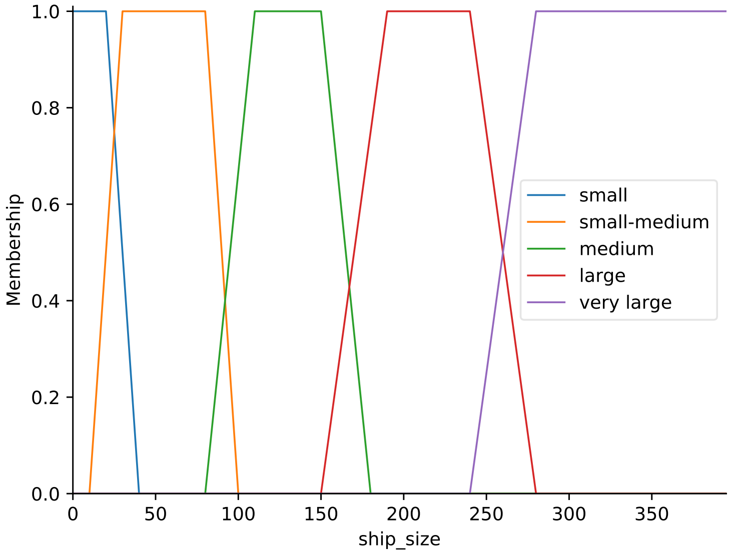


Figure 5.10: Fuzzification logic of the ship size input factor.

When evaluating how well the manoeuvrability of a ship is in a given sea state, the fuzzy rule set for the manoeuvrability evaluation have been developed based on subjective rationale knowledge from normal behaviour of observed cruise ships along the Norwegian coast. The full fuzzy rule set can be seen in Table 5.5.

Table 5.5: The fuzzy rule set of the manoeuvrability parameter.

Ship size	**Sea state**	**Manoeuverability parameter**
small	calm	good
small	slight	average-poor
small	rough	poor
small	high	poor
small	very high	poor
small-medium	calm	good
small-medium	slight	average
small-medium	rough	average-poor
small-medium	high	poor
small-medium	very high	poor
medium	calm	good
medium	slight	good-average
medium	rough	average
medium	high	average-poor
medium	very high	poor
large	calm	good
large	slight	good
large	rough	good-average
large	high	average-poor
large	very high	average-poor
very large	calm	good
very large	slight	good
very large	rough	good-average
very large	high	average
very large	very high	average-poor

5.4.3 Drift time evaluation

Remembering from section 4.7 the evaluation of the potential drift of a ship will be an important parameter in the risk model. The drift will be evaluated based on a combination of the sea state and the ship's distance from shore, assuming a worst-case scenario, that is total immobility of the ship and a on shore wind. Thus an input to the model is the ship's distance from shore, which is fuzzified as seen in Figure 5.11.

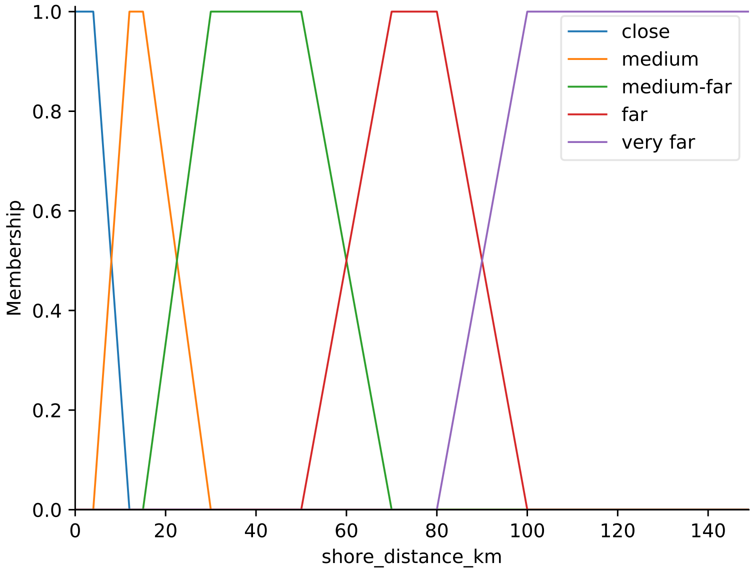


Figure 5.11: Fuzzification logic of the cruise ship's distance from shore parameter

By using the drift times based on significant wave heights presented in Figure 4.10, five different degrees of drift time can be established that will depict the worst-case potential drift time of a ship in case of a loss of propulsion and uncontrolled drifting. The definition of drift speeds from the prevailing sea state can be seen in the left table in Table 5.6 which also shows the definition of drift times from the drift time's linguistic set of membership functions.

Table 5.6: Definition of drift speed and drift time.

Sea state	**Drift speed definition**
calm	0-1 kn
slight	1-3 kn
rough	3-5 kn
high	5-7 kn
very high	7-10 kn

Drift time	**Drift time definition**
good	5+ hours
good-average	4-5 hours
average	3-4 hours
average-poor	2-3 hours
poor	0-2 hours

By using Table 5.6 in combination with the fuzzification of the shore distance input parameters seen in Figure 5.11 it is possible to obtain the drift time parameters. However, the definition of the drift time parameter is also subject to subjective inputs from the author to ensure a ship is given a slightly higher drift time parameter value (that is an increased drift time risk level) if a ship has a high drift speed even with a great distance to shore.

Hence the fuzzy rule set for the drift time evaluation is as seen in Table 5.7.

Table 5.7: The fuzzy rules set of the drift time parameter.

shore_distance	**Sea state**	**Drift time parameter**
close	calm	good
close	slight	average
close	rough	average-poor
close	high	poor
close	very high	poor
medium	calm	good
medium	slight	good-average
medium	rough	average
medium	high	average-poor
medium	very high	average-poor
medium-far	calm	good
medium-far	slight	good
medium-far	rough	good-average
medium-far	high	average
medium-far	very high	average
far	calm	good
far	slight	good
far	rough	good-average
far	high	good-average
far	very high	average
very far	calm	good
very far	slight	good
very far	rough	good
very far	high	good-average
very far	very high	good-average

5.4.4 Availability of vessel resources evaluation

To model will evaluate the availability of nearby vessel resources, that being how many ships in proximity of the ship being tracked that can be of assistance in an emergency situation, as was discussed in section 4.5. The ship availability will represent how many ships that are present in the vicinity of the cruise ship.

This is included in the model through a combination of two input values, the *distance to closest vessel*-parameter and the *number of vessels in proximity*-parameter. These two are evaluated through fuzzy logic to represent the availability of vessel resources.

The fuzzification of the *Distance to closest vessel*-parameter is defined as seen in Figure 5.12.

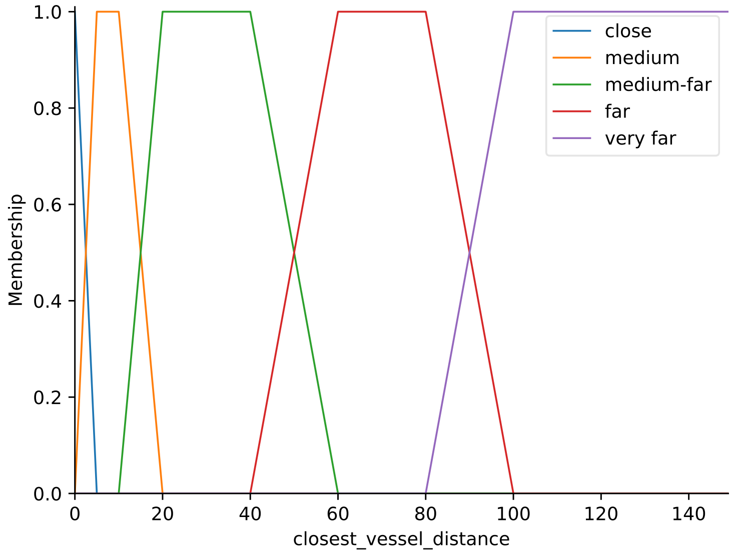


Figure 5.12: Fuzzification logic of the input factor of distance to the nearest detected ship.

It can be seen how the definition of a ship being close is within a distance of approximately 5 km and medium being from 5-20km.

To include other nearby ship resources, another fuzzy logic membership function is created, which evaluates the density of ship resources in proximity to the ship being tracked. How large the proximity around the cruise ship should span will be further considered when evaluating the risk model against AIS data. The fuzzification of the *number of vessels in proximity*-parameter is as seen in Figure 5.13.

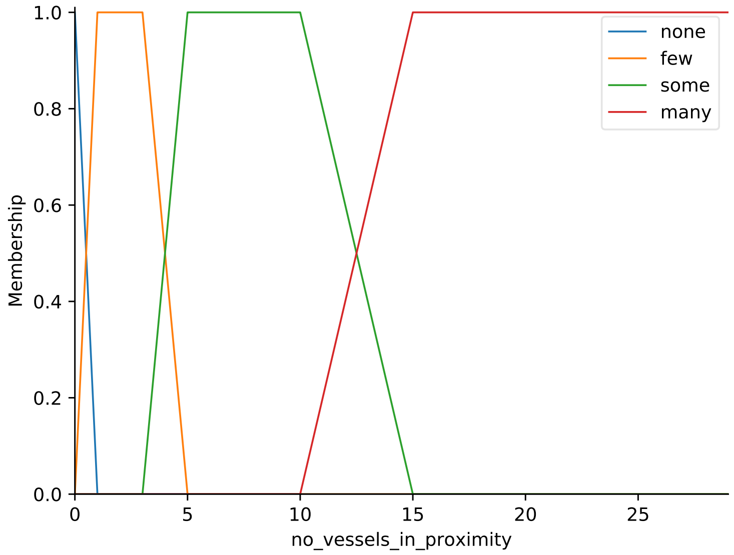


Figure 5.13: Fuzzification logic of the input factor of total number of ships within an acceptable distance around the ship being tracked.

The development of the fuzzy rule set for the availability of vessel resources have been defined based on the authors subjective inputs, as no information is easily available on the topic. It is challenging to precisely evaluate how the presence of a single or multiple ships is will act as a risk reducing measure, however the presented theory have shown how different ship types have quite different potentials to assist a cruise ship. Hence the *vessel availability*-parameter will simply serve as an input into the model of how present the ships evaluated as relevant ship resources are in the area of the cruise ship, in a combination of the closest ship and the total number of ships in a restricted proximity.

A further evaluation of the rule set will be evaluated with the full evaluation of the model. The developed rule set is seen in Table 5.8.

Table 5.8: The fuzzy rules set of the availability of vessel resource factor. Note how if there are no vessels in proximity of the ship being tracked the *vessel availability*-parameter is always poor.

Closest vessel	**No. of vessels in proximity**	**Vessel availability parameter**
close	none	poor
close	few	average
close	some	good
close	many	good
medium	none	poor
medium	few	average
medium	some	average
medium	many	good-average
medium-far	none	poor
medium-far	few	average-poor
medium-far	some	average
medium-far	many	average
far	none	poor
far	few	poor
far	some	average-poor
far	many	average
very far	none	poor
very far	few	poor
very far	some	average-poor
very far	many	average

5.4.5 Assistance reaction time evaluation

The ship availability parameter will be evaluated according to their assumed reaction time, which is based on the prior evaluations of drift time and the availability of vessels. That is how close the ship resources are in relation to the cruise ship combined with the cruise ship's drift time. That is, if a cruise ship only has an average coverage of ships in its vicinity but have a good evaluation of its drift time, this will give a relatively good assistance reaction time parameter. On the other hand, if the cruise ship's drift time is evaluated to be fairly poor, the cruise ship needs a relatively good vessel availability factor to achieve a good assistance reaction time parameter.

The above considerations have been evaluated and formulated into the fuzzy rule set of the assistance reaction time as seen in Table 5.9.

Table 5.9: The fuzzy rules set of the assistance reaction time factor.

Drift time factor	**Availability of vessels factor**	**Assistance reaction time parameter**
good	good	good
good	good-average	good
good	average	good
good	average-poor	good-average
good	poor	average
good-average	good	good
good-average	good-average	good-average
good-average	average	good-average
good-average	average-poor	average
good-average	poor	average-poor
average	good	good-average
average	good-average	good-average
average	average	average
average	average-poor	average-poor
average	poor	poor
average-poor	good	good-average
average-poor	good-average	average
average-poor	average	average
average-poor	average-poor	average-poor
average-poor	poor	poor
poor	good	average
poor	good-average	average-poor
poor	average	average-poor
poor	average-poor	poor
poor	poor	poor

5.4.6 Total dynamic risk evaluation

The fuzzy inference process of the *total dynamic risk*-evaluation connects the *ship manoeuvrability*-parameter with the *assistance reaction time*-parameter. The relationship is designed to give a larger weight to the *assistance reaction time*-parameter to make the risk model more sensitive to a poor degree of reaction time and less sensitive to how well manoeuvrable the ship is assumed to be.

When developing the fuzzy rule set for the total dynamic risk five degrees of risk have been defined, seen in Table 5.10.

Table 5.10: Definition of the five different degrees of risk levels.

Risk level	**Definition**
Low	The situation is evaluated to pose no immediate threat to the ship and its passengers and is assumed to be safe.
Low-medium	The situation is evaluated to have a slight probability of experiencing a severe accident with major negative consequences but poses no immediate threat.
Medium	The situation is evaluated to have a medium probability of experiencing a severe accident and should be given some attention.
Medium-high	The situation is evaluated to have a medium to high probability of experiencing a severe accident and should be given attention.
High	The situation is evaluated to have a high probability of experiencing a severe accident and should be given immediate attention.

The risk definitions presented in Table 5.10 will correspond to the defuzzification logic of the dynamic risk level as seen in Figure 5.14. It can be seen how the risk levels are not mutually exclusive and will because of the fuzzification logic overlap to some degree.

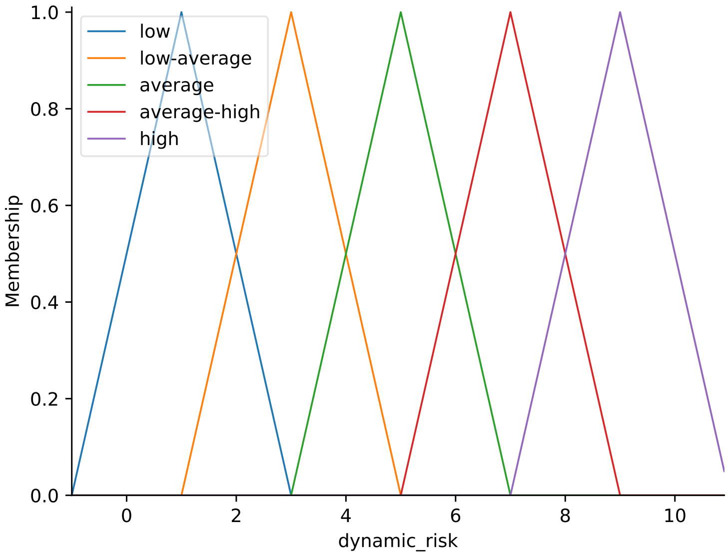


Figure 5.14: Defuzzification logic of the dynamic risk divided into five risk levels.

The fuzzy rule set have been developed based on the risk definitions presented in Table 5.10. Thus, if the assistance reaction time is good, the ship will have a relatively low dynamic risk parameter even for a poor ship manoeuvrability. However, the rule set have been formulated to include the fact that event for a ship with good manoeuvrability, that is the evaluation of the ships potential to manoeuvre in the prevailing weather conditions, if the assistance reaction time evaluated to a relative poor level, the ship will be given a risk level weighted towards the assistance reaction time evaluation.

The rule set for the *assistance demand*-evaluation is presented in Table 5.11.

Table 5.11: The fuzzy rule set of the total dynamic risk parameter.

Manoeuvrability	**Assistance reaction time**	**Dynamic risk parameter**
good	good	low
good	good-average	low
good	average	low-average
good	average-poor	average
good	poor	average-high
good-average	good	low
good-average	good-average	low-average
good-average	average	low-average
good-average	average-poor	average
good-average	poor	average-high
average	good	low
average	good-average	low-average
average	average	average
average	average-poor	average-high
average	poor	high
average-poor	good	low-average
average-poor	good-average	average
average-poor	average	average-high
average-poor	average-poor	average-high
average-poor	poor	high
poor	good	low-average
poor	good-average	average
poor	average	average
poor	average-poor	average-high
poor	poor	high

Further the final dynamic risk evaluation also includes a factor indicating if it is night or day. Thus the final dynamic evaluation will be a combination of the fuzzy relationship of the *ship manoeuvrability*-parameter and the *assistance reaction time*-parameter and a non-fuzzy relationship based on the daytime evaluation. This is performed as the general risk is thought to be increased after dark, which should be reflected in the model formulation.

A higher risk index by night is simply obtained by increasing the dynamic risk level by one degree, e.g. being changed from 'low' to 'medium-low' and similar.

5.5 Total fuzzy risk factor evaluation

Finally, for the total fuzzy risk factor evaluation is computed by combining the total dynamic and static risk factors, as seen in Figure 5.2.

Further, the presented degrees of risk and their relation to the probability and consequence of a cruise ship accident is defines as a risk matrix seen in Table 5.12. Please note how the numerical value of the probability and consequence corresponds to that of the fuzzy parameter for the dynamic risk seen in Figure 5.14, which will also be the case for the static risk.

Table 5.12: Risk matrix

Probability/ Consequence	1 Rare	3 Unlikely	5 Possible	7 Occasional	9 Fairly normal
1 Insignificant	Low	Low	Low-med	Low-med	Medium
3 Minor	Low	Low-med	Low-med	Medium	Medium
5 Moderate	Low-med	Low-med	Medium	Medium	Med-high
7 Major	Low-med	Medium	Medium	Med-high	Med-high
9 Catastrophic	Medium	Medium	Med-high	Med-high	High

The risk matrix is used to establish the total risk parameter by evaluating how probable a ship accident is based on the dynamic factors, and further how large the consequence will be based on the static risk factors. Obviously both the static and dynamic risk factors will to some degree inhabit both the assumed probability of an accident and the potential consequences of an accident and must be treated accordingly.

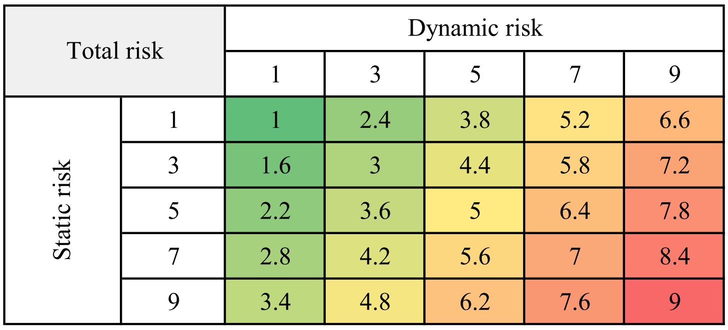
The weighting between the static and the dynamic risk have not been studied in detail and should thus be easily changeable. As presented by Balmat et al. (2009), it seems appropriate to introduce a proportional relationships between the static and dynamic risk, which can be easily modified.

As seen in Equation 5.4 a variable γ is introduced to represent the weighted relationship between the static and dynamic risk factor as

$$R_F = R_D\gamma + R_S(1 - \gamma). \tag{5.4}$$

It is assumed that the dynamic risk will be of more importance in the relationship. Thus, it seems appropriate to assign $\gamma = 0.7$ where the dynamic risk is given a higher weighting than the static risk.

The risk universe of discourse for both static, dynamic and the final fuzzy risk factor is comprised between 1 (low risk) and 9 (high risk). The weighted relationship introduced through Equation 5.4 is represented in the fuzzy risk factor matrix in Figure 5.15. It is seen how a higher fuzzy risk appears in the upper matrix triangle compared to the lower triangle meaning the fuzzy risk is dominated by the dynamic risk factor.



Total risk		Dynamic risk				
		1	3	5	7	9
Static risk	1	1	2.4	3.8	5.2	6.6
	3	1.6	3	4.4	5.8	7.2
	5	2.2	3.6	5	6.4	7.8
	7	2.8	4.2	5.6	7	8.4
	9	3.4	4.8	6.2	7.6	9

Figure 5.15: Weighting scheme for the final fuzzy risk factor with $\gamma = 0.7$. A risk factor of 1 equals low risk whilst a factor of 9 equals high risk.

It can be discussed if the static risk is given too little attention, as it is seen from the total risk matrix in Figure 5.15 that a low dynamic risk factor always gives a relatively low static risk factor. This is nevertheless thought to provide a good representation of a ship's fuzzy risk at a given time, as knowledge from historical cruise ship accidents show how dynamic factors such as geographical location, weather conditions and nearby ship resources often play a more important role than the ship's static risk.

Chapter 6

Validation of the risk model

To validate the developed model's performance a number of scenarios will be presented to illustrate how the model will respond to different input values. Firstly, it will be shown how the model will respond to a global set of input variables ranging from minimum to maximum values, to evaluate if the resulting risk levels seem to be within an appropriate range.

Further the model will be evaluated against a set of scenarios with stochastic weather variations to represent how typical cruise ship's risk level would vary.

6.1 Model validation in a global set of scenarios

Firstly, the model will be evaluated on how it responds to a large number of unique model input combinations. This will be advantageous to validate if the model gives reasonable output values based on a large range of input values.

The total calculated fuzzy risk along with the dynamic and static fuzzy risk level for a combination of input values within a set range will be calculated. This will give N unique scenarios, as calculated from Equation 6.1.

$$N = \prod_{i=1}^{n} \left(\frac{\text{Max}_i - \text{Min}_i}{\text{Range}_i} + 1 \right) \tag{6.1}$$

The range of input values for each factor can be seen in Table 6.1, which will produce 288,000 unique input scenarios to the fuzzy risk model. This will cover input values in the lower and upper feasible bounds including in-between values.

Table 6.1: Global set of input variables for the risk model validation

Factor		**Input value**
Paris MoU risk profile	[-]	[LRS, SRS, HRS]
Total No. of people on board	[-]	[100, 500, 1000, 2000, 5000]
Ship size	[m]	[50, 100, 200, 300, 400]
Wind strength	[m/s]	[0, 10, 20, 30]
Significant wave height	[m]	[0, 1, 3, 5, 9, 13]
Shore distance	[km]	[0.5, 5, 20, 50, 100]
Distance to closest ship	[km]	[5, 20, 100, 200]
Total ships in proximity	[-]	[0, 5, 10, 20]
Day or night	[-]	[Day, Night]

Total number of unique scenarios:	**288,000**

For all simulations, the number of scenarios that was calculated to a specific risk level have been summed up, and the result of this is presented as a bar chart in Figure 6.1.

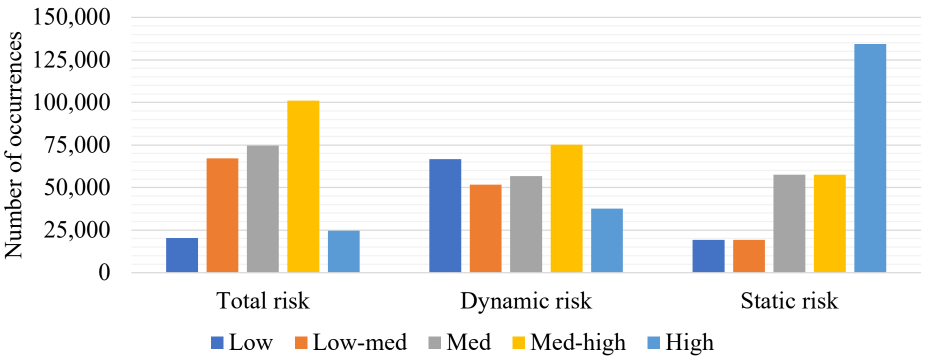


Figure 6.1: Results from the risk model validation from a global set of variables.

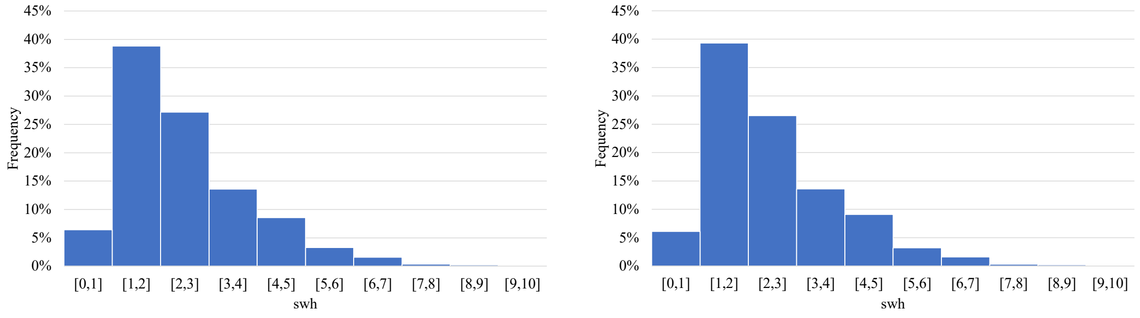
The results show how the total risk level seem to be well distributed amongst the different risk levels. The dynamic risk level is fairly evenly distributed whilst the static risk is more densely populated in the higher risk level. Thus, the total risk level is seen to be a combination of the dynamic and static risk levels with a higher weight towards the dynamic risk levels, as expected.

The reason the static risk is so heavily skewed towards the high risk is a direct consequence from the static risk formulation presented in the model formulation, see subsection 5.3.1, where a uniform distribution of the possible input values will give a high static risk. The dynamic risk on the other hand will be more evenly distributed from its model formulation.

6.2 Stochastic model validation

In this section a number of generic scenarios will be evaluated. Each scenario will have all input variables predefined except from weather input which will be based on stochastic variation from historical observations. This will give an indication to how the model will respond in a set of realistic scenarios.

Figure 6.2 shows the occurrence frequency of the simulated stochastic variations of the significant wave height compared to historic values. It is reasonable to assume that the wind strength input will strictly follow the significant wave heights ranging from 0 m/s to 30 m/s. The historical values are extracted from a weather station by Mysen south of Tromsø[1]. The weather conditions are known to be less severe in this area than on the west-coast of Norway. The weather data is however only meant to show how the model response varies with a stochastic input and will provide good results for the intended purpose.



(a) Significant wave heights from simulations.

(b) Significant wave heights from historic observations

Figure 6.2: The figure shows the occurrence frequency of simulated significant wave heights compared to historic observations.

Ten different scenarios have been evaluated. These scenarios are based on a large cruise ship and a medium-sized cruise ship each with 5 different combinations of input parameters, as seen in Table 6.2.

Table 6.2: Model validation scenarios.

	Scenario									
Input	1	2	3	4	5	6	7	8	9	10
Paris MoU profile	LRS	LRS	LRS	LRS	HRS	LRS	LRS	LRS	LRS	HRS
Tot. people	4000	4000	4000	4000	4000	1000	1000	1000	1000	1000
Length	350	350	350	350	350	200	200	200	200	200
Shore distance	5	5	50	50	5	5	5	50	50	5
Ships in proximity	None	Some	None	Some	None	None	Some	None	Some	None

As seen in the above table, the varying input parameters will be the shore distance and the number of ships in proximity in combination with a stochastic weather variation. 10,000 simulations are performed for each scenario and the fuzzy risk level is calculated for each simulation. All obtained results can be seen in Table 6.3, which shows the frequency distribution of the obtained risk level in percent for each scenario.

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[1] https://klimaservicesenter.n- o/observations/

Table 6.3: Results from the simulations for all scenarios. The figure shows the frequency distribution of the obtained risk level in percent for each of the evaluated scenarios.

	Scenario									
Fuzzy risk	1	2	3	4	5	6	7	8	9	10
Low	0.0%	0.0%	0.0%	0.0%	0.0%	10.4%	62.1%	36.5%	94.2%	0.0%
Low-med	10.1%	94.1%	61.0%	97.8%	10.3%	51.3%	32.0%	57.8%	4.0%	10.6%
Med	83.8%	5.9%	37.0%	2.2%	51.2%	32.3%	3.8%	3.6%	1.8%	50.3%
Med-high	4.1%	0.0%	2.0%	0.0%	36.3%	6.0%	2.1%	2.1%	0.0%	33.1%
High	2.1%	0.0%	0.0%	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%	6.0%

To better visualise and compare the results, the calculated results for the large ship, scenario 1-5, is presented as a line plot as presented in the below Figure 6.3.

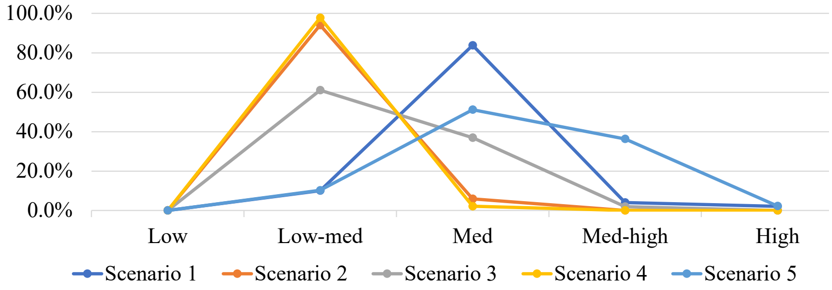

Figure 6.3: The figure shows the total risk distribution of the evaluated scenarios for the large cruise ship, scenarios 1-5.

By examining the above figure, it can be seen that none of the large ships will have a low fuzzy risk level. This is a direct consequence of the combination of the dynamic and static fuzzy risk factors, where the large ship has a high static risk level emerging from the high number of people on board, and consequently the weighting of the static and dynamic risk level will result in a higher total risk factor.

Further, it can be seen that the situation with most low-medium risk scenarios is scenario 2 and 4. These are the two scenarios where there is a large availability of ships in the cruise ship's proximity. Scenario 2 is seen to obtain a medium risk level in 5.9% of the simulations, compared to 2.2% for scenario 4. This seems reasonable as the cruise ship's distance to shore in scenario 2 is 5 km compared to scenario 4 with 50 km.

Only scenario 1 and 5 will obtain a high risk level, with a frequency distribution of 2.1% and 2.2%, respectively. The threshold for obtaining a high risk level is set to be high as this should only occur in the most extreme situations for large ships, which so far seems to correspond with the obtained results.

Based on the similar results from scenario 2 and 4, it seems that the model gives a fairly similar risk level to large cruise ships with several ships in the proximity, despite 40km difference in their shore proximity. This also seems appropriate as the two scenarios should be given a low-medium risk level, as there are several nearby ships that can assist which will give a good dynamic risk level in both scenarios. It can be seen how scenario 2 obtain a medium risk level in 5.9% of the simulation compared to 2.2% for scenario 4, which means the model does seem to correctly weigh the two different scenarios.

This can however be evidence of how the model might struggle to compare and differentiate between certain events, when it is ”forced” to categorise the risk level within one of the five different risk level categories.

Similarly, the results for scenario 6-10, that is the medium-sized ship can be seen in Figure 6.5.

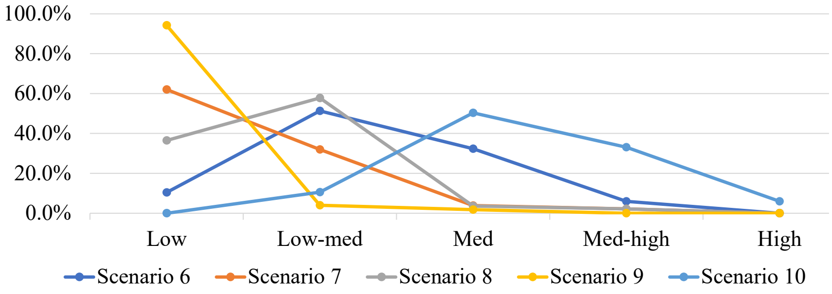

Figure 6.4: The figures shows the total risk distribution of the evaluated scenarios for the medium cruise ship, scenarios 6-10.

The results obtained from scenario 6-10 shows how the risk level for all scenarios except scenario 10 will on several occasions be calculated to a low risk level. Scenario 10 is a high risk ship and will from the model definition never be able to receive a low risk, and it can be seen that scenario 10 tend to obtain a medium, medium-high or low-medium or high risk level, in descending order. In scenario 9, given that the scenario illustrates the situation of the ship having a distance 50km from shore and having several ships in its proximity, it seems reasonable to obtain a low risk level in 94.2% of the simulations, and that only rare occasions with severe weather conditions will give a low-medium (4.0%) or medium (1.8%) risk level.

Further it can be seen how scenario 6 is seen to obtain a fairly high risk level, which seems appropriate given the short distance to shore and lack of nearby ships, where the low-medium risk level is the most frequent (51.3%).

Finally, it can be discussed how scenario 5 and 10 compare to each other, both being high risk ships with the ship in scenario 5 being a much larger ship than the one in scenario 10.

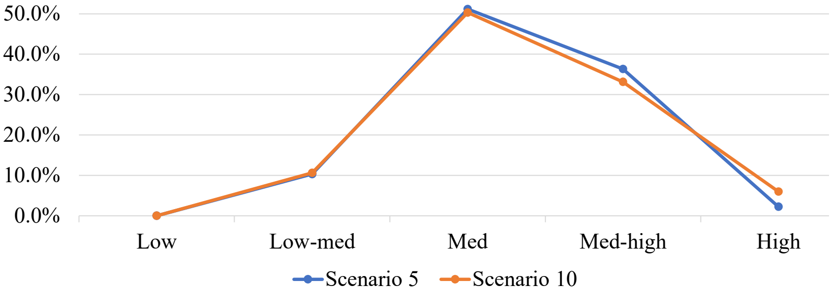

Figure 6.5: The figures shows the total risk distribution of the evaluated scenarios 5 and 10.

The above figure illustrates how the two scenarios gives a similar risk level when all input parameters are equal but the ship’s size and total number of people on board i.e. the static risk level. Scenario 10 generally obtains a higher risk level than scenario 5 (6.0% compared to 2.2%). This is a consequence of how the model will give a high static risk level to the larger ship in scenario 5, but at the same time evaluate its fuzzy manoeuvrability factor (as introduced during the model development) to be better than that of the smaller ship in scenario 5.

Thus, it might be counter-intuitive that a ship's size will give an increased static risk and simultaneously a decreased dynamic risk. However, this is also thought to be valuable to integrate into the model how larger ships' weather threshold tend to be higher than for ships of smaller sizes.

6.3 Shore distance, weather and ship proximity validation

In this section the model will be evaluated on how it calculates the fuzzy risk level for a large and a medium-sized cruise ship that increases its distance to shore for different configurations of weather and of the total number of ships in proximity-input parameters.

A ship that increase its distance to shore is expected to obtain a lower risk level as the drift time increases. The drift time will depend on the current weather conditions. At the same time, a large distance from shore in combination with a low number of ships in proximity should still give a somewhat high risk factor, especially for poor weather conditions.

6.3.1 Shore distance evaluation for a large cruise ship

Firstly, 6 different scenarios will be evaluated for a cruise ship of 350 meter length with 4,000 people on board having a low Paris MoU ship risk profile. The ship is referred to as a large ship, and the input values for each scenario can be seen in Table 6.4. It can be seen how the combination of weather and number of ships in proximity change for each scenario.

Table 6.4: Input values for scenarios 1-6 evaluating a large ship with a low Paris MoU ship risk profile increasing its distance from shore from 0 to 100 km.

Input values			
Scenario	**Ship size**	**Ships in proximity**	**Weather**
1	Large	None	Fine
2	Large	None	Moderate
3	Large	None	Poor
4	Large	Some	Fine
5	Large	Some	Moderate
6	Large	Some	Poor

For each of the six scenarios seen in the above table the ship's distance to shore is increased incrementally and the resulting fuzzy risk level is calculated. The results can be seen in the below table Table 6.5.

Table 6.5: Fizzy risk level results for scenario 1-6. In each scenario the distance from shore is increased and the resulting fuzzy risk level is calculated.

Results				
Scenario	**D<10km**	**10<D<20**	**20<D<50**	**50<D<100**
1	Med	Med	Med	Med
2	Med-high	Med	Med	Med
3	High	High	Med-high	Med-high
4	Low-med	Low-med	Low-med	Low-med
5	Med	Low-med	Low-med	Low-med
6	Med-high	Med-high	Med	Low-med

The results for scenario 1-6 presented in Table 6.5 can be summarised as follows. As all scenarios are from the evaluation of a large cruise ship, the static risk factor is medium-high, which consequentially skews the risk level towards a higher level calculated through the total fuzzy risk factor presented in section 5.5.

From the fine weather scenarios 1 and 4 it can be seen that distance to shore does not affect the resulting risk level. These results correspond to the developed fuzzy rule set as fine weather situations will evaluate a ship's drifting potential negligible, thus the risk level is seen to decrease with the increased availability of nearby ship resources.

From the moderate weather scenarios 2 and 5, it can be seen how the model gives a lower risk level to ships positioned more than 10 km from the coast but does not allow a lower risk level despite an increased distance. This is a consequence of how the lack of nearby ships in scenario 2 does not allow for a lower risk level than medium, and for scenario 5 the availability of ship's allow for a decrease from medium risk level to low-medium when the cruise ship's shore distance increase.

Further from the poor weather scenarios 3 and 6 the risk level can be seen to be high for scenario 3 until the ship is positioned approximately 20 km from the coast, when the risk level decrease to a med-high level. For scenario 6 it can be seen that the risk level decrease from med-high for shore distances closer than 20 km, to medium with an increased shore distance of 20-50 km and further to low-medium when the distance increase to more than 50km. The large decrease in the risk level for scenario 6 is closely related to the calculated drifting potential of the cruise ship in the poor weather conditions. For scenario 3, as there are no ships in the cruise ship's proximity, the risk level will not move below med-high, which seems appropriate in the prevailing poor weather conditions.

By comparing the good weather scenario 1 with the moderate weather scenario 2 it can be seen that they have a similar risk level for shore distances above 10 km. This could prove that the model should be more sensitive to shore distances to give a higher risk level to scenario 2 also for distances less than 20 km from shore, perhaps even at 50 km. The reason for this model behaviour is from the rule formulation of how large cruise ships is seen to operate as normal even in moderate weather conditions, thus having a fairly good manoeuvrability factor lowering the dynamic risk level. This have been seen advantageous to not obtain artificially high risk levels for "normal" sailings. However, as scenario 2 does not have any ships in proximity, this might also provide evidence that the model should be more sensitive to the shore distance.

The above discussion can be summarised as follows;

- In general the calculated risk level decrease with an increase in shore distance, with the risk level being one level higher if there are no ship resources available in the large cruise ships proximity;
- For nice weather conditions the model is not sensitive to an increase in shore distance;
- For moderate weather conditions the model is sensitive to changes in shore distance within the range of 0-20 km;
- For poor weather conditions with no available ship resources the model is sensitive to an increased shore distance for distances up to 20-50 km;
- For poor weather conditions with available ship resources the model is sensitive to an increased shore distance for distances up to 50-100 km.

6.3.2 Shore distance evaluation for a medium-sized cruise ship

A similar evaluation is performed for a medium-sized cruise ship, that is a ship of 200 meters length carrying 1,000 people. This gives that the medium-sized cruise ship will have a medium static risk level, that is one level beneath the static risk level obtained by the large cruise ship. The input values for each scenario can be seen in Table 6.6, and the results are seen in Table 6.7.

Table 6.6: Input values for scenarios 7-12 evaluating a medium ship with a low Paris MoU ship risk profile increasing its distance from shore from 0 to 100 km.

Input values			
Scenario	**Ship size**	**Ships in proximity**	**Weather**
7	Medium	None	Fine
8	Medium	None	Moderate
9	Medium	None	Poor
10	Medium	Some	Fine
11	Medium	Some	Moderate
12	Medium	Some	Poor

Table 6.7: The obtained fuzzy risk level results for scenario 7-12. In each scenario the distance from shore is increased and the resulting fuzzy risk level is calculated.

Results				
Scenario	**D<10km**	**10<D<20**	**20<D<50**	**50<D<100**
7	Low-med	Low-med	Low-med	Low-med
8	Med-high	Med	Low-med	Low-med
9	High	High	Med-high	Med-high
10	Low	Low	Low	Low
11	Low-med	Low	Low	Low
12	Med-high	Med-high	Med	Low-med

The results obtained from the medium-sized cruise ship in scenario 7-12 is seen to correlate with the results for the large cruise ship, except that in most situations the risk level is decreased by one level with some exceptions.

Again from the good-weather scenario 7 and 10 it can be seen that shore distance does not affect the resulting risk level, and that a the medium-sized ship will obtain a low risk level when there is a good availability of ship resources, not influenced by the cruise ship's distance to shore.

The moderate weather scenario 8 shows how an increase in the shore distance will significantly improve the risk level for the medium-sized ship with no available ship resources. It could be that the risk level is set too low despite the increased shore distance as there are still no ships in the cruise ship's proximity, and thus an incident that is not drift critical but time critical is given too little attention.

From the poor weather scenario 9 the model is seen to give the same risk level to the medium-sized ship as those obtained by the large ship. A high risk level is calculated when the distance to shore is approximately 0-20 km, and a medium-high risk level for a shore distance above 20 km. It could be argued whether the model should better differentiate between the situation with the large and the medium ship, however the risk levels seems appropriate and both situations are believed to be severe should a accident of any severe kind occur despite the ships' size difference.

For the moderate weather scenario 9 with a good availability of ships it can be seen how the model calculates the risk level as low-medium for distances closer to shore than 10 km, and how the risk level is set to low for shore distances above 10 km. This shows how the model is only semi-sensitive to an increase in shore distance for a medium-sized cruise ship in moderate weather conditions with available ship resources nearby.

For the poor weather scenario 12 with good ship availability the risk level is calculated to a similar level for both the medium-sized and large cruise ship. As discussed for the large ship scenario 6 the model seems to be more sensitive to an increase in shore distance in combination with poor weather, which is due to the drifting factor evaluation.

The above discussion of the results for the medium-sized ship in scenario 7-12 in comparison to those found for the large ship scenarios 1-6 can be summarised as follows;

- The model is seen to provide a decreased risk level for both the large and medium-sized cruise ship when there are ship resources available, with a higher risk given to more severe weather conditions;
- The model's calculated risk level is non-sensitive to an increase in shore distance for good weather conditions, semi-sensitive for moderate weather and sensitive in poor weather conditions;
- The model is seen to give a higher risk level to the large cruise ship compared to the medium-sized ship for similar weather and ship availability conditions;
- The obtained risk level for the medium-sized ship is seen to be more sensitive to an increase in shore distance for moderate weather conditions when no ship resources are available than those obtained from the large cruise ship scenario in the same moderate weather conditions
- For poor weather conditions the large and the medium-sized cruise ship obtains similar risk levels which are more sensitive to an increase in shore distance with a good availability of ship's compared to a poor ship availability

6.4 Summary of model validation

In general, the model seems to perform well in stochastic variations for similar sized ships providing correct and logically assigned risk levels. The model tends however to give similar risk levels to ships of different sizes in severe weather conditions.

Time have been spent to calibrate the model to give realistic outputs for the different scenarios which is a tedious task given the vast number of possible input combinations. However, the results from the model validation seems to give realistic results for the analysed scenarios, which will be further explored when evaluating the model against real scenarios.

Chapter 7

AIS-data processing and graphic interface program development

In the previous chapters a model capable of calculating a cruise ship's risk level based on a number of input factors built on a fuzzy logic inference system have been developed and presented. The model will in this chapter be further developed to integrate the risk model with AIS-data to directly evaluate how a dynamic flow of ships will influence a cruise ship's risk level.

Thus the following chapter will present the methodology used to develop a program that combines the fuzzy logic risk model with a continuous flow of AIS-data, also including other sources of data used to calculate the total risk level, such as weather data, ship availability data, data relating to the cruise ship's distance to shore and similar. The calculated risk level and AIS-related information will be visualised to the intended user through a graphic interface program.

The developed programs that will be presented are the following;

1) **Continuous parameter calculations based on AIS-data**

   ↪ The "heart" of the program. A number of operations will be performed on the AIS data, extracting information used as input values in the fuzzy logic risk level model.

2) **AIS data import and structuring**

   ↪ A program that transforms the raw AIS-data into a structured and sorted data format for easier readability.

3) **Continuous weather data import**

   ↪ An important part of the program's task is to be able to extract the correct weather conditions for any given ship in the AIS data, that is for any given position for any given date or time.

4) **Data and risk level representation**

   ↪ The program will continuously produce a spatio-temperal map showing the position of the tracked cruise ship along with the other available ships nearby. The graphic interface will also show the current and historic calculated risk level of the cruise ship.

The flowchart presented in Figure 7.1 show the main interactions of the developed programs and the externally available data. In the following sections, all important algorithms and theory used to develop the said combined program will be explained.

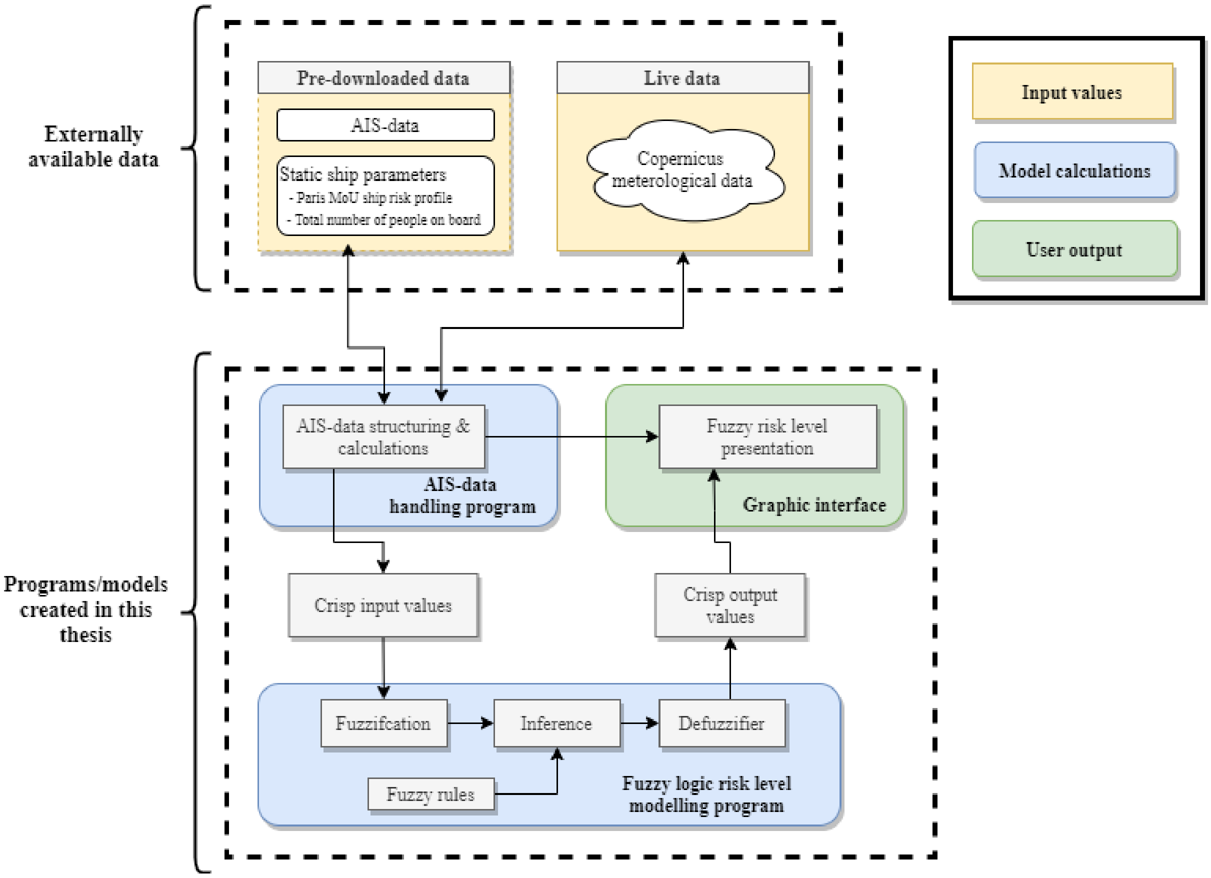

Figure 7.1: The flowchart illustrates the developed contingency monitoring model which combines data to develop and present a continuous risk level.

The model formulated in Figure 7.1 can be seen to integrate pre-downloaded data containing AIS-data, the Paris MoU ship risk profile for the cruise ship being tracked and the total number of people on board. Weather data from Copernicus[1] is also included as a model input which is continuously downloaded based on the AIS data while the model is running. The AIS is handled in a data processing program, which calculates a set of crisp values serving as input values to the fuzzy logic risk level evaluation. The obtained total risk level is further used as an input to a graphic user interface program to represent the current and previously calculated risk levels in a spatial map projection.

7.1 Continuous parameters calculations based on AIS-data

Firstly the "heart" of the program will be presented. This program will continuously calculate important parameters as well as initiate other programs used during the data handling and risk calculation process.

The following algorithm 1 will describe how all of the three programs described in the lower dotted square in the flowchart presented in Figure 7.1 share information and integrate.

---

[1] https://climate.copernicus.eu/

Algorithm 1: Continuous AIS-data calculations

```
Input: Structured AIS-data, Paris MoU ship risk profile, the total number of people on
 board the cruise ship and a list containing the ship types of interest;
Output: Continuous flow of fuzzy risk factor evaluation parameters;
Initialise;
for All MSG1 rows for the tracked cruise ship do
    Get the prevailing weather conditions;
    Calculate the cruise ship's distance from shore;
    for All ships do
        Find the newest ship unixtime that is less than or equal to the cruise ship's
         unixtime if The ships ship type is in list containing ship types of interest then
            Calculate the distance from the ship to the cruise ship;
            Save all ship details in a list which contains the available ship resources;
        end
    end
    ↪ get Fuzzy logic risk level based on the calculated values;
    ↪ run Update the graphic interface
end
```

7.2 AIS data import and structuring

The raw AIS-data provided by the NCA comes in two seperate .csv-files per day of interest, one for AIS message type 1-3 (hereby denoted only MSG1) and one for message type 5 (MSG5). The MSG1-files consists of millions of rows of compact data, which has to be extracted, structured and sorted. Further the dynamic data from MSG1 belonging to a specific ship needs to be connected to the static data obtained from MSG5.

The information available from the two message types and its structure can be seen in the below table Table 7.1. The mmsi number, IMO number, ship name and call sign is only for illustrative purposes and does not relate to a real ship.

Table 7.1: AIS data included in the AIS processing program. The above table presents dynamic data represented from message type 1, and the lower table represents static data represented from message type 5.

AIS message type 1	
Header	mmsi;lon;lat;date_time_utc;sog;cog;true_heading;nav_status;message_nr;source
Data example	123456789;1.64826;61.8767;2019-03-21 20:38:28;1.4;84.8;102;0;3;g

AIS message type 5	
Header	mmsi;imo;name;callsign;length;width;vessel_type
Data example	123456789;1234567;Ship name;Call sign;140;30;60.0

The algorithm importing, structuring, sorting and connecting the two message types is seen below in algorithm 2. This is a tedious progress hence to save computational time only 10% of the available AIS data will be selected in the structuring process, that is every 10th row when sorted by mmsi-number (as the data is sorted when downloaded from the NCA). Even though this is a severe size reduction in the data set, a validation of the data shows how this still includes all ships available from the raw data and does also give a relatively short time step between instances for all ships. In any case, this is sufficient to give valid results in the further works.

Algorithm 2: AIS data import and structuring

```
Input: Raw MSG1 and MSG5 AIS data with .csv-format ;
Output: A structured and time-sorted multidimensional dataframe with unique ship
  information;
Initialise;
Import and convert the raw AIS-data from .csv-format to a dataframe, expanding the rows
  to unique columns;
for Every 10th MSG1 row do
    Create a list of all unique mmsi-numbers from message 1;
    Convert the UTC date time stamp to unixtime and add in new column;
    Collect all rows with unique mmsi-numbers from MSG1 data in unique dataframes
      within a dataframe;
    Sort the unique lists from from oldest to newest using the unixtime column;
end
for All MSG5 rows do
    if Mmsi-number from a unique MSG1 list corresponds to a MSG5 mmsi row then
        Add the MSG5 row as a second dimension to the corresponding MSG1 list;
    end
end
↪ return Sorted ship list
```

7.3 Continuous weather data import

For each iteration in the model the prevailing weather conditions are downloaded and updated depending on the ship position and time obtained from the AIS-data. The significant wave height of combined wind waves and swell as well as the wind strength and direction is downloaded from the online database Copernicus providing ERA5 hourly data from 1979 to present time, see https://cds.climate.copernicus.eu/. The data is numerically estimated from a range of variables and might be prone to produce some inaccurate results.

The weather grid resolution available for download is a 0.5 x 0.5 degree longitude/latitude grid. The model produce a grid of the obtained weather factors around the tracked cruise ship as shown in Figure 7.2. The grid size will depend on the longitude and latitude inputs and the two-by-one degree area gives an approximate area around the ship on the west coast of Norway of about 110 x 120 km.

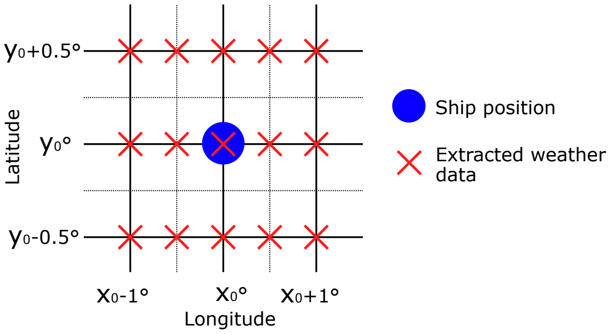

Figure 7.2: Figure showing the downloaded weather data as a grid around the ship position. The grid covers a two-by-one degree area around the ship, meaning that it is covering an area of approximately 110 x 120 km area if the ship is positioned on the west coast of Norway.

The maximum swh-value obtained within an 80 km radius of the cruise ship is extracted. The maximum swh-value is chosen as the grid often covers the main land which yields a zero-value, and that it is assumed that the largest value within a reasonable area surrounding the ship gives a valid value for the sea state the ships is experiencing. For the wind strength and direction, a mean value for all obtained data points is extracted.

As the weather data is only a rough estimation of the actual weather conditions the ship is experiencing, this gives that the model will only provide realistic weather data for ship's totally exposed to the obtained weather conditions, i.e. the model's weather data will not be well suited if a ship sails in waters protected by an island or similar.

For the intended purpose of the developed model, the rough weather estimation is however assumed to give valid results and is a powerful tool to automatically download weather data solely based on information from the AIS-data.

7.4 Data and risk level representation

The program will visualise the AIS-data in a graphic interface that continuously updates. A map is produced based on the matplotlib's basemap toolkit which is a library for plotting 2D data on maps in Python.

The algorithm presented in algorithm 3 shows the map plotting procedure.

Algorithm 3: Display the AIS data and risk level in a graphic interface

```
Input: Dataframe with ship information and calculated total risk level ;
Output: A graphic interface displaying the flow of AIS data and the cruise ship's current
  fuzzy logic risk level;
Initialise;
Plot a map of Norway's coast using matplotlib's basemap toolkit;
for Every iteration of the tracked cruise ship do
    Plot the cruise ship's position with the ship colour as a colour scale indicating the fuzzy
      risk level;
    Plot all nearby ships of interest;
end
↪ return Map
```

The cruise ship will be displayed in the graphic interface as a star, whilst the rest of the ships will be displayed as dots. The colour of the cruise ship's star will illustrates the risk level obtained from the fuzzy logic risk model as one of the five colour codes represented in Figure 7.3.

Figure 7.3: The figure illustrates the cruise ship risk level colour definitions that is used to plot the cruise ship in the graphic interface. As illustrated the risk definitions will range between low (green), low-medium (yellow), medium (orange), medium-high (red) and high (purple).

A unique dot colour will represent a certain ship type, however this is only used for visual purposes and the colour code definitions are not presented. An example of the result from the graphic interface program for a random selection of ships positioned in an area on the west coast of Norway can be seen in Figure 7.4. A ship can be seen as the ship being tracked and it's risk level colours can be seen in the magnified area of the figure.

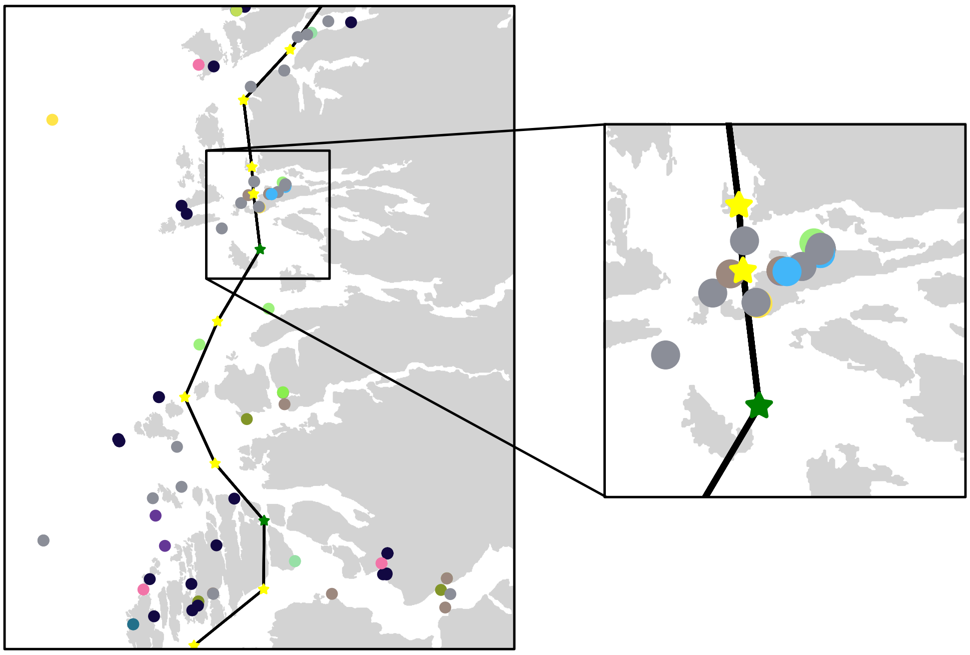

Figure 7.4: Illustrative example of how a ship's risk level is displayed graphically on a projected map along with nearby ships. For this illustrative example, the risk level is seen to be alternating between a low level (green star colour) and a low-medium level (yellow star colour).

From the above figure a number of nearby ships can be seen for a coastal segment where a specific ship is being tracked. The fuzzy risk level for this illustrative example is seen to be alternating between a low risk level (green star colour) and a low-medium risk level (yellow star colour). It can be seen how the tracked ship's previous positions and calculated risk level is being saved between each iteration (with a black line connecting the stars) whilst the surrounding ships will only be presented with respect to their last known position.

Chapter 8

Case study results

The now fully integrated fuzzy logic risk evaluation model based on AIS data will be used to evaluate how the proximity of ships affect the risk level of a cruise ship. To calibrate the model and provide the best possible results it is necessary investigate further which ships that are capable of assisting a cruise ship in distress, how they assist and if other factors seem to be of importance. Hence the following chapter will evaluate the developed model, first based on a detailed analysis of the Viking Sky incident followed by the presentation and discussion of selected case studies.

8.1 Evaluation of information available from AIS data

The results from the following calibration will be implemented into the model's fuzzy logic rule set and input values and will consequentially be restricted to the formerly developed model and its limitations. Any findings that could not be implemented due to the model's limitations will be discussed.

The developed model is able to differentiate ships from the AIS-data, and thus the following section will evaluate which ships that are important to include when evaluating the risk level.

A detailed analysis of ships involved in the recent Viking Sky accident will be performed based on available AIS data to evaluate which ships that were available at the time of incident and how they were of assistance.

8.1.1 Viking Sky incident - Ship evaluation of all ships in proximity

To evaluate information relating to the ship types typically observed in poor weather conditions The Viking Sky accident on 23 March 2019 will be used as a reference. Relevant AIS data have been downloaded from the NCA.

Figure 8.1 depicts all ships in the area at 13:00 when Viking Sky experienced black out. The different colours are unique to a specific ship type.

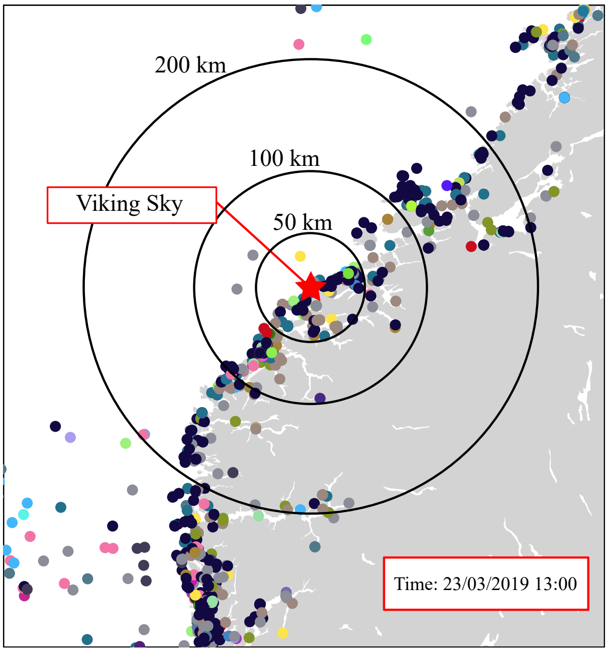

Figure 8.1: Figure showing all ships in the Hustadvika area at 1330 23 March 2019. Each ship colour represents a unique ship type.

A number of ships are seen to have been in proximity to Viking Sky at the time of the black out. Please note how many of these ships are docked, but will still emit AIS-data, and thus will be included in the analysis.

It is advantageous to evaluate the density of the different ship types, and their respective distance to Viking Sky. Thus the total number of all present ship types within a given distance have been categorised as presented in Figure 8.2. Only ships within 200 km range of Viking Sky have been evaluated.

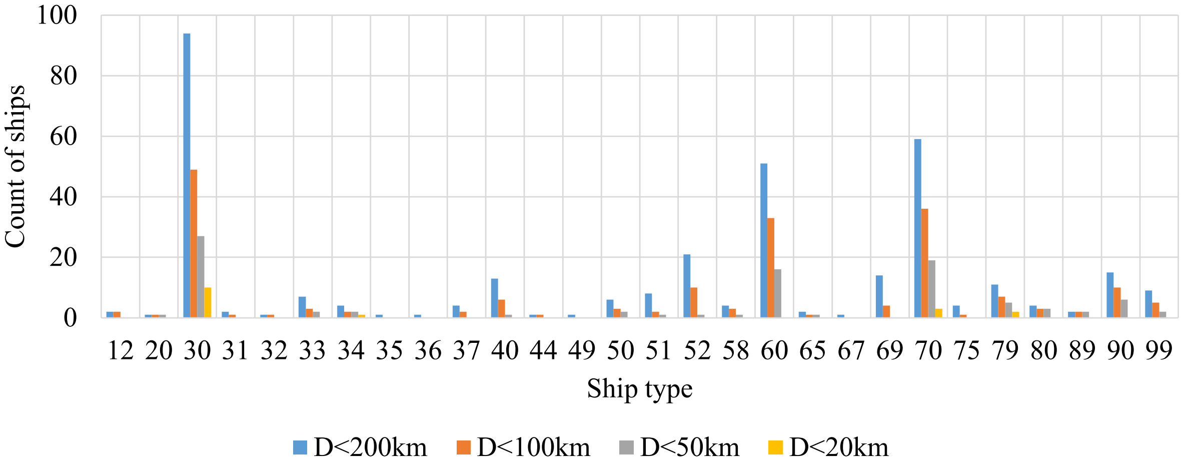

Figure 8.2: Bar chart illustrating the density of different ship types in proximity to Viking Sky at the time of the incident 23 March 2019 at 13:00. The total number of ships observed from the AIS-data are shown for four different distances from Viking Sky.

It can be seen that ship type 30, 60 and 70 is the dominating ships in the area. Remembering from the theory on AIS-data and Table 4.2 ship type 30 is fishing vessels, 60 is passenger ships and 70 is cargo ships. In total 469 ships are observed within a distance of 200 km, 233 ships within 100 km, 117 ships within 50 km and 21 ships within 20 km.

To evaluate the navigational status of the observed ships, the AIS data provides further information as seen in Figure 8.3.

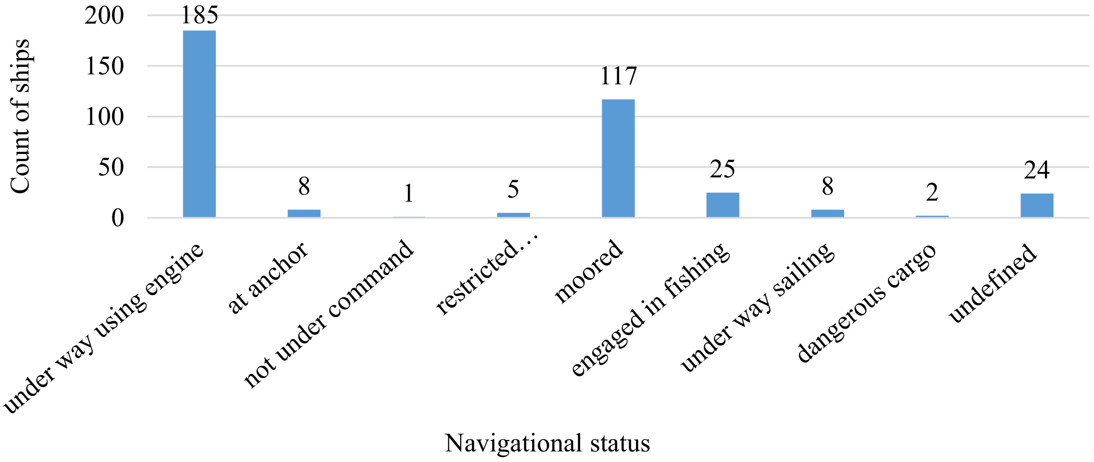

Figure 8.3: The figure shows the navigational status of ships in proximity of Viking Sky at the time of the black out.

From the figure it can be seen that the majority of observed ships are under way followed by ships being moored. To further investigate these two categories the following Figure 8.4 shows the count of all ship types either being under way or moored.

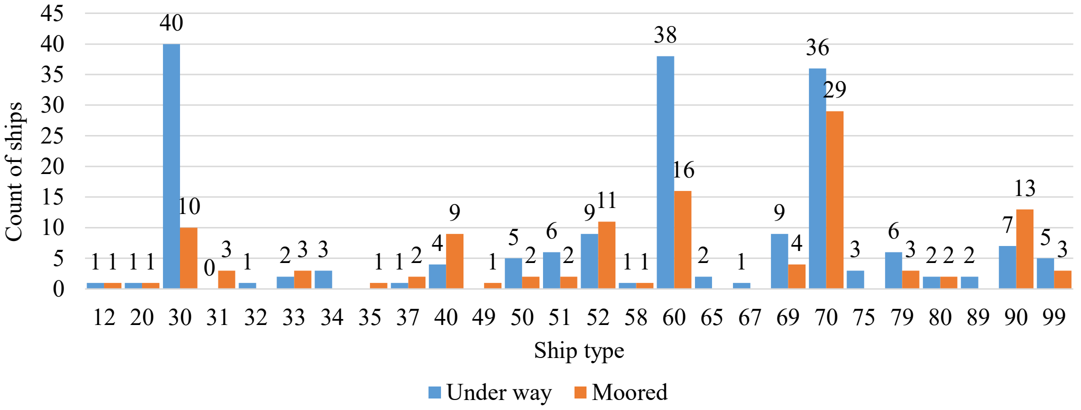

Figure 8.4: Ship types being underway and moored.

The figure shows how the majority of observed fishing vessels (ship type 30) under way despite the prevailing severe weather condition. This is similar to that of passenger ships (Ship type 60). For cargo ships (ship type 70) it can be seen that a large number of ships is moored. A good guess relating to the relatively high number of ships under way despite the poor weather conditions especially for passenger ships, can be how they might be sailing in protected waters. This have however not been explored further.

8.1.2 Detailed analysis of the ships involved in the Viking Sky incident

In general, it seems hard to deduce useful information from the prior analysis of ships in general proximity to Viking Sky at the time of the incident. To further investigate how different ships assisted in the Viking Sky incident, a in-detail analysis of the ships involved in the incident have been performed. A manual evaluation of AIS-data from the accident in combination with the available incident report makes it possible to deduct more specific information on ships thought to be of relevance during the incident (The Norwegian Directorate for Civil Protection (DSB), 2020).

A ship is defined to be involved in the incident if it is explicitly mentioned in the incident report as being scrambled to assist, or if it is seen from the AIS-data to be on standby in the immediate area of the incident any time within the time from the black out occurred until a towing line was secured.

Hence all involved ships are presented in Table 8.1. The table presents details relating to the ships' themselves, their initial distance from Viking Sky at the time of the Mayday, when they arrived at the scene and what their roles were.

Due to a confidentiality agreement regarding the use of AIS data, all presented ship details are kept to a minimum. The analysis is limited to the geographical area surrounding Hustadvika on the west coast of Norway.

Table 8.1: A list of all ships involved in the Viking Sky incident on the 23. March 2019. The ships are sorted in their respective arrival time at the scene. The table can be seen in relation with the map presented in Figure 8.5. The reader must also be aware that specific ship details, in this case GT (Gross Tonnage) is an approximate value due to the AIS confidentiality agreement. *Ship Type, **The ships initial distance from ship ID 1, *** On Scene Coordinator.

ID	**Ship details**	**ST***	**Role**	**Initial dist.* [km]**	**Arrival time**	**GT**
1	Cruise ship	60	Ship in distress	0	13:00	48,000
2	Reefer	70	First on scene	11	14:07	3,500
3	Oil/Chemical Tanker	89	First on scene	26	14:10	4,000
4	Fishing Vessel	30	First on Scene	13	14:10	1000
5	SAR vessel	51	Standby	39	15:00	100
6	Patrol Vessel	55	OSC***	39	15:50	800
7	Tug	52	Secured tow	21	16:00	500
8	Offshore supply ship	70	Standby	40	17:20	5,000
9	Multi Purpose Offshore Vessel	33	Standby	40	17:20	9,000
10	Tug	52	Standby	74	17:30	200
11	Offshore Supply Ship	70	Standby	40	17:30	5,000
12	Supply vessel	70	Standby	40	17:45	5,000
13	Tug	52	Standby	153	22:10	600
14	Standby Safety Vessel	51	Secured tow	101	01:50	4,000
15	Offshore Supply Ship	95	Standby	264	03:00	7,500

The reader should note how ship ID 15 from Table 8.1 is registered as ship type 95 in the AIS data, which according to Table 4.2 is merely classified as ship type *other*. However, a quick internet search shows how the ship is in fact an offshore supply ship.

It should also be noted how ship ID 2, a classic cargo ship, seem to be classified as ship type 70, which is also the case for ship ID 8, 11 and 12, which from further inspection is in fact offshore supply ships/similar.

The ships involved in the incident presented in the prior Table 8.1 can be seen in relation to their geographical location as presented in Figure 8.5.

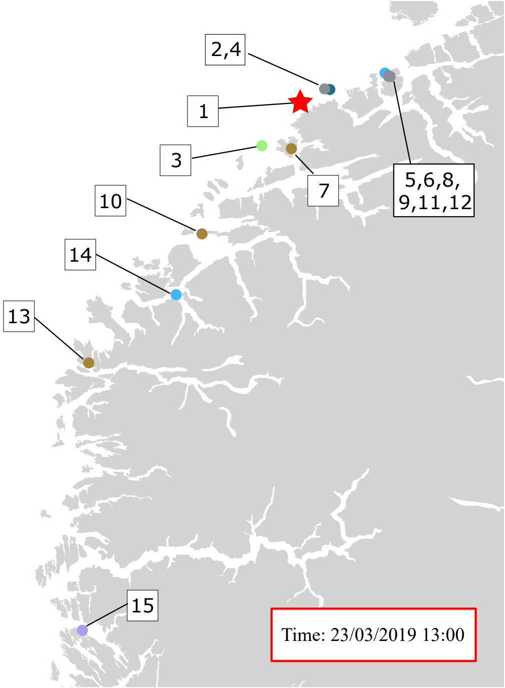

Figure 8.5: The map shows the initial position of all ships involved in the Viking Sky incident on 23rd of March 2019, as they were positioned when Viking Sky initiated a mayday at 1300. The numbers are associated with the respective ship ID's in Table 8.1.

Development of events focused on the involved ships

Viking Sky, referred to as ship ID 1 in Table 8.1, experienced a total black out only five kilometres off the coast at approximately 12:45 the 23rd of March, followed by a mayday at 13:00. This mayday initiated a large rescue operation coordinated from the Joint Rescue Coordination Centre of South Norway (JRCC SN). JRCC SN immediately started to acquire tug boats, and issued a mayday relay emphasising the need. At this point Viking Sky, given the cruise ships large side windage area, was drifting towards shore at a speed of up to 9 knots.

Three ships were under way in the area at this time, namely ship ID 2, 3 and 4. Despite their immediate proximity, they did not arrive at the scene until approximately one hour after the mayday when Viking Sky had already drifted dangerously close to shore whilst also managed to restore some engine power.

Due to the deteriorating weather conditions and shallow waters, it was not possible to connect a towing line from either ship ID 2, 3 or 4, neither to perform a ship-to-ship evacuation of the passengers. Consequently, ship ID 2, 3 and 4 was discharged by JRCC SN just before 14:00.

Helicopter evacuation started at 14:05.

At approximately 15:50 a coast guard patrol vessel, ship ID 6, arrived at the scene and JRCC SN gives the vessel the role of *On Scene Coordinator*, to communicate with nearby ships as well as with the maritime pilots and the captain on board Viking Sky. Ship ID 5, a small rescue ship similar to that depicted in Figure 4.9, was approximately an hour off Viking Sky's location staying in-fjord on stand-by.

Further, several ships arrived as can be seen from the arrival times in Table 8.1. In high seas and wind gusts of up to 25 m/s it was not possible to connect a tow from either of the arriving ships and the helicopter evacuation continued through the night. A tow was secured to Viking Sky at 07:18 24th of March by ship ID 7 and 14, when the wind had dropped to gusts of about 15 m/s.

The helicopter evacuation continued for an hour until Viking Sky reached the western-most point and it was decided to tow the ship south-east towards the port of Molde. The helicopter evacuation was called off at 08:15, 17 hours after the black out occurred.

8.1.3 Proximity distance and response time evaluation

The developed model's rule set is based on the approximate time it takes for a vessel to respond to a mayday, and thus it is advantageous to relate this to that of the Viking Sky incident.

To evaluate the general time used for a ship to respond to an accident, the below general formulation is used;

$$\text{Response time} = \text{Mobilisation time} + \text{Sailing time} \tag{8.1}$$

where

$$\text{Sailing time} = \frac{\text{Distance}}{\text{Vessel speed}}$$

The combination of Viking Sky's immediate vicinity to the shore line and the unfavourable weather conditions resulted in helpless drifting, with any nearby ships unable to reach Viking Sky until one hour later. As seen in Table 8.1 the first ship type properly equipped to secure a tow line was the patrol vessel with ship ID 6 that arrived almost three hours after Viking Sky started drifting.

From the AIS-data it was seen that the involved ships did not sail towards Viking Sky immediately after the black out occurred as they need some time to mobilise. In the following Table 8.2 information relating to the response time of the involved ships is presented as well as their observed speed in open waters.

Table 8.2: The table presents information relevant to the response time for the ships involved in the Viking Sky accident with the same ship ID's as presented in the prior Table 8.1. Ship ID 2,3 and 4 was sailing towards Viking Sky when the black out occurred, and thus had no mobilisation time. Note also how ship ID 14 was scrambled at 19:00 during sailing and therefore neither have any mobilisation time.

ID	**Initial dist. [km]**	**Mobilisation time**	**Departure**	**Arrival**	**Speed [kn]**	**Response time**
1	0	-	-	-	-	-
2	11	0h00m	13:00	14:07	7	1h07m
3	26	0h00m	13:00	14:10	13	1h10m
4	13	0h00m	13:00	14:10	6	1h10m
5	39	0h10m	13:10	15:00	10-15	2h00m
6	39	0h20m	13:20	15:50	10	2h50m
7	21	1h30m	14:30	16:00	11	3h00m
8	40	1h30m	14:30	17:20	10	4h20m
9	40	1h30m	14:30	17:20	9	4h20m
10	74	1h15m	13:15	17:30	11	4h30m
11	40	1h30m	14:30	17:30	10	4h30m
12	40	2h00m	15:00	17:45	7	4h45m
13	153	0h50m	13:50	22:10	10	9h10m
14	101	0h00m	19:00	01:50	15	6h50m
15	264	2h20m	14:20	03:00	15	13h00m

Thus the most frequent response time is seen to be approximately four hours with an average mobilisation time of 1 hour and 30 minutes and a speed of about 10 knots. In comparison, the national tug boat readiness scheme presented in section 4.4 stated that they dimensioned the tug boat capacity to have a response time (though also including time to secure a tow) of five hours. However, the tug readiness scheme mostly considers environmental damage from tank ships travelling 50 km from shore, and thus it is obvious that a cruise ship must be considered differently.

Based on the above information it is assumed that a ship positioned within a radius of the cruise ship of 50 km is considered to be *in proximity* of the cruise ship, and thus will be included as a model input when deciding the fuzzy risk level of a given situation. A proximity parameter of 50 km will from Equation 8.1 with an assumed vessel speed of 10 knots and mobilisation time of 1 hour and 30 minutes give a response time of 4 hours and 15 minutes. It should be noted how many ships of relevance have a max speed above 10 knots, and that 4 hours and 15 minutes is thought to be a worst-case scenario for severe weather conditions, as observed from the Viking Sky accident.

8.1.4 Summary and discussion on ship types of relevance

Time have been spent to understand the significance of all available ship types deducted from the AIS data formerly presented in Table 4.2 by collecting information from MarineTraffic's shiptype information web page[1] combined with the knowledge from the prior analysis of the Viking Sky incident, also including former knowledge of different ships from the theory section in section 4.5.

From Table 8.1 the ship types that can assist a cruise ship in distress are somewhat diffuse. There seems to a unanimity that general tugs can assist in most cases, but in many cases also SAR ships, offshore supply ships and cost guard ships. Ship type 70 is also seen to contain ships of relevance, but by manual investigation of the ship type it is seen that the majority of the ships are typical cargo ships not well equipped to assist a cruise ship in distress.

The ship types that are thought to be most relevant in the case of assisting a cruise ship in distress is narrowed down to include only those known to be efficient at towing operations, as presented in the previous Table 4.7 which is combined with knowledge from the Viking Sky event. Thus, the model will neglect some ships even though they might contribute positively in the event of a mass evacuation. This is done to minimise the probability that the model will reduce the cruise ship's risk level based on the presence of a ship that potentially could not have been of assistance in an emergency situation. The consequences of this choice and its limitations to the model will be further elaborated in the discussion presented in subsection 9.1.1.

The final selection of the ships that will be included in the model as ships of relevance is presented below in Table 8.3.

Table 8.3: Ship types assumed to be of relevance for assisting a cruise ship in distress. The information is collected from MarineTraffic's ship type information web-page as well as manual inspection and observations of the ships assisting in the Viking Sky accident. An observed ship type marked "No observation" is included from its general significance description from Table 4.7 but have not been observed in the Viking Sky accident-analysis.

Shiptype	**AIS ship details**	**Observed ship type**
29	SAR-vessel	No observation
31, 32	Tug	No observation
33	Special craft	Multi Purpose Offshore Vessel
35	Military Ops	No observation
51	SAR-vessel	SAR-Ship; Standby Safety Sessel
52	Tug	Tug
55	Law Enforcement	Patrol Vessel
59	Special Craft	No observation
95	Other ship	Offshore Supply Ship

8.2 Case studies evaluating the model's performance

The Viking Sky incident will be analysed using the developed contingency monitoring model utilising both the AIS data handling program and the developed risk model. This will later be compared to other events to compare the obtained results. Hence the results will serve as a reference to evaluate the results obtained from the model, as information relating to the Viking

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[1] https://help.marinetraffic.com/hc/en-us/articles/205579997-What-is-the-significance-of-the-AIS-Shiptype-number-

Sky event is readily available and can be compared to the obtained results.

8.2.1 Detailed ship event analysis

The ship details relevant for the Viking Sky analysis is shown in Table 8.4.

Table 8.4: Relevant ship details for the detailed analysis of the Viking Sky incident.

ID	**Date**	**Ship details**		**Weather condition**
		Length [m]	Tot. people	
1	March 2019	282	1,373	Poor

The detailed analysis will be performed to obtain a deeper understanding of the produced results based on knowledge from the Viking Sky incident. Further event ID 1 will act as a reference point to which event ID 2, 3 and 4 will be compared to the results of event ID 1.

The Viking Sky incident have been analysed with the developed model. AIS data from the hours leading up to the black out until the ship is moored in Molde is included. A large number of different parameters are produced that are all used to calculate a total risk level. Figure 8.6 shows the produced risk levels presented as a spatio-temperal projection.

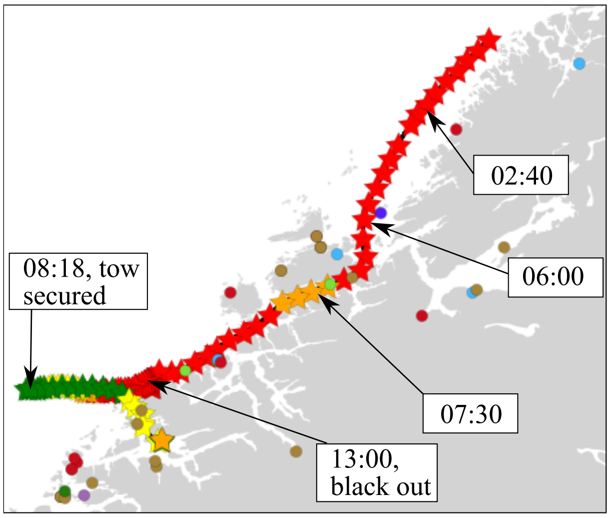

Figure 8.6: The spatial representation of the risk level results obtained from analysed event 1.

To properly present and evaluate the results they will be divided into two parts as seen in the list below;

1. **Calculated values from the AIS data:** weather parameters, distance to shore, ships of relevance within a 50 km radius of the cruise ship, distance to the closest ship of relevance and time of the day (night or day);
2. **Calculated parameters from the fuzzy logic program**: Total static risk, sea state, vessel availability, response time, manoeuvrability, drift time, total dynamic risk and total risk.

Apart from the daytime parameter, Figure 8.7 shows a line plot of all parameters calculated from the AIS-data (upper plot) that are used as input values to calculate parameters from the fuzzy logic risk model (lower plot). For reference, vertical black arrows have been added to show how the two plots are based on the same timeline where the time of the black out and when the tow was secured is visualised. The timeline stretches from midnight the 23 of March until the morning of March 24. The black out occurred at 13:00 March 23 and the towline was secured at approximately 08:00 March 24.

The reader is adviced to keep in mind from the fuzzy logic risk model development presented in chapter 5 how the fuzzy parameter is defined to range from 1 (Evaluated as a low-risk aggravating factor) to 9 (evaluated as a high-risk aggravating factor).

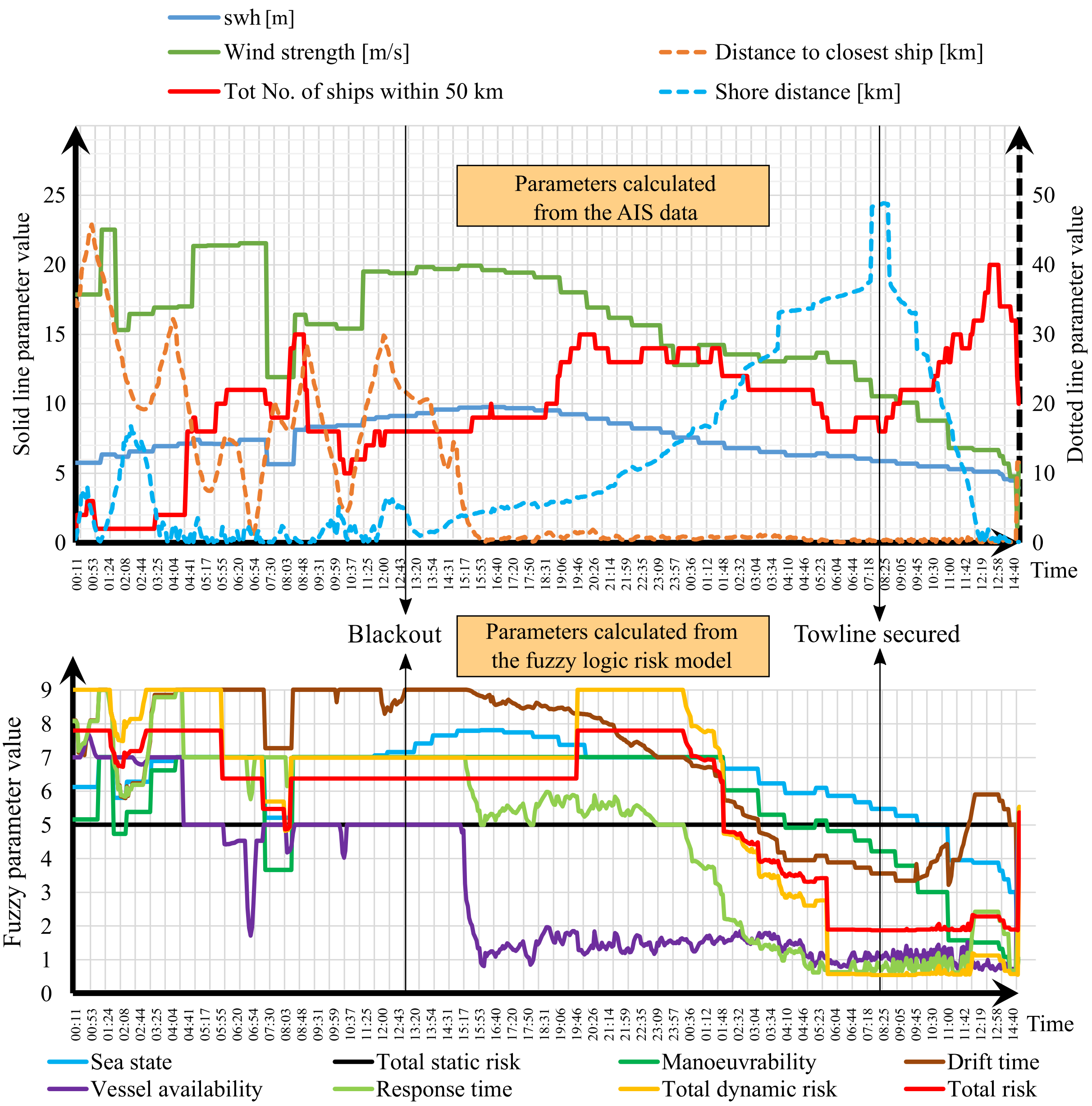

Figure 8.7: Parameter results from analysed event 1. The top figure shows all calculated values from the AIS data that are used as crisp input values to the fuzzy logic model. To ease the interpretation of the graph the vertical axis has been split into a left and right axis, solid lines belonging to the left axis, dotted lines belonging to the right axis. Further the bottom figure shows the parameters calculated from the fuzzy logic risk model. A low fuzzy parameter value corresponds to a poor performance of the evaluated parameter, such as how the static, dynamic and total risk level is defined to be *low* for a fuzzy parameter value of 1 and *high* for a corresponding parameter value of 9.

8.2.2 Parameters calculated from the AIS data

Significant wave height and wind strength

From the parameters calculated from the AIS data (the top plot) it can be seen how the wind strength fluctuates between 15 and 23 m/s within relatively short time steps before the black out and then steadily decline. The significant wave height (swh) is seen to raise steadily until a few hours after the black out when it also declines.

The weather inputs are a major contributing factor when deciding the total risk level, as will be explained.

Shore distance

From the shore distance it is observed that the cruise ship sailed close to shore in the hours before the black out, before gaining some distance just before arriving at Hustadvika. Then it can be seen to steadily move close to shore before increasing its distance to approximately 50 km from shore.

Total number of ships within 50 km

It is important to keep in mind that that all ships observed are ships defined to be ships of relevance for a ship in distress, that is the ship types as defined in Table 8.3.

The number of ships within 50 km from the cruise ship can be seen to be only 1-3 ships in the first few hours until around 05:00 when it reaches a total of 7 ships. This is as the cruise ship is positioned just west of Trondheim. The number is further raising to 11 before reaching a total of 15 observed ships just after 08:00. It can be seen that a steady increase of ships within 50 km does not occur until after 16:00. It is known from the prior ship analysis of the Viking Sky incident that most ship that where scrambled to assist Viking Sky were already within a distance of 50 km, which will explain how there is no obvious increase in the number of ships in the hours after the incident.

To further explore the total number of ships in vicinity of Viking Sky the total number of ships within 20 km and 100 km have been extracted to compare with that extracted for a proximity of 50 km. This is seen in Figure 8.8.

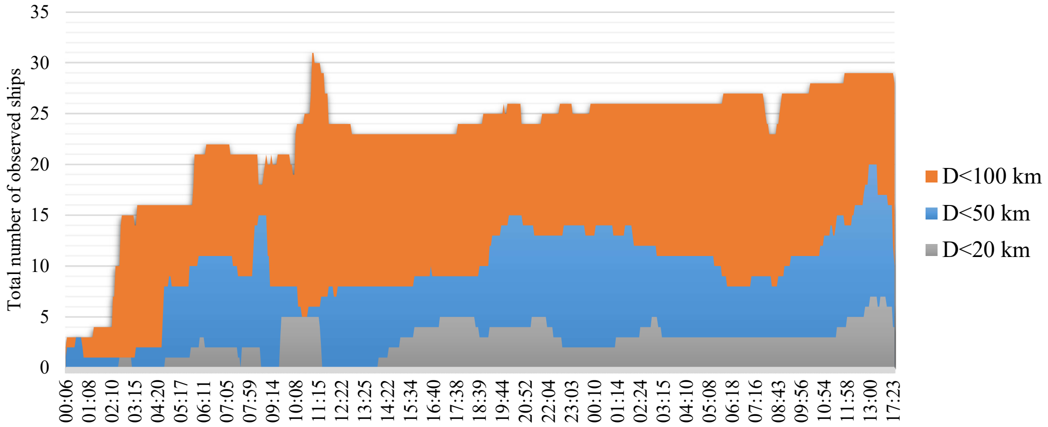

Figure 8.8: The figure shows the development of ships in vicinity to Viking Sky from analysed event ID 1 for 20 km, 50 km and 100 km distance.

Knowing that the accident occurred at 13:00, it can be seen that no ships (of assumed relevance) were positioned closer than 20 km from Viking Sky at the time of the incident. However, it is seen how the number of ships within a proximity of 20 km increased after 14:00. It is hard to deduce any information from the ships positioned within 100 km from Viking Sky, except how the developed model seem to have a transition period in its early hours.

Distance to closest ship

The closest ship, again only including ship types defined to be of relevance, can be seen to vary throughout the event. It is seen how the distance range from approximately 2-40 km. It can be seen that the distance to the closest ship in general decrease as the cruise ship moves towards Hustadvika, until it rapidly decrease when the first ships arrive to assist just before 16:00.

Day or night

The daytime parameter will influence the total dynamic risk level only at night time, defined as the hours from 20:00 - 06:00. At night, the total dynamic risk level will be increased from its current state to the next state, that is an increase of the fuzzy parameter value by 2, not exceeding the highest possible state with a fuzzy parameter value of 9. This is indirectly presented in Figure 8.7 from the total dynamic risk parameter values.

8.2.3 Fuzzy logic risk model parameters

Sea state

The sea state fuzzy parameter is calculated based on the crisp inputs of significant wave height and wind strength from the AIS data.

The sea state parameter is observed to fluctuate between a *rough* and *high* state in the first few hours of the event and further stabilise at a *high* state at approximately 08:00. The *high* state is kept constant, almost reaching *very high* at 15:50 (observed fuzzy parameter value of 8.9) before steadily decreasing in the following hours. The sea state is seen to reach a fuzzy parameter value below 6 at 04:30, that is a *rough* fuzzy parameter state, before dropping to a *slight* state (a fuzzy parameter value below 4) just after 11:00.

The relatively high sea state throughout the event contributes to increase the total calculated risk, which is seen to often correlate well with the sea state. This is only the case however until approximately 02:00 when Viking Sky is seen to have a shore distance of 20 km and steadily increasing which results in a decreased total risk level.

Manoeuvrability

The manoeuvrability parameter is calculated on a basis of the size of the cruise ship and the sea state. As the ships size is a fixed parameter the manoeuvrability will correlate closely with the sea state as observed. The manoeuvrability parameter can be seen to have vary between just below 4 and 7 until 08:30 when it stabilises at 7, that is a manoeuvrability state of *average-poor*. The manoeuvrability parameter is seen to decrease after 02:00 with the improved weather conditions until it reaches a value of 1 (*good* state) just after 12:00 March 24th.

The manoeuvrability parameter is a direct input into one of the final fuzzy logic evaluation "boxes" in the model formulation, hence it will correlate with the final risk level value. The overall *average-poor* manoeuvrability level will thus contribute to increase the total risk factor throughout the event until the sea state improves which consequentially improves the manoeuvrability factor and further the total risk level.

Drift time

The drift time parameter will essential by definition evaluate the ship's potential to drift in the prevailing weather conditions by also integrating the ships distance to shore. As discussed in the model development the parameter does not include the direction of the wind or the size of the cruise ship.

It can be observed how the drift time parameter is calculated to a value larger than 8, that is a *poor* state, for almost every time-step up until 21:20 except for a few situations where the sea state is seen to sparsely improve over short time intervals. As Viking Sky increased its distance to shore just before it reached Hustadvika the drift time parameter is seen to improve slightly for a short period. Further, as Viking Sky increased its distance from shore the drift time parameter can be seen to improve.

In general, the drift parameter is seen to have a *poor* state, which is a contributing factor to obtain the a high risk level.

Vessel availability

The vessel availability parameter is a combination of how many ships are observed within the set proximity parameter, in this case 50 km, and how close the closest ship is. However, the closest ship is not given as much weight as how many ships that are observed as discussed in the previous model development chapter chapter 5.

The vessel availability can be seen to have a *average-poor* state in the first few hours of the event, with a large sudden improvement just before 07:00. From the spatio-temperal presentation of the total risk level in the previous Figure 8.6 it can be seen that this occurred when Viking Sky passed into the narrow fairway, where a number of ships can be observed. This in combination with the calculated parameter of *distance to closest ship* from the AIS data it can be seen that Viking Sky must have sailed close to a observed ship, thus lowering the vessel availability factor.

Despite a temporary *good* vessel availability parameter, the total risk level is seen to be unaffected. This is a direct consequence of how the drift time parameter have a *high* state, which as defined in the fuzzy rule set will "force" the risk level to remain at a high level. This is further explored in the next section discussing the response time parameter.

Response time

The response time parameter is calculated from the result of the drift time parameter and the vessel availability factor, and is seen to have relatively high parameter value, that is an *average-poor* state, until ships start arriving and Viking Sky have maintained some distance from the shore.

As a consequence of the response time being calculated from the drift time parameter evaluation, the response time parameter will only improve to a state of *average* until the drift time parameter improves further, despite a good availability of ships. Consequently, as the ships distance from shore increase as well as the weather improving, the drift time parameter is seen to improve beyond the state of *average* after 00:30.

The calculated total risk level can be seen be sensitive to changes in the response time parameter, which is a direct consequence of how the response time is an input parameter to the total dynamic risk parameter, which further directly correlates with the total risk.

Total dynamic risk

As previously introduced the total dynamic risk parameter is calculated based on the results from the manoeuvrability and the response time parameter. It can be seen how the total dynamic risk is calculated to a *very high* state in the early hours of the event, when the manoeuvrability parameter is calculated to an *average-poor* state (fuzzy parameter value of 7) and the response time is calculated to a *poor* state (a fuzzy parameter value of 8.9).

Further the total dynamic risk parameter is seen to maintain a level of a *medium-high* state (fuzzy parameter value of 7) for most of the event until the rest of the parameters start to decline.

Total static risk

The static risk can be seen to have a fuzzy parameter value of 5 throughout the event, that is a state of *average* static risk, which is calculated from the Paris MoU-factor and the total number of people on board.

Total risk

Finally, the total risk can be evaluated. By definition the total risk level will be a weighted relationship of the static and dynamic risk level, which consequentially never gives a total risk level above the dynamic risk level if the dynamic risk level is at a worse state than the static risk level, and similarly never give a better total risk level than the dynamic risk level if the dynamic risk is better than the static risk level. This can be observed in the presented Figure 8.7.

The total risk level can be seen to be at its highest when the dynamic risk is increased in the night time between 20:00 and 06:00. The total risk is seen to be high despite the vessel availability being reduced after 15:00.

8.2.4 Comparison of obtained results

A case study is presented were three unique events have been analysed with the developed model and will be compared against each other and with the reference level obtained from event ID 1. Relevant event information and ship details including those for event ID 1 is seen in Table 8.5.

Table 8.5: Ship events analysed with the model.

ID	**Date**	**Ship details**		**Weather condition**
		Length [m]	Tot. people	**/Day or night**
1	March 2019	282	1,373	Poor/Day
2	July 2017	282	1,373	Good/Night
3	January 2016	120	700	Poor/Day
4	February 2017	140	1,200	Good/Day

To obtain comparable results, a specific ship position on Hustadvika have been extracted for all four events, as can be seen in Figure 8.9. The figure shows the trajectory and risk level for all four incidents. The risk level is represented by a coloured star with an edge colour category on the stars indicating which event the coloured stars belong to. The four events are exploded in the right hand side of the figure to better differentiate the events. The exploded figure shows when the ships pass Kristansund as a reference position. The figure also shows a certain point along the route that will be used in the further analysis.

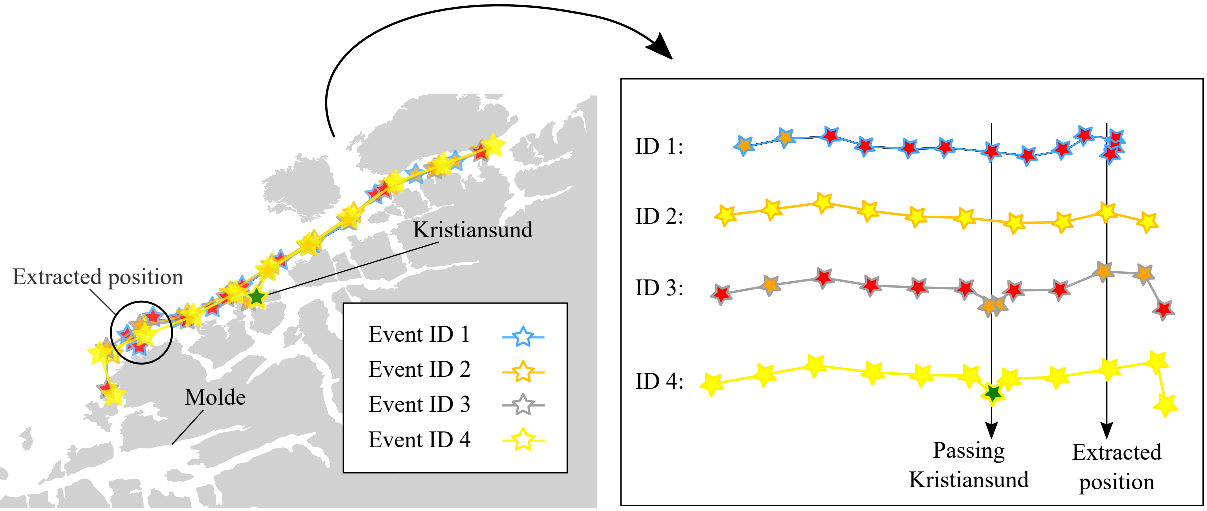

Figure 8.9: The figure shows the graphic representation of all four analysed events labelled with the extracted position. The left ship tracks are exploded to better differentiate the events.

It is important to mention that all positions are extracted at day except event ID 2 which is extracted at night, meaning its dynamic parameter value is increased by one degree of risk (which equals to a fuzzy parameter increase of two) and thus giving it a higher total risk parameter as well. Figure 8.10 shows the development of dynamic and total risk for all four events, also showing the reference points introduced in Figure 8.9.

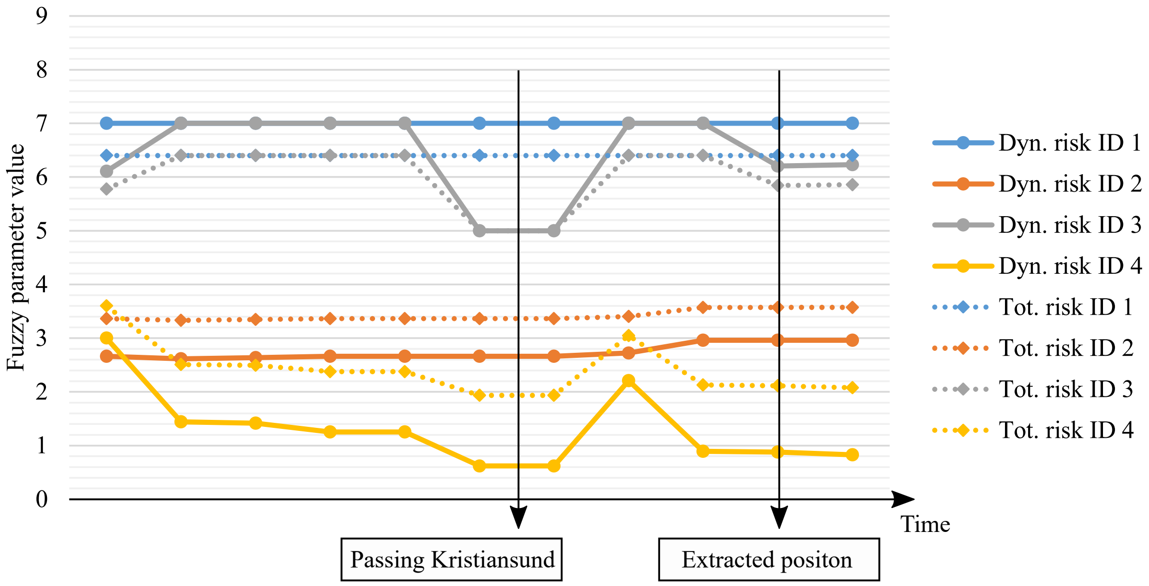

Figure 8.10: The development of the risk dynamic and total risk level for the four analysed events. The figure shows when the ships passed Kristiansund as well as the position that have been extracted for further analysis.

It can be seen from Figure 8.10 how the dynamic and total risk level for all four events have a minor variation, although being relatively stable in the high or low risk level region. The dynamic and total risk level can be seen to decrease for all events except event ID 1 and 2 when the ships pass Kristiansund.

The total risk value can be seen to provide a higher risk relative to the dynamic risk for event ID 2 and 4, which is a result of the static risk level (not represented in the figure) has a fuzzy parameter value of 5. The same logic gives how the total risk level for Event ID 1 and 3 is lower than the dynamic risk level.

To better understand how the event differs from each other, the calculated parameter values for the extracted position for all events will be further discussed. All parameter values calculated from the AIS data for all four ships can be seen in Figure 8.11. The plot also shows the total number of ships within 20 km, 50 km and 100 km, even though only the parameter indicating the number of ships within 50 km is used to calculate the risk level.

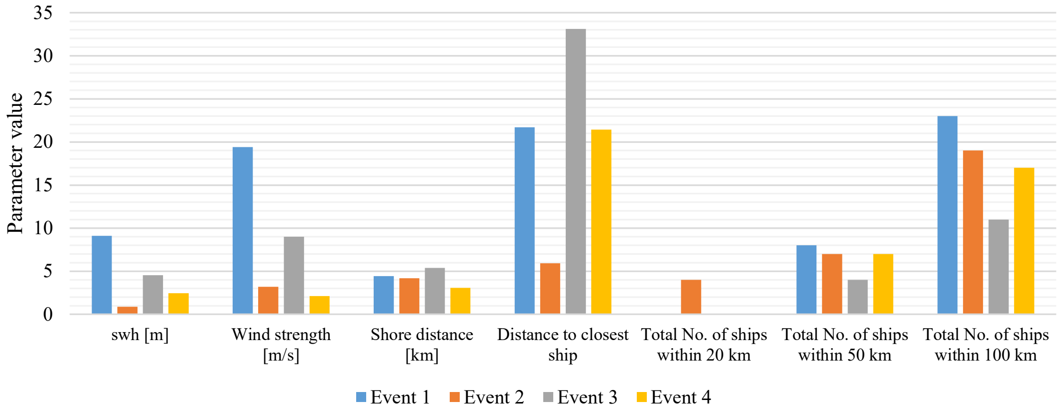

Figure 8.11: The figure shows all input parameters for the four events at the extracted location.

By examining the presented values calculated from the AIS data it can be seen how event 1 experienced the worst weather, with both high waves (9 m) and strong winds (19 m/s). Event 2 is seen to experience a swh of 4 m and a wind strength of 9 m/s. Event 3 and 4 are seen to experience better weather conditions, though event ID 4 has a swh of approximately 2.5 m. Not depicted in the presented graph is how for all events the wind is westerly, except for event ID 2 which is a calm south-easterly.

The ships shore distance is seen to be approximately similar as the ships are positioned in the same area. A detailed inspection of the presented events risk levels in the map-projection of Figure 8.9 that the ships sailing in good weather sail closer to shore in the inner navigational fairways.

It can be seen that the distance to the closest ship, when only including the tow-relating ships as presented in Table 8.3, how all ships had a ship assumed to be of relevance within 35 km, the closest being 6 km for event ID 2. It should be mentioned how the port of Molde is positioned approximately 35 km off the position from where the event's positions are extracted, where it can be expected to be ships of relevance.

Further it can be seen how only event ID 2 was observed to have ships of relevance within a proximity of 20 km, whilst the ships in vicinity increase for all events when the proximity distance is increased. The graph shows how event ID 1 had the most ships of assumed relevance within a proximity distance of both 50 and 100 km.

The presented input parameter values calculated from the AIS data have been used to calculate all fuzzy risk parameters for each event, which is presented in Figure 8.12.

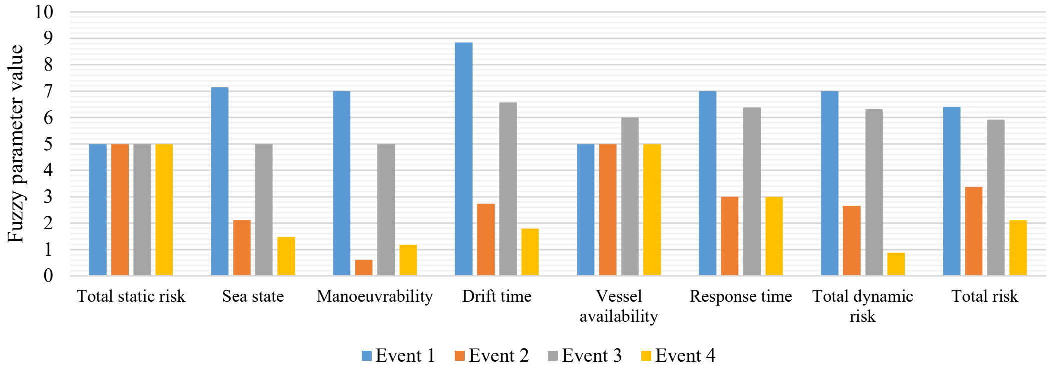

Figure 8.12: The figure shows the fuzzy parameters for all four events for the extracted position.

When evaluating the fuzzy parameter values presented in Figure 8.12 it is important to understand the significance of the y-axis, that is how the fuzzy parameter value relates to the parameters risk level, which was discussed in the model development in **??** defining how a high fuzzy parameter value indicates a high risk level.

Firstly it can be observed how all ships are given a similar static risk level, even though they carry a different amount of people, from 700 with event ID 3 to 1,373 with event ID 1 and 2. This is a consequence of how the model categorise all ships with a low Paris MoU ship risk profile with a total amount of people on board ranging from 550 to 2,800 to an average static risk level (fuzzy parameter value of 5). This could prove as evidence towards how the model should better differentiate the static risk level between ships of similar Paris MoU ship risk profiles with a different number of people on board. This can be done by altering the fuzzification logic of the *total number of people on board* parameter from the current distinct trapezoidal shapes to triangles which will give a better transition between states. This was discussed in the model development in subsection 5.3.1.

Further, the sea state is seen to provide a good representation of prevailing weather condition for each scenario. It is known from the model formulation that the sea state will reach a fuzzy parameter of 9 if the for wind is stronger than 20 m/s in a combination with waves larger than 9 meters, which event ID 1 is close to achieving. It can be discussed whether the sea state calculation should be more sensitive to the weather conditions observed for event ID 1, giving this event a fuzzy parameter of 9, that is a *very high* sea state, hence giving a higher total risk to events experiencing similar weather.

From the manoeuvrability parameter it is seen how the ship's sizes influence the parameter, where event ID 2 is given a lower manoeuvrability parameter value than event ID 4 despite experiencing a higher sea state. This is a consequence of the ship evaluated in event ID 2 is double the size of the ship evaluated in event ID 4. Furthermore, the drift times can be seen to correlate well with the current sea state for each situation, which also comprises the fact that the all ship events are positioned no further from shore than 6 km.

Further the vessel availability can be seen to be similar for all events, except for event ID 3 which has a slightly higher parameter value, meaning the availability of ships is worse for event ID 3. From the input parameter values it is known how event ID 3 both has the least ships positioned within 50 km as well as having the longest distance to its closest ship resource. It can also be observed how the model does not weigh the distance to the closest ship as heavily as the total number of ships within 50 km.

The response time is evaluated based on the drift time parameter and the vessel availability parameter, and is seen to give a similar good-average parameter state for event ID 2 and 4 and a higher state for event ID 1 and 3. Further the total dynamic risk is seen to be lower for event ID 4 than for event ID 2, which is due to the increased dynamic risk at night. Without the additional "night-risk" event ID 2 would have obtained a fuzzy risk parameter of 1.4 and would have had the dynamic and total lowest risk level. As the total static risk is similar for all events, the total risk is seen to correlate closely with the total dynamic risk, increasing the risk level of event ID 2 and 4 and slightly lowering the risk level of event ID 1 and 3.

8.3 Summary of results

AIS data and knowledge from the Viking Sky accident have been evaluated to better understand which how factors should be used in the developed model based on the proximity of different ship types. These results were further used as a basis when evaluating events using the developed contingency monitoring model.

Four events were evaluated with the contingency monitoring model to evaluate the produced risk levels based on the input parameters. The Viking Sky event was analysed in detail to better understand all involved parameters before three events were analysed and compared to that of Viking Sky.

The produced results have been discussed in detail throughout the presentation of the results and will be subject to a general discussion in the following chapter.

Chapter 9

Discussion and conclusion

9.1 Discussion of results

The presented results have been divided into two parts. Firstly the AIS data from the Viking Sky incident was used to obtain a broad overview of which ships that were available in the immediate area of Viking Sky at the time of the black out followed by a detailed analysis of the ships that is known to have assisted in the Viking Sky event. This was used as a point of reference to understand which ships that can assist a cruise ship in distress and how they may assist, which was evaluated in a combination with the theory presented on ship resources present on the Norwegian coast as seen in section 4.5. The analysis was not focused on how ships could assist in a MRO but rather in terms of their towing capabilities, thus the following analysis is limited to only include ships relevant for towing a cruise ship. This was performed as ships capable of towing a cruise ship will in most cases also be equipped to handle a MRO.

Secondly the results have been focused on evaluating the risk levels calculated from the developed model for four different scenarios. The Viking Sky incident was first analysed in detail to provide a deeper understanding of how the model works. This was done by presenting and discussing the values calculated from the AIS data that are used as crisp inputs into the developed risk model. Further all values calculated from the risk model, that is the fuzzy parameter values for each step in the hierarchical and modular risk model architecture seen in Figure 5.2, were presented and discussed.

The results show that the developed contingency monitoring model is capable of providing a dynamic risk level to cruise ships solely based on information from AIS-data in combination with weather data. The model is also seen to be able to separate events in terms of the dynamic risk level being produced, and that the produced dynamic risk level gives reasonable values that is easily understood based on the input values provided by the AIS-data. By also providing the contingency monitoring model with data relating to the static risk level, that is a Paris MoU ship risk profile and the total number of people on board, the model will provide a total risk level based on the calculated dynamic and static risk level. As a consequence of the total risk definition the static risk level of a ”typical” cruise ship as the ones analysed, will often have a medium static risk level, and thus ”pulling” the total risk level towards a medium risk level consequentially not allowing the model to reach a minimum or maximum value, that is a *low* or *high* risk level.

The model is defined with an emphasis on how the dynamic risk will account for the *probability* of a cruise ship accident and the static risk will account for the *consequence* of the accident, mostly due to how the total number of people on board the cruise ship is included in the static risk level. From the validation of the risk model it was seen that a larger ship will be given a higher total risk compared to a smaller ship for the same input parameters which follows the general idea on how a larger ship should be given more attention purely based on how there are more people at risk.

9.1.1 Ship availability

Time was spent through the thesis work to understand how different ships can assist a cruise ship in distress. By individual assessment of different ship groups also using work conducted in the National tug readiness concept study (2006), it was possible to provide a rough estimation of how different ships could aid a cruise ship in distress, divided into the categories of *towing*-assistance and *mass-evacuation*-assistance, as presented in Table 4.7.

Furthermore, only ships that were defined as relevant for towing-operations was used to assess the developed contingency monitoring model. This was a consequence of how the Viking Sky event was used as a point of reference, and how it was discussed in subsection 8.1.2 that it would provide a false risk level if ships would be included that would not have the necessary equipment to potentially secure a tow line to the tracked cruise ship. The author recognises how it could be favourable to divide the observed ships into two groups, namely ships relevant for towing and ships relevant for a MRO, and evaluate these two groups individually. The individual assessment would be based on variations in the observed input parameters, such as distance to shore and the prevailing weather conditions, which further would decide which of the two groups of ship resources that would be preferred.

9.1.2 Model usage areas within decision support

A model following a similar methodology as the model developed in this thesis will have the potential to aid decision makers in various ways. Firstly, a cruise ship or its responsible organisation could use a similar model when establishing sailing routes to evaluate how the proposed route would perform based on the produced risk levels. Another, and perhaps a more probable scenario, is how a governing agency in Norway, such as the NCA, will have the authority to interfere with cruise ship's planned route if the route exceeds or is predicted to exceed a certain risk level. Off course, many aspects must be considered in such a risk evaluation that might not have been mentioned in this thesis. Even so, a model integrating and emphasising the presence of nearby ship resources can be relevant and perhaps even imperative to properly mitigate a possible future cruise ship accident.

9.1.3 Validity of the presented results

9.1.4 Discussion on the limitations and uncertainty of the model results

Model behaviour

The detailed analysis of event ID 1 depicted in Figure 8.7 showed how several values will be produced from the AIS data and weather data, which further acts as crisp input values to the risk model producing a number of fuzzy parameters before calculating a final risk level. A proper assessment of the obtained values was seen to require proper knowledge of how the model was developed and how the fuzzy rules were defined. It is important to be aware how the obtained risk model results are directly affected by how the fuzzy logic is formulated and defined, as presented during the model development in chapter 5. Even with the presented theory on risk influencing factors, several subjective choices have been made by the author throughout the model development that will affect the obtained results. This especially relates to how the rule set for each of the fuzzy parameters is defined e.g. how the combination of two distinct input gives a predefined output value.

Spatio-temperal uncertainty from the AIS data

The AIS data will be prone to uncertainty in its positional accuracy, that is how a ship's position tend to be an approximate value and will vary based on a number of factors, as discussed in the theory section on AIS data in section 4.2. The reader should also remember from the development of the AIS handling program in the prior chapter 7 how only 10 % of the available AIS data for the events are used in the analysis, which is still seen to provide valid results.

Further the non-uniform distribution of the timestamp of the AIS data was seen to give rapid increases or decreases in values calculated from the AIS data that should increase or decrease steadily, such as a sudden increase of shore distance or distance to the closest ship. As stated, the AIS data calculation will have a minimum of two-minute steps between the extracted data, which in some instances gives two minutes between steps, and in others more.

The largest step size in the Viking Sky analysis was observed to be 12 minutes, with an average step size of 3 minutes 30 seconds and a standard deviation of 1 minute 37 seconds. The author recognises the observed average step size and standard deviation also including the largest time step of 12 minutes to be within an acceptable range providing realistic and valid results from the parameters calculated from the AIS data.

Ship availability

From the presented parameters in Figure 8.7 a transition period is expected to occur in the first hours of the analysis relating to the observation of ships. This is a consequence of how the AIS data is calculated, where a ship is only included in the analysis if the timestamp of an AIS data message is less than or equal to the time stamp of the cruise ship's current position.

In theory all ships with a functional AIS transmitter will send out AIS messages every few minutes, thus the transition period should only be a few minutes. However, there is reason to be critical to the ship availability in the first few hours of the analysis.

Furthermore, the model will continuously calculate the distance from the cruise ship to all ship resources in vicinity. However, the calculation will not consider local geographic variations such as islands, shoals and fjords and will thus only provide the distance between the cruise ship and the evaluated ship calculated as a straight line. Hence the distance calculated between the cruise ship and a ship resource will always be a best-case scenario distance. This can ultimately provide a false model result which the one must be aware of.

Geographical limitations

During the development of the model, factors have been developed based on accidents from a limited geographic area, that is the area of Hustadvika as well as the northern part of Norway. This is a consequence of the scarcity of cruise ship accidents and available data. Additionally, the events studied in the evaluation of the developed contingency monitoring model have only been performed for the immediate area surrounding Hustadvika, partly to obtain comparable results to the Viking Sky incident and partly due to difficulties obtaining AIS data for other geographical areas. Thus, the conducted evaluation and resulting performance of the model might be prone to geographical limitations of the Hustadvika area.

Furthermore the model utilise weather data from the online Copernicus Climate Data Store[1] which only provides an approximate knowledge of the weather conditions with a rough grid representation. This will essentially give false model results if the cruise ship being monitored is not exposed to the obtained weather conditions which will most often be the case in protected waters.

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[1] https://cds.climate.copernicus.eu

9.2 Conclusion

The objective through the conducted Master's thesis have been to investigate aspects relating to cruise ship incidents to establish a method for cruise ship contingency monitoring based on dynamic risk assessment to circumvent potential high-risk situations with a special emphasis on the availability of ships. The thesis presents how a number of aspects must be considered when developing such a model and how the scarcity of cruise ship incidents and theory relevant to mass rescue operations pose as a challenge. It is of importance to understand which ships that can assist in a cruise ship incident, how they can assist and how external factors such as weather conditions will affect the situation. Presented theory have assessed two aspects of ship-based cruise ship assistance through *towing assistance* and *mass evacuation assistance*.

The presented ship contingency monitoring model have been developed using risk assessment theory combined with fuzzy logic reasoning. The fuzzy logic reasoning approach was chosen due to how it is well fit to handle uncertain and vague input parameters to provide transparent results rooted in the human ability to make rational decisions. The model was evaluated through the use of AIS data from a few selected events. The results proved the model efficient in terms of providing a continuously updated risk level to individual cruise ships thus capable of monitoring and prioritise these. The model's architecture is based on a modular and hierarchical structure integrating linguistic rule sets which can easily be understood and altered. Results from the model validation and analysed events show how the model response is strongly affected by the definition and knowledge of the defined fuzzy rule sets, thus this must be given careful consideration. The author wants to emphasise how the major challenge is to evaluate *how* ships should be implemented in the model. Nevertheless, this Master's thesis has shown the potential usage areas of a dynamic risk model that is capable of integrating nearby ship resources to assess the dynamic risk of cruise ships sailing along the Norwegian coast.

9.3 Further works

A number of ideas for further works beneficial to the development of such a model have been established and will be presented. As concluded, a future study relating to a cruise ship contingency monitoring model integrating the presence of ships should be focused on assessing how different ships can assist in a cruise ship accident, based on a number of concerns. Firstly, it must be evaluated how a cruise ship would require assistance, that being in terms of towing, mass evacuation or other possibilities. In the event of a cruise ship requiring towing assistance it is important to assess the bollard pull power required to tow a cruise ship exposed to different external conditions such as wind, waves, and currents. This must be further assessed in combination with the exploration on the procedure of connecting a physical tow line from the towing ship to the cruise ship. Conversations with experts presented in this master revealed how tow lines are hard to connect to cruise ships as the ship's superstructure often encumbers the connection procedures, which is especially the case in harsh weather conditions.

For the case of mass evacuation assistance, it is evident that a ship-to-ship transfer of passengers is a challenging task which must be given careful attention. This is of especial concern when the cruise ship and assisting ships is exposed to harsh weather conditions hampering the ship-to-ship transfer of passengers. A proximate shore line in poor weather is also of concern during an ordinary cruise ship evacuation, which could be the reality for cruise ships travelling along the Norwegian coast shown through the Viking Sky incident March 2019. Ultimately, the assessment of cruise ship safety in Norwegian waters needs careful consideration and needs further attention.

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APPENDIX

Appendix A

Results from the project thesis

A.1 Major risk factor definitions

Definition of major risk influencing factors

Factor	Definition
Weather	How the weather affects the risk picture. That is both in terms of casual effects, as well as how the weather contributed to aggregate or mitigate an incident.
Emergency preparedness	How well prepared both the ship itself and uts crew is to handle an emergency, as well as how The Company is prepared. This section also covers how well prepared SAR authorities are, but in the selected accidents studied, SAR authorities have solely contributed in a positive manner.
Maintenance	Maintenance of operation critical components and systems, eg. machinery, fire fighting systems and electrical systems, This does not include 'maintenance' of emergency preparedness routines and other human aspects.
Navigation	How the navigational decisions made affect the total risk picture. This is often done in combination with authorities, The Company and the Officers, whilst sometimes this is individual navigational decisions made on the spot, then often by Officers or similar.
Communication	Both internal and external communication. This covers how the ship Officers during incidents manage passenger announcements, communication with The Company and with SAR authorities, as well as how The Company and SAR authorities communicate.
Geographical location	How the location contriubted to an incident. This covers many aspects, like how remoteness of an incident influences the total risk picture, and how being close to shore can both aggregate or mitigate the consequential effects of an incident.
Passengers	How the passengers state contributed eg. age, cultural background, country of origin, physical state and actions performed.
Ship design	How did the ship design contribute in a cruise ship incident. This can be on the casual or consequential side, eg. how the ship was designed to handle an emergency, easily accesible means of escape and adequate alarm systems.

A.2 Results from the individual accident assessments

Incident	**Viking Sky**		**Carnival Triumph**		**Costa Concordia**		**Star Princess**	
Factor	**Discussion**	**Factor**	**Discussion**	**Factor**	**Discussion**	**Factor**	**Discussion**	**Factor**
Weather	The heavy weather was a large contributors, both on the causual and consequential side	**-3**	Weather conditions were good, which had a minor positive impact on the accident	**+1**	The weather was favourable in terms of calm seas. The darkness might have contributed to harder navigational visual aids, but the total factor is thought to be somewhat positive	**+1**	Weather is thought to have had a minor positive impact, as the weather in general was good and that the wind could be used to redirect the smoke away from the ship	**+1**
Emergency preparedness	The interim report is not specific on how the emergency response influenced the situation. The fast mayday might have contributed positively had the vessel struck shore	**+1**	The crew were well trained on the fire in the engine room, and the situation was in genereal well handled	**+2**	The crew, and especially the management, in the Costa Concordia incident was clearly not adequately prepared	**-2**	The crew's fire fighting response was professional and well prepared for. Minor deviation in terms of some communicational issues with passengers but nothing too negative	**+3**
Maintenance	The faulty maintenance on the engine oil is the main contributing casual factor, which was realised through the heavy weather	**-3**	The flexible pipe rupturing was a result of a flaw in the maintenance plan, and is the main contributing factor	**-3**	Maintenance issues (technical that is) is not revealed to be of any major importance	**0**	Maintenance issued is not thought to have had a major contribution. The analysis revealed that some deluge-sprinklers did not activate as intended	**-1**
Navigation	The decision to skip Bodø, as the ship might not have been able to leave on schedule to due a narrow port exit in heavy seas, is a negatively contributing factor	**-2**	Navigation is not thought to have influenced the result in a positive or negative way	**0**	Human navigational decisions was the main contributor to the accident	**-3**	Navigational factors did not contribute positively nor negatively	**0**
Communication	Communication was good, and a fast mayday and good PA's was a positive influence	**+2**	The PA's to passengers were confusing at times making passengers unsure of the situation status	**-1**	Communication was not adequately performed, as the Master refused to admit the seriousness of the situation, and both The Company and SAR-authorities were misinformed. The Company should also behaved differently in terms of SAR-communication. Passengers were also severly misinformed.	**-3**	Communication during the incident seems to have been only contributing in a positive manner. Officers kept a clear chain of command, and also kept passengers informed by PA.	**+2**
Geographical location	Passing notorious areas such as Hustadvika in heavy weather should be carefully concidered. The GC ship also evacuating is proof that both weather and location was unfavourable	**-3**	The remote location of the ship contributed to a prolonged journey to shore without essential systems. This caused major discomfort amongst the passengers, however, not critical for life and death	**-2**	The immediate proximity of the shore is of course the reason for the hull rupture, but in the total picture the shore proximity eased the evacuation of passengers, and ensured a higher survival rate than what could have been expected had the rupture occured mid-sea	**+2**	The ships position did not contribute in a major negative nor positive way as such, apart from that the ship could relatively quickly get to shore.	**+1**
Passengers	Some passengers were elderly and thus with a lot of ship movement some had a hard time to evacuate	**-1**	The passengers on board did not contribute negatively nor positively in the incident	**0**	Elderly passengers had troubles evacuatin with the increasing list of the ship and has therefore a minor negative impact	**-1**	As it is suspected a passenger started the fire by irresponsibly disposing of a cgarette, this factor is somewhat negative. After this event there is no evidence that passengers contributed in any negative way, only somewhat positive in terms of mustering according to muster plan	**-2**
Ship design	The blackout of the ship with total loss of propulsion is a proof of inadequate ship system redundancy. However, the design also made it possible to restart engines within a limited amount of time	**-1**	The ship design comprised of tenders that was not suitable to transfer people to other ships, and the power redundancy was not adequate. Thereore the impact is fairly negative	**-2**	A rather large negative impact is due to the poor redundancy in critical systems that provided information of the ship's status to the bridge e.g. the stability software that would have given immediate warnings of the unstable ship. Also, the ships list made the use of life boats a challenging task	**-2**	The ship design was the main contributing factor. Flammable materials used on the balcony is a major contributing factor. However, the ships design overall also contributed to isolate the fire and prevent situation escalation. Also passengers claim not to have heard fire alarms in accommocation nor in hallway which could be a design issue. Better detection of early fires should be discussed. Inaccesible life boats could also be discussed to be a design issue	**-2**

A.3 Results from the statistical accident assessments

Statistical analysis result

Factor		Hull/Machinery damage		Fire/Explosion		Contact		Collisions		Stranded	
		Discussion	**Factor**	**Discussion**	**Factor**	**Discussion**	**Factor**	**Discussion**	**Factor**	**Discussion**	**Factor**
Weather	**Heavy weather**	Heavy weather is seen from the analyses to be very present in the accidedent class. It is also seen from the selected accident analysis that weather often contributes to casual effects of especially machinery damage. However, in most cases the weather is not reported.	**3**	From the conducted analyses, heavy weather does not seem to influence the chance of a fire/explosion. In allmost all cases however the weather is not reported.	**0**	Heavy weather seems to be of influence from the results. However, in most cases the weather is not reported.	**3**	Heavy weather seems to be of influence from the results. However, in most cases the weather is not reported.	**3**	Heavy weather seems to be of influence from the results. However, in most cases the weather is not reported.	**3**
	Good weather	Good weather is represented in many of the cases in the statistical analyses, and from the selected accident investigations it is seen that a ship can have severe damage to hull/machinery even in good weather seen from the Costa Concordia accident. It is however not possible to say that good weather does contribute negatively.	**0**	Not seen to be of significant negative relevance. Hard to draw any conclusions.	**0**	Not seen to be of significant negative relevance. Hard to draw any conclusions.	**0**	Hard to draw conclusions, but the "good"-weather classification is relatively over-represented for collisions compared to other accident cases. This, as well as general knowledge of that many often underestimate their capability to maneuver properly in good weather conditions, leads to that good weather has a minor contribution to collisions.	**1**	Also hard to draw conclusions, but good weather is also relatively present in this accident category compared to the other accident categories, and it is thought to contribute. Also, the analysis of the Costa Concordia incident leads to the conlusion that straning is indeed possible with good weather, which might make ship's underestimate their surroundings.	**2**
	Poor visibility	Not seen to be of any significant negative relevance.	**0**	Not seen to be of any significant negative relevance.	**0**	Not seen to be of any significant negative relevance.	**0**	From the statistical analyses, some collisions are labelled with fog and poor visibility. This, with common sence, gives reason to believe that fog/poor visibility contributes to collisions	**2**	Not seen to be of any significant negative relevance from the data reviewed.	**0**
Ship age	**<5 years**	Very present in statistical analysis. It is hard to use the investigated incidents to conclude with anything. However, statistics show that it is indeed present	**3**	From statistical data. It is hard to use the investigated incidents to conclude with anything.	**1**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data even though some ship ages seem to be represened somewhat more than others. No useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**
	5-15 years	From statistical data. It is hard to use the investigated incidents to conclude with anything.	**2**	From statistical data. It is hard to use the investigated incidents to conclude with anything. Carnival Triumph was allmost 15 years at the time of the fire incident which caused a total power loss, which gives reason to support a somewhat contributing factor.	**2**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data even though some ship ages seem to be represened somewhat more than others. No useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**
	15-25 years	From statistical data. It is hard to use the investigated incidents to conclude with anything.	**1**	From statistical data. It is hard to use the investigated incidents to conclude with anything.	**1**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data even though some ship ages seem to be represened somewhat more than others. No useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**
	>25 years	From statistical data. It is hard to use the investigated incidents to conclude with anything.	**2**	From statistical data. It is hard to use the investigated incidents to conclude with anything.	**2**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data, and no useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**	It is hard to come to any meaningful conclusions from the statistical data even though some ship ages seem to be represened somewhat more than others. No useful information have been found from the individual incident investigations. Therefore, it seems not to contribute of any significance, whatever the ship age.	**0**
Ship size	**<100,000 GT**	The distribution follows the total No. of accident class distribution, and no information can therefore be deduced.	**0**	The distribution follows the total No. of accident class distribution, and no information can therefore be deduced.	**0**	The distribution follows the total No. of accident class distribution, and no information can therefore be deduced.	**0**	The distribution follows the total No. of accident class distribution, and no information can therefore be deduced.	**0**	The distribution follows the total No. of accident class distribution, and no information can therefore be deduced.	**0**
	>100,000 GT	It is hard to draw conclusions from the analyses performed, but from the statistical analyses in relation with the selected investigated accidents, it seems to be that a large ship have a complex machinery system, which is then somewhat prone to accidents.	**1**	It is hard to draw conclusions from the analyses performed, but from the statistical analyses in relation with the selected investigated accidents, it seems to be that a large ship have a complex machinery system, which is then somewhat prone to accidents.	**1**	Also hard to draw conclusions, but mainly there does not seem to be a large contribution.	**0**	Also hard to draw conclusions, but mainly there does not seem to be a large contribution.	**0**	Also hard to draw conclusions, but mainly there does not seem to be a large contribution.	**0**

Emil Carlsson

Dynamic cruise ship contingency monitoring and risk assessment based on a fuzzy logic approach using AIS data

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