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Design for Operational Efficiency and HSE in Marine Operations between Floating Cage Collars and Service Vessels in the Aquaculture Industry

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Preface

This master thesis represents the final result of a Master of Science within the study programme Marine Technology at the Norwegian University of Science and Technology (NTNU), Trondheim. The thesis is written by Odd Helge Gåsdal Hatlem and Bettina Wickman Kvamme during the spring semester 2016, and counts for 30 credits for each of us.

This master thesis is the continued work of a project thesis written in the autumn semester 2015, which was a literature study of the aquaculture industry looking into development, challenges and previous work with respect of safety and efficiency. The objective of this master thesis was to define whether the service vessels and floating collars in the industry are fitted to each other to create optimal working conditions with respect to safety and efficiency. Furthermore, to define measures that can improve and optimise the working conditions. For this purpose, a Formal Safety Assessment and a Continual Improvement Assessment have been utilised.

The motivation for the study was to learn more about the aquaculture industry, which is one of Norway's fastest growing industries. Furthermore, to contribute to make the increasingly demanding marine operations, safer and more efficient. There are not published any research studies defining the overall risk level within the industry, neither any studies regarding continual improvement of marine aquaculture operations. This have motivated us to make all information easily understood after best effort, in order to make this study available as a guideline for further safety and efficiency work within the industry.

We would like to thank our supervisor Professor Bjørn Egil Asbjørnslett at the Department of Marine Technology, NTNU, for help and guidance throughout the project and master thesis. Further, we would like to thank Noralf Rønningen and Martin Søreide in Aqualine and Ove Løfsnæs in AQS providing us with the problem definition. A special thanks to Kristoffer Pedersen and AQS who brought us out on the different operations and to all the personnel who showed us the operations and shared helpful and valuable information. Lastly, a special thanks to all others not mentioned who have contributed, discussed problems and answered questions from us.

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Odd Helge Gåsdal Hatlem Bettina Wickman Kvamme

Summary

In the shadow of challenges with salmon lice, fish escapements and a desire of increased production growth, there have been less focus on the safety for the personnel on the fish farms and in the marine aquaculture operations. Studies shows that the aquaculture industry is the second most dangerous industry in Norway after the fishery industry. At the same time, the industry is facing increasing production costs. Considering this, it is important to assess systematically every operation with respect to both safety and efficiency. Larger vessels, heavier operations, together with more exposed sites, makes operations more demanding and will reinforce this need. Furthermore, due to the new development concessions, many new concepts and methods are under development and will enter the market shortly. This will lead to unfortunate consequences if not properly assessed. Therefore, in order to secure the predicted growth in a sustainable way, it is more important than ever to ensure health, safety and the environment (HSE) together with efficient operations in Norwegian Aquaculture.

The objective of this master thesis was to perform a Formal Safety Assessment (FSA) and a Continual Improvement Assessment (CIA) in order to answer the research questions established in the problem definition. These questions were to investigate whether the service vessels and floating cage collars are fitted to each other to create optimal working conditions with respect to both operational efficiency and HSE. The study will thus, give awareness of issues regarding risk, safety and efficiency in marine operations in the aquaculture industry. Furthermore, measures on both vessels and floating collars that could improve both operational efficiency and HSE, have been investigated.

The thesis is limited to look at three essential marine operation between service vessels and floating net collars. These operations are net cleaning, service and maintenance of floating collars and delousing with tarpaulin. These operations are regularly performed, and especially the last operation demands many people and vessels to participate in order to be carried out.

From hazard identification, a total of 62 hazards were found within the following operational phases: work on deck/net cage and entering/disembarking vessel/net cage (8 hazards), lift operations (10 hazards), net cleaning operations (5 hazards), vessel berthing to net cage (18 hazards), delousing the fish (12 hazards) and cleaning of floating collar (9 hazards). Based on these hazards, generic accident categories were established and the following accident categories were identified to represent the total risk picture: trip/slip, hit by object, squeeze/trapped and collision/contact.

Based on predefined risk acceptance criteria, the overall individual risk and overall individual third parties risk were found to be unacceptable, which agrees with the fact that the industry is the second most dangerous to work in. Thus, according to the ALARP principle, risk-reducing measures are mandatory to implement. Furthermore, the risk related to environment and property were found to be high. Thus, service vessels and floating cage collars are according to these results, not fitted to each other in order to create optimal working conditions with respect to HSE.

To evaluate efficiency in the operations, the third step of the continual improvement model, KOSTER III, was utilised. This showed that; poor and inadequate design, not properly fitted equipment, lacking or inadequate planning and procedures leading to among others delayed and aborted operations, are recurring causes to inefficient operations. Thus, service vessels and floating cage collars are in many areas not properly fitted to each other in order to create optimal working conditions with respect to operational efficiency. Measures for increased efficiency and safety should therefore be established.

For each of the assessments, a brainstorming session were held in order to establish risk control measures and improvement measures. These measures were combined into ten practical and well thought out control options for improving of both safety and operational efficiency. These ten control options consist of six main areas: Planning, prevent falling into sea and drowning, prevent collision and contact, improve vessel stability and crane operation, improvement for new vessels and operation specific improvement.

Re-evaluation of the risk picture shows that it is necessary to implement a combination of control options in order to reduce the overall risk level sufficiently.

Based on individual risk reduction potential, the following recommendations has been made:

- Control option 1: Measures related to better planning and decision support system
- Control option 4a: General measures related to improving vessel stability and crane operation
- Control option 2c: Measures for personnel training and safety related to prevention of falling into sea and drowning

Based on third parties individual risk reduction potential, the following recommendations has been made:

- Control option 3a: Measures on net cage related to prevention of collision and contact
- Control option 1: Measures related to better planning and decision support system

- Control option 2c: Measures for personnel training and safety related to prevention of falling into sea and drowning

Based on environmental and property risk reduction potential, the following recommendations has been made:

- Control option 1: Measures related to better planning and decision support system
- Control option 3a: Measures on net cage related to prevention of collision and contact

Furthermore, some recommendations have been made based on implicit cost-effectiveness consideration and on how difficult they are to implement:

- Control option 1: Measures related to better planning and decision support system
- Control option 2c: Measures for personnel training and safety related to prevention of falling into sea and drowning
- Control option 2a: Measures on net cage related to prevention of falling into sea and drowning

The risk level is found to be unacceptable, and the main recommendations are therefore based on the quantitatively risk reduction potential. Many of the established control options that are not further recommended above might therefore in an operational efficiency point of view, give a larger improvement in the efficiency. However, as the control options are based on both risk reduction and improvement measures, they will also improve operational efficiency. Overall, the study shows that by ensuring efficient operations often contribute to safe operations and vice versa.

An extended summary are given in Norwegian, as this is the main working language within the aquaculture industry in Norway.

Sammendrag

Norsk havbruksnæring har hatt en formidabel vekst de siste tiårene og er forutsatt til å vokse ytterligere og estimeres å ha en verdiskapning på rundt 500 milliarder i 2050. I dag er oppdrett av atlanterhavslaks og regnbueørret en av Norges viktigste næringer etter olje og gass. De siste årene har oppdrettsnæringen slitt med utfordringer som rømming, arealbehov og spesielt lakselus som kan sies å nærmest være ute av kontroll.

I skyggen av utfordringene og samtidig et ønske om økt produksjonsvekst, har det vært mindre fokus på sikkerhet for personell på oppdrettsanleggene og de marine operasjonene som foregår der. Studier viser at oppdrettsnæringen er den nest farligste næringen etter fiskeri. Samtidig ser man en trend i økende produksjonskostnader, der kostnadene har økt jevnt siden 2005. Dette som følge av større og krevende operasjoner for avlusning med mye personell og båter, samt dyrere smolt og fiskefôr. Med tanke på dette, er det viktig å systematisk analysere hver operasjon som foregår på anleggene med hensyn til både sikkerhet og effektivitet. Større fartøy og tyngre operasjoner, samtidig som anleggene flyttes ut mot eksponerte havområder, gjør operasjonene mer krevende og vil forsterke dette behovet. Videre vil mange nye konsepter komme på markedet som følge av de nye utviklingskonsesjonene fra Fiskeridirektoratet. Dette vil føre til nye operasjoner som kan lede til uheldige konsekvenser dersom operasjonene ikke blir grundig evaluert. Det er derfor svært viktig å sikre helse, miljø og sikkerhet (HMS) samt effektivitet i de marine operasjonene i oppdrettsnæringen.

Studiets formål er å utføre en Formal Safety Assessment (FSA) og en Kontinuerlig forbedringsprosess for å svare på problemstillingen i masteroppgaven. Problembeskrivelsen er å undersøke om servicebåtene og flytekragene er tilpasset hverandre for å skape optimale arbeidsforhold med hensyns til effektiv drift og HMS. Studiet vil derfor gi bevissthet om risiko, sikkerhet og effektivitet i operasjoner i oppdrettsnæringen. Neste steg i oppgavebeskrivelsen er å se på hvilke tiltak som kan gjøres for forbedre dette, både på flytekragene og servicebåtene.

Oppgaven var begrenset til å se på tre utvalgte operasjoner, nemlig vasking av nøter, avlusning med presenning samt service og vedlikehold av flytekrager. Dette er viktige operasjoner mellom servicefartøy og flytkrager som gjøres ofte samt krever mange arbeidstimer.

En grovanalyse identifiserte totalt 62 faremomenter ved følgende arbeidsområder: arbeid på båtdekk eller merd (8 farer), løfteoperasjoner (10 farer), notvask operasjon (5 farer), fortøye fartøyet til merden (18 farer), avlusning (12 farer) og rens og vedlikehold av flytekrage (9

farer). Følgende ulykkeskategorier ble etablert basert på dette: skli/snuble, truffet av et objekt, klemt/fanget og kollisjon/kontakt.

Basert på forhåndsdefinerte risikoakseptkriterier, ble den samlede individuelle risikoen og samlet individuell tredjeparts risiko funnet å være uakseptabelt, som kan stemme overens med det faktum at industrien er den nest farligste å jobbe i. Det er derfor i henhold til ALARP-prinsippet, ("så lavt som praktisk mulig"), obligatorisk å innføre risikoreduserende tiltak i operasjonene. Videre viser resultatene at risiko knyttet til miljø og eiendom er høy. Ut fra dette kan en derfor si at servicefartøy og flytekrager ikke er tilpasset hverandre for å skape optimale arbeidsforhold med tanke på HMS.

For evaluering av effektivitet i operasjonene, ble det brukt siste steg av en kontinuerlig forbedringsprosess utviklet av Forsvaret, kalt KOSTER III. Resultatene herfra viser at utilstrekkelig eller upassende design, utstyr som ikke er skikkelig tilpasset operasjonen, mangelfull eller dårlig planlegging av operasjoner og mangelfulle prosedyrer, kan føre til forsinkede eller avlyste operasjoner, ofte i sammenheng med værforhold. Dette er typiske årsaker til dårlig effektivitet som går igjen gjennom effektivitetsstudiet. Resultatene viser derfor at servicefartøyene og flytekragene ikke er optimalt tilpasset hverandre med hensyn til operasjonell effektivitet. Tiltak for forbedring både med tanke på både HMS og effektivitet ble undersøkt.

En brainstorming (idédugnad) ble avholdt for å etablere kontrolltiltak for risiko, samt forbedringstiltak for effektivitet. Disse tiltakene ble så koblet sammen til ti praktiske og godt gjennomtenkte kontrolltiltak. Tiltakene består av seks hovedområder: Planlegging av operasjoner, hindre fall i sjø og drukning, hindre kollisjon/uønsket kontakt mellom fartøy/merd, forbedre fartøysstabilitet og kranoperasjoner, forbedring av nye fartøy og operasjonsspesifikke tiltak. Re-evaluering av risikobildet viser at det er nødvendig å implementere en kombinasjon av flere tiltak for å få senket risikonivået tilstrekkelig.

Baser på reduksjonspotensiale for individuell risiko, er følgende tiltak anbefalt:

- Kontrolltiltak 1: Forbedret planlegging og system for beslutningsstøtte
- Kontrolltiltak 4a: Generelle tiltak for forbedret fartøysstabilitet og kranoperasjoner
- Kontrolltiltak 2c: Trening og sikkerhetskurs for personell med tanke på fall i sjø og potensiell drukning

Basert på reduksjonspotensiale for tredjeparts individuell risiko, er følgende tiltak anbefalt:

- Kontrolltiltak 3a: Tiltak på merd for å forhindre kollisjon/kontakt

- Kontrolltiltak 1: Forbedret planlegging og system for beslutningsstøtte
- Kontrolltiltak 2c: Trening for personell og sikkerhetskurs med tanke på fall i sjø og potensiell drukning

Basert på reduksjonspotensiale for miljø og eiendoms risiko, er følgende tiltak anbefalt:

- Kontrolltiltak 1: Forbedret planlegging og beslutningsstøtte system
- Kontrolltiltak 3a: Tiltak på merd for å forhindre kollisjon/kontakt

Videre er det gjort noen anbefalinger basert på en implisitt kost-nytte vurdering og på hvor vanskelig tiltakene er å implementere:

- Kontrolltiltak 1: Forbedret planlegging og system for beslutningsstøtte
- Kontrolltiltak 2c: Trening og sikkerhetskurs for personell med tanke på fall i sjø og potensiell drukning
- Kontrolltiltak 2a: Tiltak på merd med tanke på å forhindre fall i sjø og drukning

Resultatene viser at risikonivået er uakseptabelt, og derfor er hovedanbefalinger basert på kvantitativt risiko-reduksjonspotensiale. Noen av de foreslåtte tiltakene i dette studiet som ikke ble videre anbefalt kan derfor gi en større forbedring med hensyn til operasjonell effektivitet Men ettersom kontrolltiltakene er basert på forbedring i både sikkerhet og effektivitet, vil flere av de anbefalte tiltakene derfor også forbedre effektiviteten i operasjonene. Generelt sett viser studier at ved å sikre effektive operasjoner vil en også forbedre sikkerheten i operasjonene og visa versa.

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Abbreviations

AGD	Amoebic gill disease
AIBN	Accident Investigation Board Norway
ALARP	The As Low as Reasonably Practicable
CBA	Cost-Benefit Analysis
CIA	Continual Improvement Assessment
CO	Control option
COG	Centre of gravity
ETA	Event Tree Analysis
FFI	Norwegian Defence and Research Establishment
FSA	Formal Safety Assessment
FTA	Fault Tree Analysis
HDPE	High-density polyethylene
HE	Hazardous event
HSE	Health, safety and the environment
IMO	International Maritime Organisation
LARS	Launch and recovery system
NDF	Norwegian Directorate of Fisheries
NLIA	Norwegian Labour Inspection Authority
NMD	Norwegian Maritime Directorate
NS 9415	Norwegian technical standard
NYTEK	The National Regulation for Certification and Inspection of Fish Farm Systems
PHA	Preliminary Hazard Analysis
RCM	Risk Control Measures
RCO	Risk Control Options
SMED	Single Minute Exchange of Die

STEP	Sequentially Timed Event Plotting
VMO	Veritas Marine Operation

1 Introduction

1.1 Background

The aquaculture industry has grown significantly the last decades and developed from being an experience-based industry, to become a more knowledge-based industry. From 2000 until 2015, Norway has had an annual production growth of 7.1% (SSB, 2016a). In 2015 a total of 1 386 575-ton salmon and trout with a total value 46 514 million Norwegian kroner were produced (SSB, 2016b). It is estimated that marine value creation in Norway will grow to above 500 billion kroner in 2050, where the main value creation will be in aquaculture of salmon (Olafsen et al., 2012).

A comprehensive review identifying the development, challenges and prevoius work in the aquaculture industry were studied in the project thesis “A Literature Review of the Aquaculture Industry – Development, Challenges and Previous Work” (Hatlem and Kvamme, 2015). This study showed that the industry has met and solved several challenges. Due to bacterial diseases, the use of antibiotics exploded during the 1980s and limited the growth (FHL, 2013). The development of vaccines for salmon reduced the use of antibiotics in the start of 1990s and allowed continued growth in the industry (FHL, 2013). Today salmon only use 1% of all antibiotics used in Norway, while agriculture usage is 11% (FHL, 2013).

After the millennium and towards today, escapement of salmon has been an increasing problem. In the period of 2006-2009, 68 % of the escapes occurred due to structural failure (Jensen et al., 2010). In order to improve the fish farms and to reduce structural failures and hence the amount of escaped salmon, the NYTEK regulation and requirements for certification and the Norwegian technical standard (NS 9415) was implemented in 2006. This has contributed to a higher tolerance for environmental conditions on the cages and components, and reduce the total number of escaped salmon (Jensen et al., 2010). Two-thirds of all escapements after the NYTEK regulation was implemented, is in association to a hole in the net (Jensen et al., 2010). However, the dominant causes of fish escapement have changed from being structure related to being operation related.

More recently, farms tend to be established in more exposed areas and thus be exposed to rougher sea conditions. Exposed sites have stronger and steadier currents that increase water quality and better oxygen supply, which is needed to maintain the salmons normal vital functions (Jensen et al., 2010). The current will contribute to a transportation of waste away from the cage, which increase the well-being for the fish. However, the risk of accidents causing both human injury and escapement of salmon is increasing with exposed sites. Rougher weather conditions makes operations between vessels and cage more difficult to perform. Thus, as the fish farms are located in more exposed areas, the industry need new technology adapted for topography and the environmental conditions. Further, it needs a more effective way of running essential operations like maintenance, delousing etc. and at the same time be safe for the personnel.

Today the largest challenge within the industry is the salmon lice. Salmon lice is the most important cause of financial loss for Norwegian aquaculture, with approximately NOK 3-4 billion in direct loss together with costs for chemicals, extra work needing many vessels and personnel, additional preventive operations and possible loss of the fish (Iversen et al., 2015). The most common treatment against lice is use of chemicals, but challenges with resistant lice and environmental impact of treatment have lately introduced many new treatment methods leading the use of medicine to be reduce with approximately 60% the last year (Nodland, 2016).

Since 2005, the real production costs of salmon have increased with 40% (Iversen et al., 2015). Half of this increase came from 2012 towards today, much because of the large cost with delousing (Iversen et al., 2015). Because of these problems, there has been limited production growth and increased profits comes mainly from record high salmon prices. This has led some critical voices to point towards the oil and gas industry and warned against what can look like a similar uncritical development regarding costs.

To arrange for continued production growth of salmon in Norway, the government has lately introduced development concessions that can contribute to development new technology that can contribute to solve one or several challenges concerning environment and area. (Salmon Allocation FOR-2004-12-22-1798, 2016). However, this has led to many completely new concepts during short time and not all might be sufficient thought-through. The new concepts may not only change how operations are performed and introduce new challenges and hazards for the personnel, but also further increase the production costs in the industry. Different concepts might also lead to one specific operation has to be performed in different ways and hence reduce the efficiency of the operation.

In the shadow of increased costs, wanted increase in production growth and challenges with salmon lice and escapements, there have been less focus on the safety of the workers on the fish farms and in the marine operations. A study performed by Holmen et al. (2016) shows that the aquaculture industry is the second most dangerous industry to work in after the fishery

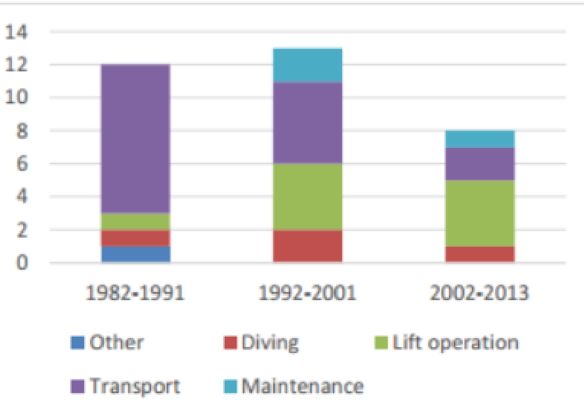


Figure 1.1: Main causes of occupational fatalities (Holmen, 2015)

industry. During 1982 to 2015, there have been 34 fatalities and from 2001 to 2012, there are registered 761 accidents with personnel injuries (Holmen et al., 2016). Figure 1.1 shows how occupational fatalities are connected with different operations in the period from 1982-2013 (Holmen, 2015). In 1982-1991, transport was the main cause of occupational fatalities, while it have developed towards lift operations being the main cause in the period 2002-2013. Drowning and hit by object are today the most common cause of deaths witinh the industry (Holmen et al., 2016).

Being one of the most dangerous industries in Norway, having challenges with lice and increasing production costs – it is important to assess systematically every operation with respect to both safety and efficiency. Larger vessels, heavier operations, together with more exposed sites makes operations more demanding and will reinforce this need. Many new concepts and methods are under development and will enter the market shortly, because of the development concessions. These will lead to unfortunate consequences if not safety is properly assessed. Therefore, in order to secure sustainable growth, it is more important than ever, to ensure health, safety and the environment (HSE) together with efficiency in operations.

1.2 Objective

SINTEF Fisheries and Aquaculture has earlier performed some projects regarding fish escapment and human safety, and lately a couple of new reasearch projects are looking into how the industry can be more safe and efficient. However, none published studies have systemtically defined the overall risk level for marine aquaculture operations. Neither looked into measures that can increase both efficency and safety.

To ensure safe and efficient marine operations, the objective of this thesis is to perform a Formal Safety Assessment (FSA) and a Continual Improvement Assessment (CIA) on different marine operations in the aquaculture industry. With larger and more exposed fish farms, larger vessels, new methods for threating salmon lice and lately new fish farm concepts, the industry is continually changing and new operations take place. The study shall give awareness of issues regarding risk, safety and efficiency in such operations in the aquaculture industry, and introduce recommendations in order to increase operational efficiency and HSE in marine aquaculture operations.

1.3 Structure

This master thesis is built up on several parts. The first part (Chapter 2-4) contains problem description, methodology, system description and data collection. The second part (Chapter 5-7) contains documentation of operations, a Formal Safety Assessment and a Continual Improvement Assessment. The third and last part (Chapter 8-10) contains recommendation, discussion and conclusion. The structure is illustrated in Figure 1.2.

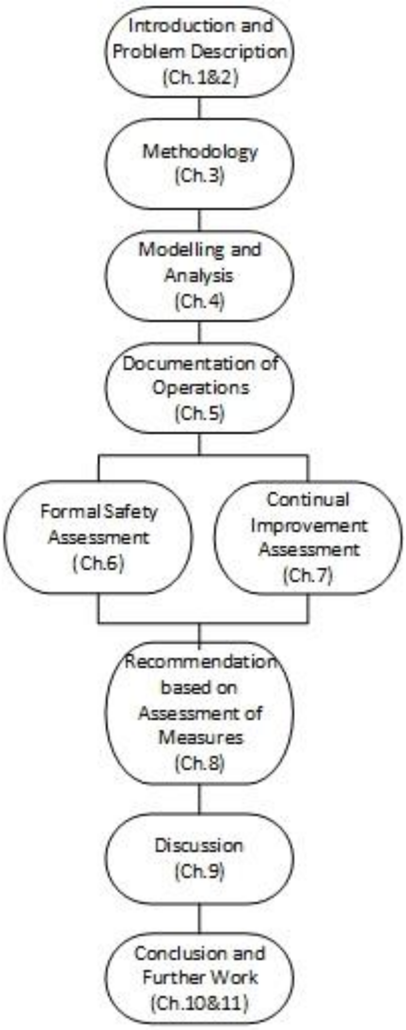


Figure 1.2: Structure of master thesis

In the first part, the focus is to explain the selected methodology and methods used to solve the problems. The problem description of this master thesis is elaborated in Chapter 2. In Chapter 3, the two methodologies, Formal Safety Assessment and Continual Improvement Assessment, are elaborated in detail. Further, the selected methods used in the two methodologies are explain. Chapter 4 contains a system description of generic service vessel and generic floating cage collars together with description of locality classification and environmental loads. Available statistics are presented and an explanation of software used are included in this chapter.

Chapter 5 contains documentation of the three operations; net cleaning, delousing and service and maintenance of floating collar, attended during this master thesis. In Chapter 6, the first part of the Formal Safety Assessment is performed, including hazard identification, risk analysis and establishment of risk control measures. Chapter 7 contain the Continual Improvement Assessment, including analyse and improvement of individual activities and improvement of the overall equipment effectiveness in the operations.

Chapter 8 contains the last part of the Formal Safety Assessment, but is combined into control options with measures from the Continual Improvement Assessment. These control options are assessed by re-evaluate the risk picture from the risk analysis in order to make recommendations for decision-makers. Chapter 9 discuss the findings. In the final Chapters 10 and 11, a conclusion and suggestions for further work are included.

1.4 Limitations

The limitations in this master thesis are related to the definition of generic vessel and floating collar, type of operations, the operations attended, limitation in available data and lack of previous work.

In the system description, the generic vessel is limited to service vessels used in the industry. The generic floating net collar is limited to circular floating HDPE cages, which is most common today. However, the risk assessment and improvement assessment can, by few changes, be adopted for other vessels and net cages used in the industry. Furthermore, some of the suggested recommendations will have synergy effects to other parts of the industry although it is based on the given system description.

The marine operations are limited to operations where net cage and service vessel is involved. Further, the assessments are limited to the three attended operations pointed out by the collaborating companies. These are service and maintenance of floating collars, delousing with tarpaulin and net cleaning. The operations demand many work hours, are performed regularly and/or demands many people and vessels to participate. Human interaction is therefore central in all the operations.

Limitation in available data has limited the causal and frequency analysis to contain a simplified frequency analysis. This, together with simplifications and expert judgement in the consequence analysis might affect the result in the risk analysis.

There are not found any previous Formal Safety Assessments or Continual Improvement Assessments of operations in the aquaculture industry. It is neither found any previous studies performing a combination of a risk and continual improvement assessment, neither in the aquaculture industry nor in any other industry. It has therefore been challenging to perform this study. Furthermore, it sets a limitation to the discussion of results and in determining whether the results are credible or not.

2 Problem Description

The aquaculture industry is the second most dangerous industry to work in after the fishery industry. The industry has experienced several accidents causing injuries and some accidents ending with fatalities. In addition, the industry is facing several challenges with lice, area restrictions, fish escapement, increased production costs and the last couple of years a reduction in the annual production growth.

In order to secure continued production growth, the industry is facing and already going through several changes. The fish farms are larger and tends to be established more exposed. In order to meet the increasing demands, as harsher environment and heavier equipment, the vessels are built larger. The Norwegian government has in addition lately introduced development concessions in order to arrange for innovation and technology development that can contribute to solve one or several of the environmental and area challenges and thus contribute to future production growth.

The fight against salmon lice and the chase of increased production growth might come at the sacrifice of ensuring good planning of safe and efficient operations. More exposed and harsh environment, heavier equipment and larger vessels, new technology and lately the introduction of completely new fish farm concepts, has and will in the future lead to new methods to perform different operations. Instead of standardising the technology used and the operations performed, this can lead to new hazards, inefficient operations and further increase in production costs.

To meet these challenges, the objective and problem definition of this master thesis is to:

- Investigate whether the service vessels used in the aquaculture industry and the floating cage collars are fitted to each other to create optimal working condition with respect to both operational efficiency and HSE.
- Investigate measures on both the vessels and the floating cage collars, which can improve both operational efficiency and HSE.

For the purpose of this report, HSE is defined as health and safety for personnel, and safety of property and environment.

The problem definition is established in collaboration with Aqualine AS and AQS AS.

2.1 Case – AQS Loke

A fatal accident during an anchor handling operation south of Hitra in Sør-Trøndelag in 2013 was awful for the aquaculture industry and contributed to introduce changes. Accident Investigation Board Norway (AIBN) (2015) investigated the accident with the service vessel Stålbjørn where one of two crewmembers died from injuries during an anchor handling operation. A mooring line slipped over the guide pin due to wave movements in the vessel and hit one of the crewmembers with great force on the upper body. The triggering factor to the accident was found to be that the mooring line moved across the guide pin at the same time as the crewmember was positioned in a hazardous zone on the vessels deck. AIBN (2015) identified the company's work procedure to be inadequate, and the job safety assessment had not identified the relevant hazards during the operations. The company had neither full overview of the crew's actual competence and training, nor did the training system assure that the crew had the competence needed to perform the different operations.

In dialogue with Sigurd Bjørgo, Advisor and Aquaculture Contact in Sør-Trøndelag county authority, Bjørgo (2016) pointed on some of the changes in the years after the accidents. The use of and need for a professional company to perform demanding operations has become more usual. The large and demanding operations are today mostly done by service companies rather than the fish farmers. Together with the lice problems, these service companies have grown significantly. The service companies have contributed to develop new technology and specialised vessels in order to perform the operation more efficient and safe.

Few published research projects have looked into design for safe and efficient operations. AQS AS has however, together with the supplier industry, worked goal-oriented in order to design a service vessel with improved safety and efficiency measures for anchor handling operations. AQS (2014) has in 2014, in collaboration with Gråfjord Mekaniske Verksted, designed and built AQS Loke, which has several safety and efficiency features. The vessel is AQS most modern and largest service vessel with length of 25.5 meter and a breadth of 12 meter. The vessel is specialized for anchor handling operation, and is equipped with two large cranes (150 t/m), one 60 tons winch which can measure the pulling force and several smaller capstans.

In order to secure safe and efficient anchor handling operations the vessel is fitted with specialised arrangements from SHM Maritime. The vessel is equipped with remotely control system of guide pins, designed to block unwanted movements or slipping of the mooring lines (AQS, 2014). This system can therefore prevent similar accidents as with the vessel Stålbjørn. Further, the vessel is equipped with SHM mooring plate lock in order to be able to lock the plate safely on the vessel deck reducing the risk of accidents. In addition to anchor handling, Furthermore, AQS Loke is designed to be a flexible service vessel enabling it to quickly change from performing one operation to another, increasing the efficiency of the vessel. It is among others, designed to bring five containers of hydrogen peroxide for delousing operations.

3 Methodology

This chapter covers the description of various methodologies and methods used in this master thesis. First, the approaches of the two methodologies, Formal Safety Assessment and Continual Improvement Assessment, are explained. Lastly, the selected methods used in the assessments are explained.

3.1 Formal Safety Assessment

3.1.1 Introduction

Formal Safety Assessment is a rational and systematic process for assessing the risk associated with any sphere of activity, and for evaluating the costs and benefits of different risk control options (RCO). Its aim is to enhance maritime safety including protection of life, health, the marine environment and property (IMO, 2013). International Maritime Organisation (IMO) (2013) has developed guidelines for FSA studies including five steps:

1. Identification of hazard
2. Risk analysis
3. Identifying risk control options
4. Cost-benefit assessment
5. Recommendations for decision-making

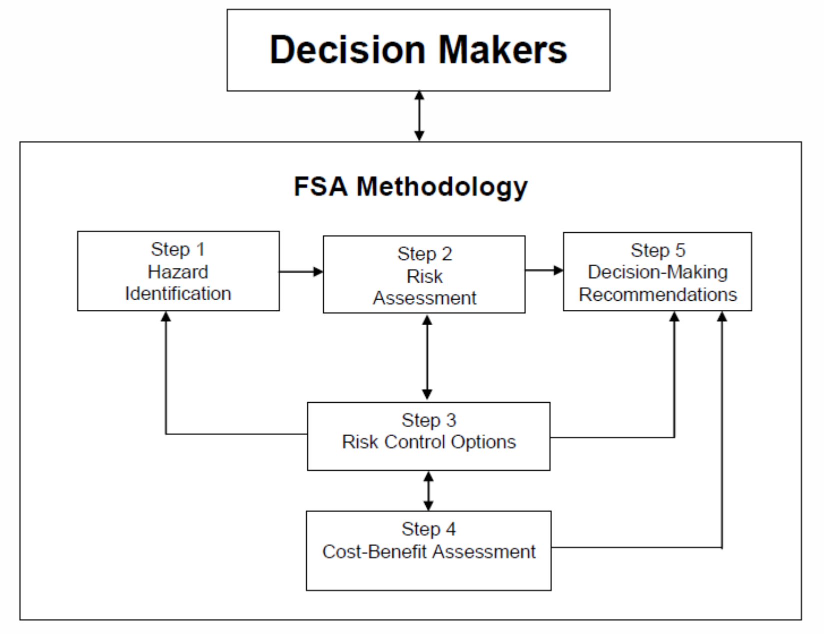


Figure 3.1: Flow chart of FSA methodology (IMO, 2013)

Figure 3.1 illustrate the flow chart of the methodology and shows the relation between the different steps. The FSA guideline is developed by IMO for evaluation of new regulations or comparison between existing and improved regulations (Kristiansen, 2005, IMO, 2013, Vanem et al., 2008). However, the methodology is a comprehensive method to systematically evaluate and improve the risk in a system and to give recommendations to a specific industry or company independent of rule makers (Wang and Pillay, 2003). Wang and Pillay (2003) reason that the FSA may:

1. Improve the performance of the current fleet, be able to measure performance change, and ensure that new ships are good designs.
2. Ensure the experience from the field is used in the current fleet and that any lessons learned are incorporated into new ships.
3. Provide a mechanism for predicting and controlling the most likely scenarios that could results in incidents.

Beside been used to evaluation of IMO rules, the methodology has been used to improving and developing classification rules and as a safety assessment of individual ships (Kristiansen, 2005).

The FSA methodology is quite complex and involves a range of different techniques that will be described in the following sections. The steps have to be followed, as results from one step often are used as feedback and input into the following step (Kristiansen, 2005).

3.1.2 Generic Model

Before performing a FSA, a proper problem definition must be established. The problem definition should define the bounds of the study and a generic model (IMO, 2013). Rules and regulations must apply to ships or areas on a general basis, and the use of generic model is therefore used in the FSA approach. A generic model should be defined to describe functions, features, characterises and attributes which are common to all ships or areas relevant to the problem in question (IMO, 2013).

> "The generic model should not be viewed as an individual ship in isolation, but rather as a collection of systems, including organizational, management, operational, human, electronic and hardware aspects which fulfil the defined functions. The functions and systems should be broken down to an appropriate level of detail. Aspects of the interaction of functions and systems and the extent of their variability should be addressed (IMO, 2013)."

3.1.3 Step 1 – Hazard Identification

Hazard identification involving "the process of identifying and describing all the significant hazards, threats, and hazardous events associated with a system (DEF-STAN 00-56, 2007)". The aim of Step 1 is, thus, to identify possible hazards and associated scenarios, which can affect the object under consideration (IMO, 2013). The identified hazards and associated scenarios should further be prioritized by risk level specific to the problem under review (IMO, 2013).

The objective of a process of hazard identification is according to Rausand (2011):

a) Identify all the hazards and hazardous events that are relevant during all intended use and foreseeable misuse of the system, and during all interactions with the system.
b) Describe the characteristics, and the form and quantity, of each hazard.
c) Describe when and where in the system the hazard is present.
d) Identify possible triggering events related to each hazard.
e) Identify under what conditions the hazard could lead to a hazardous event and which pathways the hazard may follow.
f) Identify potential hazardous events that could be caused by the hazard (or in combination with other hazards).
g) Make operator and system owner aware of hazards and potential hazardous events.

3.1.3.1 Approach

The hazard identification may follow an approach of two phases (IMO, 2013, Kristiansen, 2005):

1. Hazard identification
2. Hazard screening

The first phase, hazard identification, comprises a combination of creative and analytical techniques to ensure both a proactive process together with a process learning from the past (IMO, 2013). One approach to identify potential hazards may be use of brainstorming sessions and/or use of hazard checklists.

Hazard screening or ranking is the second phase, and involves structuring the previous phase. The aim is to rank the identified hazards according to consequence and frequency in order to prioritise them and to discard scenarios found to be of minor significance (IMO, 2013). Last, the findings shall be structured and grouped into generic accident categories for further assessment in Step 2 (IMO, 2013, Kristiansen, 2005)

Several methods including both these phases are available and are listed in the following section.

3.1.3.2 Available Methods

Different methods can be used to identify hazards in the marine operations, such as Preliminary Hazard Analysis (PHA), Change Analysis, Failure Modes, Effects, and Criticality Analysis (FMECA), Hazard and Operability analysis (HAZOP), Structured What-If Technique (SWIFT), Master Logic Diagram (MLD), Boolean Representation Method (BRM) and Simulation analysis (IMO, 2013, Rausand, 2011).

The method should be able to rank the identified hazards by use of clearly defined categories of frequency and consequence. The ranking should be performed to be able to prioritize scenarios relevant for the problem under consideration and to discard scenarios that are of minor significance to the problem (IMO, 2013).

3.1.4 Step 2 – Risk Analysis

The purpose of the risk analysis is to perform a more detailed analysis of the causes and consequences of the most important scenarios identified in the hazard identification in Step 1. The main aim of the risk analysis is to estimate the risk to individuals, property, and the environment involved in the operations (IEC 60300-3-4, 2007).

The risk analysis is carried out to give answers to three main questions (Kaplan et al., 1981):

1. What can go wrong?
2. What is the likelihood of that happening?
3. What are the consequences?

In a FSA, the question “What can go wrong?” were answered in Step 1 through the hazard identification. The purpose of the risk analysis, in view of FSA, is in other words to answer the two last questions by performing a more detailed analysis of causes and initiating events and consequences of the most critical hazardous events identified in Step 1 (IMO, 2013).

3.1.4.1 Approach

A risk analysis can be either qualitative, semi-quantitative or quantitative and the choice of method may depend on the level of failure data available, the scope of the FSA and which types of hazards that were identified in Step 1 (IMO, 2013, Rausand, 2011). However, a risk analysis in FSA shall be quantitative and if there is lack of data – calculation, simulation or expert judgement should be used (IMO, 2013).

To realize the full potential of a risk analysis, it should involve following two main steps:

1. Causal and Frequency Analysis
2. Consequence Analysis

These are further described in the following sections.

3.1.4.2 Causal and Frequency Analysis

The goal of the Causal and Frequency Analysis is to answer the second question, "What is the likelihood of that happening?", by identify the causes of each hazardous event and to calculate the frequency of the hazardous event to further use in the consequence assessment (Rausand, 2011).

The objective of the Causal and Frequency Analysis is according to Rausand (2011) to:

a) Determine the causes of the defined hazardous event.
b) Establish the relationship between the hazardous event and the basic causes.
c) Determine the frequency of the hazardous event based on a careful examination of the basic causes and the causal sequences.
d) Determine how important each cause is in relation to the frequency of the hazardous event.
e) Identify existing and potential proactive barriers and evaluate the effectiveness of each barrier and the barriers in combination.

There are different methods, both qualitative and quantitative, available for selection for a Causal and Frequency Analysis. This include among others: Cause and Effect Diagram, Fault Tree Analysis (FTA), Bayesian Networks, Markow methods and Petri Nets. Choice of method should be based on purpose of the study.

The different methods have their strengths and weaknesses. Some are more suitable for the problem in question than others are, while some are more preferred methods in the FSA approach. FTA is the most commonly used method for Causal and Frequency Analysis and is well suited for handling complex systems involving both technical faults and human errors. However, it may lose its clarity when systems not fall into simple failed or working states as e.g. human error and bad weather (Rausand, 2011). In such situations the Bayesian networks is more flexible than FTA. On the contrary, the Bayesian network is much more time consuming and less used method compared to FTA.

3.1.4.3 Consequence Analysis

The goal of the Consequence Analysis is to answer the last question in the Risk Analysis, "What are the consequences?" by developing accident scenarios. By establish a sequence of events that can develop from the hazardous event and their probability of happening, the potential consequence can be identified (Rausand, 2011).

The objective of the Consequence Analysis is according to Rausand (2011) to:

a) Determine the possible accident scenarios (event sequences) that can possibly take place after a specified hazardous event has occurred.
b) Identify external events or conditions that can influence each accident scenario.
c) Determine and describe the possible end events of each accident scenario.
d) Determine the consequences of each end event (and accident scenario).
e) Determine the probability of each end event and the frequency of each accident scenario.

There are different methods available for selection for a Consequence Analysis. This include among others: Event Tree Analysis (ETA), Event Sequence Diagrams, Cause-Consequence Analysis and Consequence Models. Choice of method should be based on purpose of the study.

The results from the Causal and Frequency and Consequence Analysis gives raise to the total risk picture and shall identify the high-risk areas that need to be addressed further in Step 3 of FSA, by proposing Risk Control Options. Further, according to IMO (2013) FSA guidelines a risk acceptance criteria must be defined in order to evaluate the risk.

3.1.4.4 Risk Acceptance Criteria

The risk estimated in the Risk Analysis in Step 2, should be evaluated by defining appropriate risk acceptance criteria. The criteria should be established independent of the actual risk analysis and hence be established prior to the risk analysis (Vanem et al., 2008). The As Low as Reasonably Practicable (ALARP) principle is a commonly accepted principle and is recognized as the current best practice by IMO (2013). The ALARP principle provides a framework for both analysing risk and a method to determine the cost-effectiveness of the risk-reducing measure (Rausand, 2011). Thus, it is suited to fulfil the purpose of FSA, which is to reduce the level of risk to a level that is tolerable.

The ALARP principle divides risk into three levels, as illustrated in Figure 3.2 (HSE, 2001):

- An unacceptable region, where risks are intolerable and risk-reducing measures are mandatory.
- An ALARP region, where risk-reducing measures should be implemented as long as the cost is not disproportionate to the benefits gained.
- A broadly acceptable region, where no further risk-reducing measures are necessary and considered uneconomical.

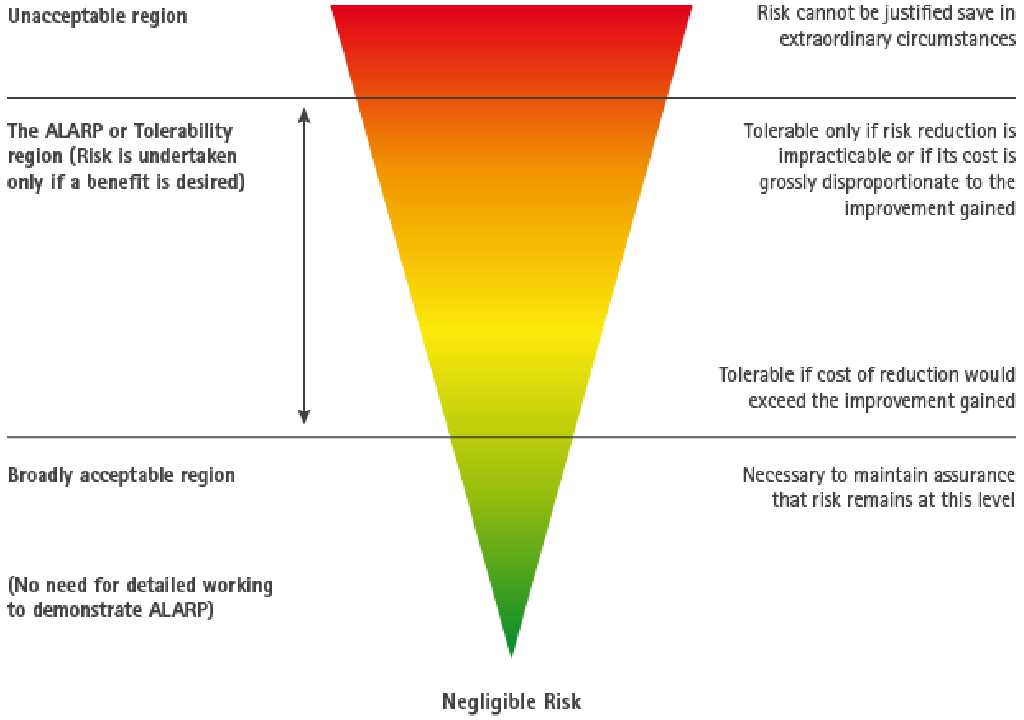


Figure 3.2: ALARP principle (Rausand, 2011)

The risk acceptance criteria is often divided between individual and societal risk acceptance criteria and use of one or both of them depends on the system under consideration.

Individual risk is used to estimate the risk from an accident experienced by a particular individual at a given location (IMO, 2013). The criteria for individual risk is most appropriate if individual or a group of individuals are exposed to occupational risk due to e.g. work-related hazards (MSC, 2008).

Societal risk is expressed by frequency versus number of fatalities and is often graphically presented in a risk matrices or FN-curves (MSC, 2008). The risk matrices or FN-curves can be connected to the ALARP principle to show if the level of risk are acceptable or not. System or activities having a wider scope may use Potential Loss of Lives (PPL), which combine frequency and fatality into a one-dimensional measure of societal risk (MSC, 2008, IMO, 2013). However, societal risk is most appropriate to use for larger systems where accidents can affect several persons (MSC, 2008).

3.1.5 Step 3 – Risk Control Options

The purpose of Step 3 is to propose potential Risk Control Options (RCO) on areas identified in Step 1 and 2 that need control and that address both existing risks and risks introduced by new technology or new methods of management and operation (IMO, 2013).

3.1.5.1 Approach

The objective of the Step 3 – Risk Control Options are to (IMO, 2013, Kristiansen, 2005):

a) Focusing on risk areas needing control.
b) Identifying potential Risk Control Measures (RCM).
c) Evaluating the effectiveness of the RCMs in reducing risk by re-evaluating Step 2.
d) Grouping RCMs into practical regulatory options.

In deciding which area that is most in need of risk control, following aspect according to IMO (2013) FSA Guidelines can be followed:

1) Risk level, by considering frequency of occurrence together with the severity of outcomes. Accidents with an unacceptable risk level become the primary focus and RCO must be implemented in order to make the risks acceptable and ALARP. Risks within the ALARP region should be implemented if the benefits are desired and its cost is not grossly disproportionate to the improvements gained.
2) Probability, by identifying areas that have the highest probability of occurrence. These should be addressed irrespective of their severity of the outcomes.
3) Severity, by identifying areas that contribute to highest severity outcomes. These should be addressed irrespective of their probability.
4) Confidence, by identifying areas where there is considerable uncertainty in either risk, severity or probability.

Potential risk control measurers can address technical, human and management aspects of an operation. The measures may address both the prevention of the accident and the mitigation of the consequence severity through effect on single or several hazards or the whole operation (Kristiansen, 2005).

Identified potential RCMs should be evaluated regarding to their risk reduction effectiveness, and potential side effects should be considered. According to IMO (2013) FSA guidelines, the RCMs should further aim at one or more of the following:

1) Reducing the frequency of failures through better design, procedures, organizational policies, training etc.
2) Mitigating the effect of failures, in order to prevent accidents.
3) Alleviating the circumstances in which failures may occur.
4) Mitigating the consequences of accidents.

The last phase is to group RCMs into practical and well-thought Risk Control Options. It might be helpful to group the RCMs into RCOs in different categories based on practical type of regulatory options that can be used, and/or based on their effects on the system or activity under consideration (Kristiansen, 2005).

Potential side effects of the RCOs should be documented and when adopting a combination of RCOs – a qualitative evaluation of interdependencies between the RCO is useful and may take form as a matrix as illustrated in Table 3.1:

Table 3.1: Example of interdependencies of RCOs (IMO, 2013)

RCO	**1**	**2**	**3**	**4**
1		Strong	No	Weak
2	Weak		Weak	No
3	No	Weak		No
4	Weak	No	No	

3.1.6 Step 4 – Cost-Benefit Analysis

The purpose of Step 4 – Cost-Benefit Analysis (CBA) is to identify and compare costs and benefits of the RCOs identified in Step 3, and to determine whether the benefits outweighs the cost or not (IMO, 2013). IMO (2013) propose following approach in the FSA Guidelines for the CBA:

1) Consider the risks assessed in Step 2, both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration.

2) Arrange the RCOs, defined in Step 3, in a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO.
3) Estimate the pertinent costs and benefits for all RCOs.
4) Estimate and compare the cost-effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option.
5) Rank the RCOs from a cost-benefit perspective in order to facilitate the decision-making recommendation in Step 5.
6) Consider a sensitivity analysis and uncertainty analysis of the CBA and cost-effectiveness.

The two first stages are a problem definition of the CBA, based on the two previous step in the FSA. The boundaries from these previous steps should be implemented in the CBA in addition to geographical and base-line year boundaries (Kristiansen, 2005).

In stage 3, pertinent costs and benefits for all RCOs shall be identified and quantified. These may not only be positive effects, and potential negative effects must be evaluated and included. Costs shall be expressed in terms of life cycle costs and typical costs can according to Kristiansen (2005) be: capital/investment cost, installation and commissioning cost, operating or recurrent cost, labour cost, maintenance, training, inspection, certification and auditing and/or downtime or delay cost. Further Kristiansen (2005) reasons that benefits from implementing RCOs may be: reduced number of injuries and fatalities, reduced casualties with vessel, including damage to and loss of cargo and damage to infrastructure (e.g. berths), reduced environmental damage, including clean-up costs and impact on associated industries such as recreation and fisheries, increased availability of assets, reduction in costs related to search, rescue and salvage and/or reduced cost of insurance.

In the fourth stage, the cost-effectiveness of each RCO shall be compared and evaluated. A criterion for cost-effectiveness has to be established to be able to determine what is reasonable practicable in the ALARP principle. In the maritime safety regulation, Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF), defined by Equation (1) and (2), are often used (MSC, 2008).

$$GCAF = \frac{\Delta C}{\Delta R} \tag{1}$$

$$NCAF = \frac{\Delta C - \Delta B}{\Delta R} = GCAF - \frac{\Delta B}{\Delta R} \tag{2}$$

where ΔC is the marginal cost of the risk control option (RCO), ΔR is the risk reduction and ΔB is the economic benefit from implementing the RCO. Both concepts are used to evaluate the ratio of cost to the reduction in risk to personnel. NCAF is in addition, taking account for possible economic benefit. Based on IMO (2013) FSA Guideline, the RCO should be implemented if NCAF $\leq$ GCAF $\leq$ USD 3 million $\approx$ NOK 26 million (Exchange rate, 02.03.2016: USD 1 = NOK 8.67).

In the two last stages, the RCO shall be ranked in order to facilitate the decision-making recommendation in Step 5. In addition, the uncertainty and sensitivity of the analysis should be assessed.

3.1.7 Step 5 – Recommendations for Decision-Making

The purpose of Step 5 – recommendations for decision-making, is to define recommendations to the relevant decision makers on which RCO(s) that should be implemented in order to reduce the overall risk level (IMO, 2013). All information from Step 1-4 is relevant in establishing the results from Step 5, which according to IMO (2013) FSA guideline shall include:

1. An objective comparison of alternative options, based on the potential reduction of risks and cost-effectiveness, in areas where legislation or rules should be reviewed or developed.
2. Feedback information to review the results generated in the previous steps.
3. Recommended RCO(s) accompanied with the application of the RCO(s), e.g. application of ship type(s) and construction date and/or systems to be fitted on board.

3.2 Continual Improvement Assessment

3.2.1 Introduction

Generally, a Continual Improvement Assessment includes several concepts from the lean philosophy. The lean philosophy involves approaching production on an analytical way, where you reduce all that is unnecessary in the system, and at the same time maximizes the value for the customer (Koskela, 1992). Lean is centred on pointing out what adds value by reducing everything else (Womack and Jones, 2003). The philosophy is derived from the Toyota

Production System and was identified as “lean” in the 1990s (Womack et al., 1990, Holweg, 2007). Industries have traditionally tried to increase productivity by “cost cutting”, thus reducing labour and other essential elements. However, Moore (2011) reasons that things can be done in a better way with what you have at disposal by choosing Lean to analyse the system. Lean comprise both efficiency and quality including all that bring value to the customer (Baskoro, 2014).

In traditional lean, there are generally five principles that can summarize the approach (Moore, 2011, Womack and Jones, 2003, Lean). The five principles are shown in Figure 3.3 and indicates that lean is a continuous process. Step 1 is to specify what value is for the customer. Step 2 is to identify all the steps in the value chain and eliminate waste. Step 3 is to make the value-creating steps occur in a tight sequence. This will induce a smooth flow in the process. Step 4 is to establish pull and to involve the employees and give them influence and impact. Step 5 is to continually look for improvements by repeating the process to seek perfection.

Figure 3.3: The five principles of lean (Lean, 2015)

Lean has traditionally been used for manufacture lines, but is lately successfully introduced to all kind of industries and services. One model based on the lean philosophy is the KOSTER III Model, which will be presented in Section 3.2.2.

3.2.1.1 Lean Concepts

One very important concept in Lean is the concept of value. Value is determined by the customer and is defined as the worth of goods, services, or both (Sayer and Williams, 2012). Worth can among others, be expressed in terms of money, an exchange, a utility or a merit (Sayer and Williams, 2012). Value creation is the process of developing and delivering products or services that the customer wants and is willing to invest in (Sayer and Williams, 2012). In every process in a company, there is activities that either adds value or not adds value. In terms of Lean, non-value-added activities are described by the three *Ms – muda, mura and muri* (Sayer and Williams, 2012).

Muda (waste) is an activity that consumes resources without creating value for the costumer. Muda can be divided into two types:

- Type 1 muda is an activity that do not creates value for the costumer, but are deemed necessary for the process.
- Type 2 muda are all activities that do not create value for the costumer and that are unnecessary for the process.

Mura (unevenness) is waste caused by variation in quality, cost, or delivery (Sayer and Williams, 2012). Such activities can be the cost of testing, inspection, containment, rework, returns, overtime, and unscheduled travel to the customer.

Muri (overdoing) is the unnecessary or unreasonable overburdening of people, equipment, or systems by demands that exceed capacity (Sayer and Williams, 2012). This can be an activity require repeatedly movements that are harmful, wasteful, or unnecessary. Ergonomic evaluation and detailed job analysis can be used to eliminate such movements that are harmful or unnecessary.

The customer is in Lean defined as "the person or entity who is the recipient of the product or services that are produced", while a consumer is defined as "one who obtains goods and services for his own use (Sayer and Williams, 2012)." The customer is therefore not necessary the consumer of the product or service that are produced and it may in some cases be important to keep in mind that customers and consumers may define value in different ways.

As the customer is the person or entity who is the recipient of the product or services that are produced, it is the customer who place the value on the company's outputs. It is therefore important to assess who actually is the customer and what outputs the company's process is producing. The customer will, based on many requirements and decision criteria, buy the option they believe gives the best overall value for them (Sayer and Williams, 2012). The greater the outputs of the process fulfil the customer's requirement, the greater are the customer's satisfaction and hence the greater the customer's attributed value.

3.2.2 KOSTER III Model

KOSTER III Model, as shown in Figure 3.4, is developed by the Norwegian Defence and Research Establishment (FFI) and is a model for Continual Improvement of processes and operations (Kvalvik et al., 2011). The model includes three stages:

1. Establish and revise goals
2. Assessment of requirements and reprioritizing of activities.
3. Improvement of individual activities.

Figure 3.4: KOSTER III model (Kvalvik et al., 2011, adapted)

3.2.3 Step 1 – Establish Goals

According to Kvalvik et al. (2011) the first step shall answer the following three questions:

1) What are the most important outputs the company shall achieve?
2) What is the most important performance measures the company shall carry out to achieve these outputs?
3) What is the level of ambition for the different performance measures?

By establishing and revise goals, and to define the activity's main goals, production goals and level of ambition of the company, these questions are answered. This will ensure that the company can reach its goals and make it possible to assess different activities against each other (Kvalvik et al., 2011).

3.2.4 Step 2 – Assessment of Requirements and Reprioritizing of Activities

The second step in the KOSTER III model is to assess whether the activities in the company, and the composition of these, are fitted to reach the objectives defined in Step 1 or not (Kvalvik et al., 2011). According to Kvalvik et al. (2011), this can be assessed by answering the following three question:

1) Is the balance between the company's activities suited for reaching the goals?
2) Is the level of ambition of the different production goals in agreement with the requirements?
3) Is it possible to achieve the main goals in a better way by changing the reciprocal prioritising of the production goals?

This can be assessed by carry out a requirement analysis, which will make a foundation for the company to reprioritise the activities within the company. The requirement analysis should include the following four stages (Kvalvik et al., 2011):

1) Interview of important decision-makers to get feedback on Step 1 and how thing can be done differently by reprioritising activities.
2) Survey of external stakeholders and/or internal process leaders to find out what they are dissatisfied and satisfied with, or what activity that can be given a lower priority to.
3) Value analysis to document the activities in the company into three categories: productive, partly productive and not productive.
4) Synthesis of the three previous stages by categorising the activities in the company into a requirement-importance matrix as shown in Figure 3.5.

		Importance	
		Low	**High**
Requirement	**Uncovered**	Continue	Consider increase
	Covered	Consider reduction	Keep if possible

Figure 3.5: Requirement-importance matrix (Kvalvik et al., 2011, adapted)

The results from Stage 4 in the requirement-importance matrix shall form two lists of the activities in the company. List A contain a ranking of the activities that are assessed as least covered, and where increased use of resources will give largest profit (Kvalvik et al., 2011).

List B contain a ranking of the activities that are assessed as best covered, and where cost reduction will give least consequence for the company's solving of tasks (Kvalvik et al., 2011).

3.2.5 Step 3 – Improvement of Individual Activities

The last step in the KOSTER III model is to evaluate individual activities or processes in the company to assess if they are performed optimal. This step includes five stages (Kvalvik et al., 2011):

1. Mapping the process.
2. Establish key performance indicators.
3. Analysis of the process.
4. Generate improvement measures.
5. Implementation of measures.

3.2.5.1 Stage 1 – Mapping the Process

The purpose of Stage 1 is to get a good understanding of the situation in the company. The stage starts with the whole company, before individual processes are mapped. The stage includes four phases (Kvalvik et al., 2011):

1) Mapping of the company.
2) Choose processes for further analysis.
3) Map the individual process.
4) Draw flow charts of the individual process.

Phase 1 – Mapping of the Company

The purpose of this phase is to visualise all the processes that exist within the company through main and support processes, by drawing a general process chart of the company (FFI). This shall not include individual working processes, only the processes within the company. Figure 3.6 illustrate how this general process chart can be formed.

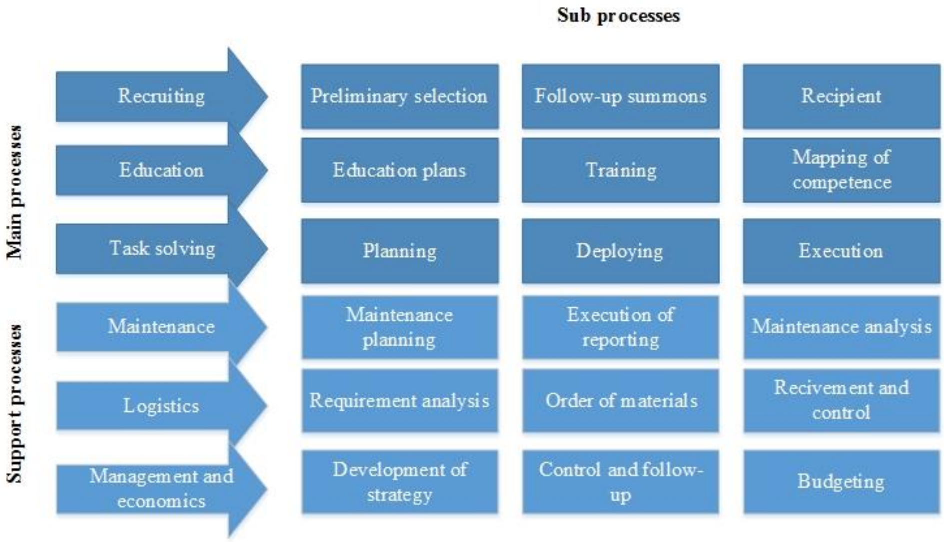


Figure 3.6: General process chart (Kvalvik et al., 2011, adapted)

Phase 2 – Chose Processes for Further Analysis

The purpose of this phase is to analyse the productivity in the company in order to select two or three processes where it is assumed largest improvement potential. The productivity can be analysed by assessing existing productivity measurements by answering following questions (Kvalvik et al., 2011):

1) Have the costs increased disproportionate much in any years? Moreover, what type of costs have increased?
2) Does the production vary between years? Is this caused by changes in production volume or in unstable quality?
3) Are there any units where it is possible to compare the productivity? Do these have lower or higher costs, do they produce more or do they have higher quality?

If productivity measurements are not available, other measurements and the knowledge of the improvement team should be used to select two to three processes (Kvalvik et al., 2011).

Phase 3 – Map the Individual Process

The purpose of this phase is to get knowledge of the process selected in Phase 2. Such knowledge can include input to and output from the process and whom the process delivers to. Furthermore, more detailed information about the process itself, supports systems and interference with other departments can be included (Kvalvik et al., 2011).

Phase 4 – Draw Flow Chart of the Individual Process

The purpose of this phase is to visualise all the details in the processes selected in Phase 2 and 3, and make a foundation to the analysis of the process in the next stage (Kvalvik et al., 2011). In order to make good flow charts, the following questions can be asked before starting up (Kvalvik et al., 2011):

1) What activity is the first activity in this process?
2) What activity is the next activity, and what activity follow thereafter?
3) Who take the decisions, if any, during the process?
4) Who is responsible for this activity?

3.2.5.2 Stage 2 – Establish Key Performance Indicators

The purpose of this stage is to ensure successful improvement initiative and to get a proper understanding of the present situation (Kvalvik et al., 2011). At least one measurement and one performance indicator for each of the processes selected for further analysis, must be identified or established in order to describe the performance of the processes.

3.2.5.3 Stage 3 – Analyse the Process

The purpose of the stage is to investigate the processes in order to find problems where there is waste (ref. Section 3.2.2.1) (Kvalvik et al., 2011). By identifying problems and their causes, it is possible to propose possible measures. This phase may be separated into three phases (Kvalvik et al., 2011):

1. Identify areas of problems – critical events.
2. What is the cause of the problems?
3. Identify possible bottlenecks.

Phase 1 – Identify Area of Problems

The purpose of Phase 1 is to identifying possible areas of problem in the process (Kvalvik et al., 2011). The problems can be identified by studying the process and interview workers. Another approach can be to use the technique *Critical Events.* A critical event can typically be events that is most complicated to handle, events that cause large problems with respect to delivering results or events that cost most in form of additional resources and direct costs (Kvalvik et al., 2011). This technique is simple and involves three steps (Kvalvik et al., 2011):

1. Choose participants with good knowledge of the process.
2. Survey the 20 most critical events from the last year.
3. Analyse and graphically represent the events after frequency.

The most frequent events should be further investigated.

Phase 2 – What is the Cause of the Problems?

The aim of Phase 2 is to identify the causes of the problems identified in Phase 1, by using a Pareto diagram or Cause-Effect Diagram. After identifying the main causes, a five why-analysis should be performed to analyse the causal relation further (Kvalvik et al., 2011).

Phase 3 – Identify Bottlenecks

The purpose of Phase 3 is to identify potential bottlenecks. Only looking at the causes and overlook the bottlenecks, may lead to improve just some parts of the process without improving the total efficiency of the process (Kvalvik et al., 2011). A bottleneck can limit the efficiency in whole the process and, if any, they must be identified to improve the process. The bottlenecks can be identified by studying the process maps and flow charts.

3.2.5.4 Stage 4 – Generate Improvement Measures

The aim of Stage 4 is to use the knowledge adopted in the previous stages of the analysis to generate improvement measures that can increase the efficiency in the process. Depending on what the identified causes are, following four tools might be useful (Kvalvik et al., 2011):

1) Brainstorming – Always to be used
2) Streamlining – Use when production flow is inefficient
3) Ideal process – Use when many and complex challenges
4) Best practice – Use if there are other comparable processes within the company

3.2.5.5 Stage 5 – Implementation of Measures

The purpose of Stage 5 is to ensure good implementation and correct selection of the measures from Stage 4. This stage includes five phases (Kvalvik et al., 2011):

1) Sorting and prioritising
2) Organisation of implementation
3) Adapt goals
4) Development of implementation plan
5) Perform the implementation

Phase 1 – Sorting and Prioritising

The aim of Phase 1 is to sort and prioritise between the generated improvements measures from Stage 4. This is done in order to be able to implement the measures that is believed to have largest effect. Following criteria can be used (Kvalvik et al., 2011):

1) Investments necessary to introduce new a method or process.
2) Training necessary for workers to be able to perform the activities in the new process.
3) Limitation in available time to carry out the implementation.
4) The organisations level of motivation

By using a prioritising matrix, as illustrated in Figure 3.7, with degree of expected efficiency improvement and degree of difficulty of implementation on the axis, a prioritised list of improvement measures can be generated (Kvalvik et al., 2011).

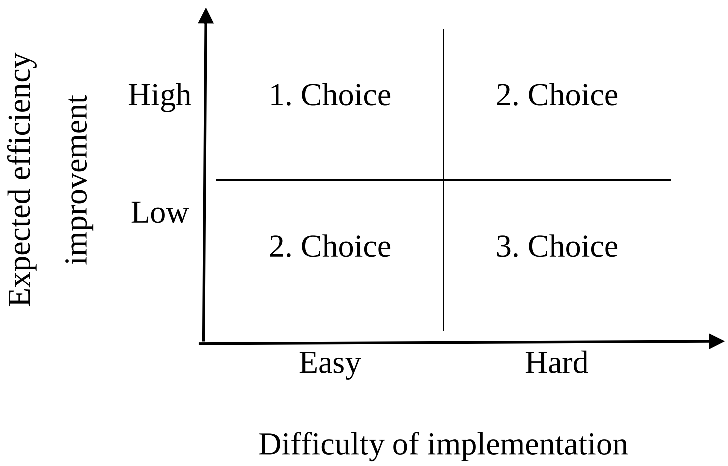


Figure 3.7: Prioritising matrix for improvement measures (Kvalvik et al., 2011, adapted)

Phase 2 – Organisation of Implementation

The aim of this phase is to decide who should be responsible for the implementation in order to ensure a successful implementation. There are several possibilities to choose from (Kvalvik et al., 2011):

1) The original improvement team – the advantage of this team is that they have good knowledge of the project and what the solutions involves.
2) Development of a new team – the advantage is that a new well-qualified team for the specific task can be selected and take responsible for the implementation.
3) Responsible line management – the advantage is that people with daily responsibility of the activity is responsible for the implementation.

Phase 3 – Adapt Goals

The aim of Phase 3 is to ensure that the implementation is not only successfully implemented, but that the activity or process has a goal to reach after in order to continue the improvement of the process (Kvalvik et al., 2011). An ambitious level of productivity must be established and followed up through reporting to the responsible for the implementation, the employer and the company (Kvalvik et al., 2011).

Phase 4 – Development of Implementation Plan

The purpose of Phase 4 is to ensure that the implementation is done correctly and implemented in a good way into the process through development of a proper project plan. Generally, the plan should contain which activities that shall be carried out, in which sequence, distribution of responsibility, time plan and estimation of implementation costs (Kvalvik et al., 2011). Proper planning of implementation processes will create acceptance and a good environment for the implementation. Furthermore, it is shown that it will increase the degree of a successfully implementation (Kvalvik et al., 2011).

Phase 5 – Perform the Implementation

When all Phases 1 to 4 is successfully established and performed, the implementation of measures can start and be followed up according to goals and plans (Kvalvik et al., 2011).

3.3 Methods

This section presents the analysis methods used in this report in order to carry out the Formal Safety Assessment and the Continual Improvement Assessment. The aim and approach of the methods is presented together with an examination of some relevant advantages and disadvantages of the methods.

3.3.1 Observation and Documentation

3.3.1.1 STEP

Sequentially Timed Event Plotting (STEP) diagram can be used to document operations in a structured way. In a STEP diagram the sequence of contributing events are plotted, starting with an undesired change in the system and ending with harm of an asset (Rausand, 2011). In addition to sequence including initiating and end event, the STEP includes actors, the flow in the process and a timeline. The method was developed as an accident investigation tool used to reconstruct an accident. However, it is also well suited to document an operation, and will therefore be used in this thesis. The initiating event will in this case, be the start of the observed operation, while the end event is the end of the observation.

3.3.2 **Risk Analysis**

3.3.2.1 Hazard Log

Hazard log is a useful tool to record information about hazards, and for keeping this information updated if more hazards are found (Rausand, 2011). The log can include all kinds of hazards that threatens the system's success in achieving its safety objectives (Rausand, 2011). It should be established early in the project and be updated when new hazards are discovered. A hazard log should describe the hazard and where it is present. It can also give further information available about the amount of the hazard and which triggering event it can release (Rausand, 2011).

3.3.2.2 Preliminary Hazard Analysis

Preliminary Hazard Analysis (PHA) is an analysis used to identify hazards and potential accidents in a system, and therefore well suited to use in this report. The PHA is often used early in the process of assessing risk, hence the name "preliminary", and is usually followed by more comprehensive studies (Rausand, 2011).

The main advantages of the PHA are that (Rausand, 2011):

- Is simple to use and requires limited training.
- Is a necessary first step in most risk analysis.
- Identifies and provides a hazard log and their corresponding risks.
- Can be used early enough to allow for design changes.
- Is a versatile method that can cover a range of problems.

The principle of the method is to identify hazards that may develop into accidents (Kristiansen, 2005). The objectives are (Rausand, 2011):

a) Identify the assets that need to be protected.
b) Identify the hazardous events that can potentially occur.
c) Determine the main causes of each hazardous event.
d) Determine how often each hazardous event may occur.
e) Determine the severity of each hazardous event.
f) Identify relevant safeguards for each hazardous event.
g) Assess the risk related to each hazardous event.

h) Determine the most important contributors to the risk.

By doing this, it makes it possible to remove, reduce or control the identified hazards in an existing system or early in a system under development.

The main aim of the PHA is to provide input to the risk analysis in Step 2 of the FSA, by investigate and identify hazards and to rank them according to frequency and consequence. Appropriate frequency classes and consequence categories must be established according to the scope of the study (IMO, 2013).

To assign risk level to each combination of frequencies and consequences of events, the risk matrix in Table 3.2 is used in this thesis. Following the IMO (2013) FSA guideline, the risk level assigned in the table are defined on a logarithmic scale defined by Equation (3) and (4):

$$Risk = Probability * Consequence \tag{3}$$

$$\log(Risk) = \log(Probability) + \log(Consequence) \tag{4}$$

Table 3.2: Risk matrix (Rausand, 2011)

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent	5	6	7	8
3	Occasional	4	5	6	7
2	Possible	3	4	5	6
1	Unlikely	2	3	4	5

3.3.2.3 Event Tree Analysis

For the Consequence Analysis, it is necessary to develop accidents scenarios. There are several methods available to help identify and describe the possible pathway from a hazardous event (HE) to one or more assets. However, the most commonly used method is Event Tree Analysis (ETA) (Rausand, 2011).

An event tree presents the event sequence following from a HE to the consequence spectrum. ETAs advantage is that it easily identifies system weaknesses and it provides a good basis for evaluating new or improved barriers (Rausand, 2011). However, its limitations are that only one HE can be analysed at a time and it does not permit partial successes or failures (Rausand, 2011).

The principle of ETA is to develop a logical diagram that describes the relation between an initiating event and the possible consequences, and it is a quantitative method for estimation of consequence probabilities (Kristiansen, 2005). The first step is to define the initiating event, which is the first sequence of events leading to an accident (Kristiansen, 2005). Then the safety systems and mechanisms that function as barriers are established in chronological order, and the probabilities for the outcomes of each dichotomy event (e.g. the success of a barrier) are estimated (Kristiansen, 2005). A barrier is also called defences, safeguards or safety functions, and can include technical equipment, human interventions, emergency procedures, or combinations of these, and may range from complex safety systems to simple devices (Rausand, 2011).

The main objectives of ETA are to (Rausand, 2011):

1. Identify the accident scenarios that may follow the hazardous event.
2. Identify the barriers that are (or planned to be) provided to prevent mitigate the harmful effects of the accident scenarios.
3. Assess the applicability and reliability of these barriers in relevant accident scenarios.
4. Identify internal and external events that may influence the event sequences of the scenario – or its consequences.
5. Determine the probability of each accident scenario.
6. Determine and assess the consequences of each accident scenario.

3.3.2.4 Consequence Spectrum

A hazardous event may lead to a number of potential consequences. The probability that a consequence will occur depend on the success of the barrier (Rausand, 2011). Possible consequences after a HE are shown in Figure 3.8.

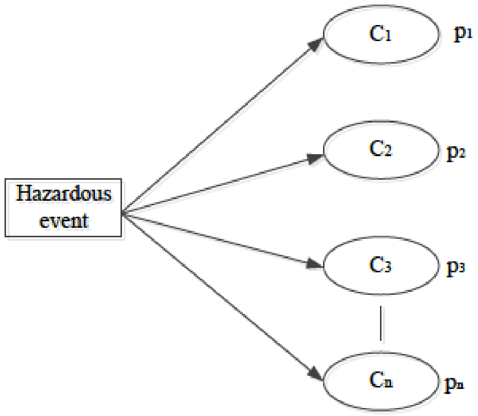


Figure 3.8: Consequence spectrum (Rausand, 2011)

A consequence spectrum is also called a risk picture or a risk profile (Rausand, 2011). After conducting an ETA, a number of consequences can be described with its risk contribution. Table 3.3 shows how the consequence spectrum can be summarised.

Table 3.3: Consequence spectrum for an Event Tree Analysis

i	Consequences	Risk contribution per year
No. 1		
..		
No. n		

3.3.3 Continual Improvement Assessment

3.3.3.1 SIPOC Diagram

In continual improvement processes it may be helpful to use a SIPOC (suppliers, inputs, process, outputs, and customers) diagram, which helps identify and characterize the key driving influences on a process without focusing on the process it selves (Sayer and Williams, 2012). The diagram is illustrated in Figure 3.9.

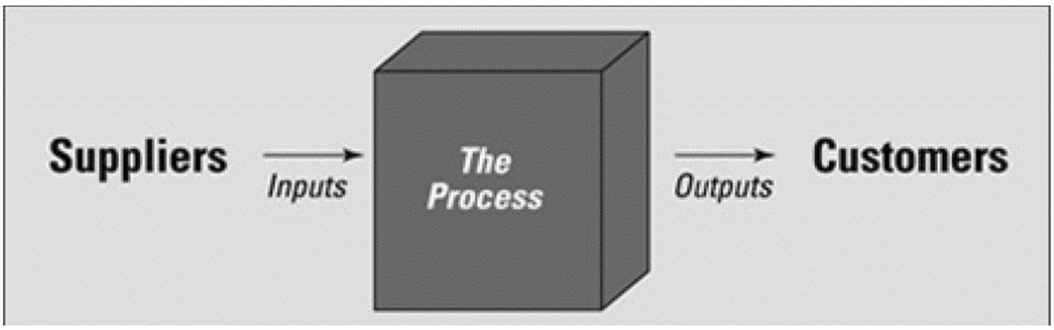


Figure 3.9: SIPOC diagram (Sayer and Williams, 2012)

3.3.3.2 Kano Model

A Kano model can be used to get an understanding of the customer's satisfaction. An example of Kano model is shown in Figure 3.10. The model is divided between needs, wants and delighters. Needs are what the customer sets as absolute fundamental requirements and must be satisfied (Sayer and Williams, 2012). Wants are what the customer expects and must be fulfilled to satisfy the customer (Sayer and Williams, 2012). However, the relationship is linear, indicating that lack of fulfilment of wants never will create the dissatisfaction that unfulfilled needs will. Delighters are not required by the customer and will not make the customer dissatisfied, but it will increase the customer's satisfaction exponentially if fulfilled (Sayer and Williams, 2012).

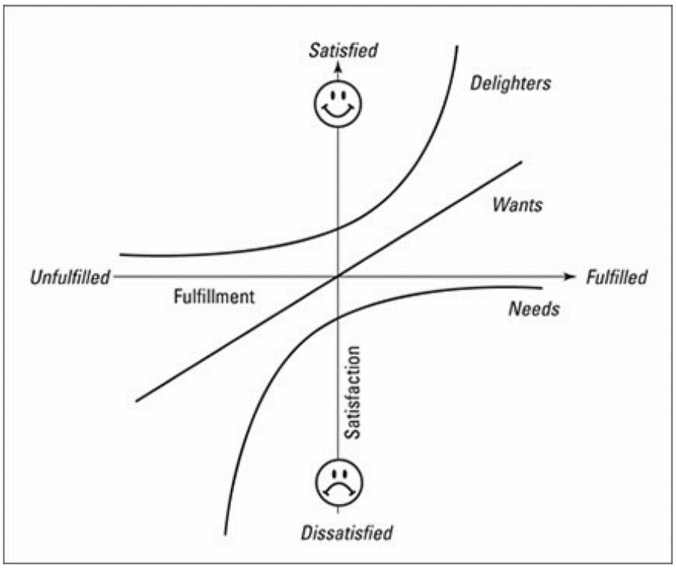


Figure 3.10: Kano model (Sayer and Williams, 2012)

3.3.3.3 Flow chart

A flow diagram or a flow chart is a visual tool to map the process of an operation (Oglesby et al., 1989). The chart includes an overview of the process and use different symbols to indicate which type of action that are performed in each step during the process. A flow chart may favourably be used in combination with a process diagram like the STEP diagram that define the different steps in an operation chronologically. The flow chart is a useful tool in this report to analyse operations in order to identify areas that can improve efficiency and safety in a processes.

An example of how the flow chart can be presented is shown in Table 3.4.

Table 3.4: Flow Process Chart (Oglesby et al., 1989, adapted)

Flow Process Chart		Summary				
Process:		Action		Present	Proposed	Difference
		○	Operation			
Charted by:	Date:	⇨	Transportation			
		□	Inspection			
Organization:		D	Delays			
		▽	Storage			
Illustration						
1.		○ ⇨ □ D ▽	n.		○ ⇨ □ D ▽	

3.3.3.4 Cause and Effect Diagram Analysis

A Pareto diagram is preferable if there is good availability of data, while a Cause and Effect Diagram is a good alternative if there is limited data available.

A Cause and Effect Diagram may be used to identify, sort, and describe the causes of a specified event (Rausand, 2011). It is a tool to identify possible casual connections, based on an experienced problem (Kvalvik et al., 2011). The cause and effect diagram analysis is best done by a brainstorming session with a study team (Rausand, 2011).

Cause-Effect diagram is also called a fishbone diagram. The critical event (e.g. the problem) is the "head of the fish", and the major categories of potential causes for the problem is drawn as bones to the spine. When analysing technical systems, the following six (6M) categories are frequently used (Rausand, 2011):

1. Man (i.e. people);
2. Methods (e.g. work procedures, rules, regulations);
3. Materials (e.g. raw materials, parts);
4. Machinery (e.g. technical equipment);
5. Milieu (e.g internal/external environment, location, time, safety culture);
6. Maintenance (of for example equipment).

Figure 3.11 illustrates the how the cause and effect diagram can be presented.

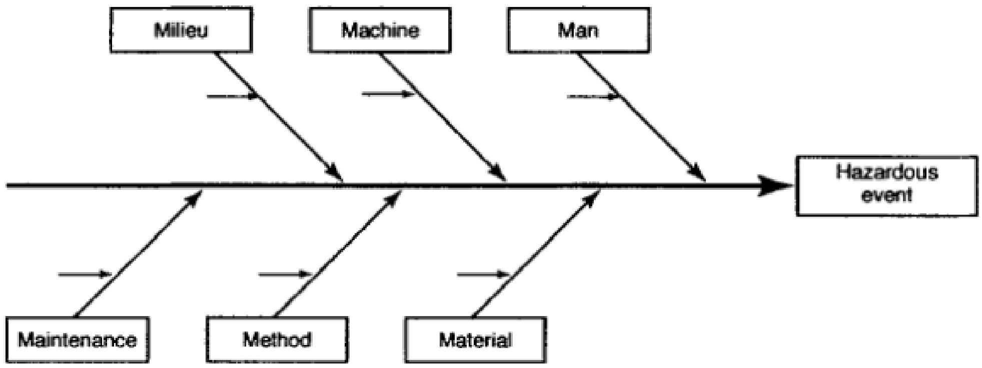


Figure 3.11: Cause and effect diagram (Rausand, 2011)

During brainstorming, each major category is checked for relevant issues that may affect the critical event (Rausand, 2011). Further, each factor is analysed to produce sub-factors that are represented as arrows pointing at the category. The category "man" can for instance have sub-factors like lack of skills and stress, while the category "machinery" can have a sub-factor of poor design (Rausand, 2011).

The main advantages of the Cause and Effect Diagram method are that it is easy to learn and is a good tool to determine causes of deviations (Rausand, 2011). Further, it helps to organise and relate causal factors. Some limitations are that it may become very complex and it cannot be used for quantitative analysis (Rausand, 2011). However, it will be used for qualitative analysis in the continual improvement process and is therefore a good tool to use in this report.

After analysing the causes, the causes should be analysed further in a Five-Whys Analysis in order to identify the true root cause of the problem (Kvalvik et al., 2011).

3.3.3.5 Five Whys Analysis

A Five Whys Analysis is a simple tool to find the root cause(s) to a problem. The method is used after conducting either a Pareto diagram, a Cause-Effect Diagram or other causal studies. Each cause is analysed to ensure to find the real cause of the problem, and not just a symptom of another cause (Kvalvik et al., 2011). The question "Why?" is repeated until no more causes are identified, usually five times.

The approach in a Five Whys Analysis are described in the following steps (Kvalvik et al., 2011):

1. For every identified cause in the Cause and Effect Diagram, ask the question “why is this a cause for the initial problem?”
2. For every cause, ask the question again until more causes cannot be found. This is most likely the true root cause for the problem.

3.3.3.6 Single Minute Exchange of Die

Single Minute Exchange of Die (SMED) is a method used in continuous improvement processes to increase the overall equipment effectiveness and thus increase the equipment availability (Adanna and Prof. Shantharam, 2013). The method involves separation and conversion of internal setup operations into external setup operations (Carrizo Moreira and Campos Silva Pais, 2011). The method was developed by Shingō (1985) in the mid-1980s to systematically reduce and simplify the setup time during changeover in a process. This lead to reduced setup times through elimination of waste (muda) in the operation. The benefits from applying SMED can be divided into direct and indirect benefits. The main direct benefits are according to Shingō (1985) reduction in setup time, reduction of time spent with fine-tuning, fewer errors during changeovers, product quality improvement and increased safety. Indirectly SMED application according to Shingō (1985) lead to reduction in inventory, increase of production flexibility and rationalization of tools.

Internal operations (Die exchange) are fitting of equipment while the machine or operation is off, while external operations are operations performed while the machine or operation is running (Carrizo Moreira and Campos Silva Pais, 2011).

There are seven steps and according to Shingō (1985) four phases that need to be implemented using SMED (Carrizo Moreira and Campos Silva Pais, 2011, Adanna and Prof. Shantharam, 2013):

1. Observation of the current system/methodology (Phase A).
2. Separation of internal and external activities (Phase B).
3. Conversion of internal activities into external activities.
4. Streamlining the internal activities (Phase C).
5. Streamlining the external activities (Phase D).
6. Documentation
7. Repeat

The adapted chart shown in Table 3.5, can be utilised in order to systematic perform the SMED method on a process or operation. The chart follows the steps presented above. First, each process step in the process is systematic evaluated to identify if the process step is internal (In), external (Ex) or waste (W). This is followed by suggestion of improvement that can reach wanted goal that can be either eliminate (El), make external (ME) and/or reduce (R). The improvement is divided into different Types (Ty) and can be related to equipment (E), design (D), procedure (P), upgrade (U) or modification (M). The improvement might include streamlining of the internal and external activities.

Table 3.5: SMED chart for documentation (Arun, 2016, adapted)

Operation:										
Current operation			Type			Improvement		Goal		
#	Task	Detail	In	Ex	W	Plan	Ty	EI	ME	R

4 Modelling and Analysis

4.1 System Description

As elaborated in Section 3.1.2, a generic model should be defined to describe functions, features, characterises and attributes which are common to all ships or areas relevant to the problem in question. This study will analyse operations involving interaction between service vessel and net cages. The generic model should therefore include a generic vessel and a generic floating net collar used for the operations, to adjust the method for this reports study.

Vessel for technical operations can be divided into two main categories of site vessel and service vessel (Hatlem and Kvamme, 2015). The ships used in the operations analysed in this study falls into the category of service vessel. These vessels are characterised by being larger than normal site vessels, ranging from 15 meter and longer, enable it to perform lager and heavier operations. Furthermore, the service vessels are normally not stationary at on site, but are transported between sites in order to perform heavy and advanced operations. In addition, several companies have started to use older, rebuilt offshore service vessels in their operation.

There are several different cage technology system depending on if the farm is sea-based, land-based or offshore-based (Hatlem and Kvamme, 2015). There are several new concepts under development because of the new development concessions. However, the most common is sea-based farms using open cage technology, consisting of plastic floating collars. The plastic cages are characterised by being simple circular floating collars welded together of plastic pipes. However, the system is special designed for site, weather conditions etc. in order to withstand environmental impact and prevent structure failure. These cages are normally installed in a pre-stressed mooring system, which is design to spread the forces acting on the system equally over the entire system (Lekang, 2013).

4.1.1 Generic Service Vessel

The generic service vessel is a hypothetical vessel of any size and type of operation. It is an appraisal of all the function of operation that is necessary for all service vessels. The use of the vessels are combined by both transport and performing the actual operation itself. The operations are cyclic with following distinct phases of life:

- Design, construction and commissioning;
- Entering port/net cage, berthing, put off and leaving port/net cage;
- Operation;
- Passage;
- Dry dock and maintenance period;
- Decommissioning and scrapping.

The description of the generic service vessel can be divided into several aspects for safety analysis purposes, as illustrated in Figure 4.1. As the status of the vessel's function changes throughout its phases of life, these aspects will affect the safety and reliability of the vessel.

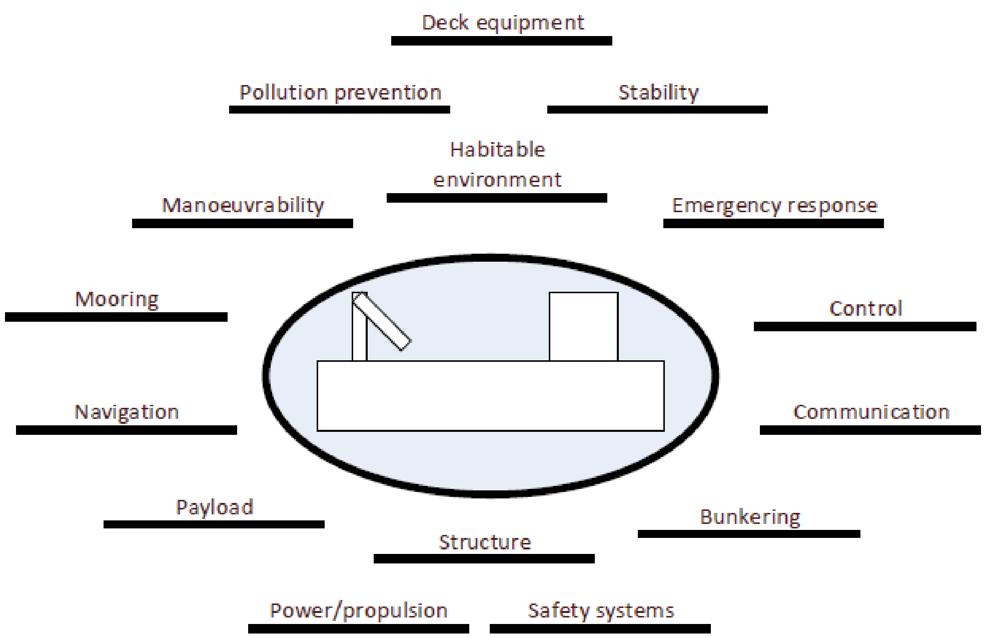


Figure 4.1: Generic service vessel

Power/propulsion: Auxiliary power of a service vessel is normally provided by one or two diesel-electric generator sets or by main engine driven alternators. Emergency power sources are normally battery based. Propulsion power of a service vessel is normally provided by two main engines connected to two reduction gears, shafts and propeller. The vessels are normally provided with one or more thrusters.

Bunkering: Bunkering is normally undertaken when berthed, with manual connection of fuel from shore to a receptor on the vessel.

Communication: Service vessels is normally provided with VHF radio.

Control: The wheelhouse is normally the only control centre on a service vessel. The wheelhouse has facilities for communication, navigation, safety and ship control equipment. Deck equipment is normally controlled locally or by portable controls. The main machinery spaces are unmanned during operation, but periodically operated during passage.

Deck equipment: The service vessel is normally fitted with one or two cranes with varying capacity and with one or several capstans.

Emergency response/control: The vessel normally carries first-aid kits in addition to a life raft.

Habitable environment: The crew are provided with a habitable environment. The wheelhouse is normally equipped with seating groups and a table. The service vessel is also normally provided with one or several cabins. To ensure a habitable environment, it requires consideration of ship motion, noise, vibration, ventilation, temperature and humidity.

Manoeuvring: It is more and more important that service vessels have an accurate and sensitive manoeuvring system. When entering and berthing next to a net cage, it is vital to avoid collision and hard contact with the net cage that may damage the cage or net. The farms tend to be located further offshore so operations are performed in a harsher environment, which make the requirements for accurate manoeuvring even more important. The service vessels are normally fitted with two rudders used with conventional propeller propulsion systems and in some cases with a pitch propeller propulsion system. The vessels are normally provided with one or more bow thrusters and in some cases with stern thrusters.

Mooring: Mooring during berthing is normally undertaken in a conventional manner using rope mooring lines, bollards and capstans. Mooring to a net cage is normally undertaken by securing the forward and aft spring to the cage, followed by securing the forward and aft brest and use of capstan to tighten the brests. For smaller vessels it may only be used a forward and aft hawser to moor the vessel to the net cage.

Navigation: Service vessels are normally fitted with radar and map-plotter with integrated GPS, echolocation system, magnetic compass, a speed and distance measurement device and autopilot. It is not normal that the vessels are fitted with DP system.

Payload: Service vessels have usually large deck capacity, which can store different equipment depending on type of operation. Payload capacity varies from 10 tonnes and up.

Pollution prevention: Used oil and oily bilge water is normally stored on board and discharged when the vessel is berthed to quay. Oily water separator is not provided on board. Exhaust gases is not cleaned and are normally visually monitored.

Stability: Until recently, there has not been any requirements for service vessels. However, several vessels have been built accordingly to Nordic Vessel Standard. Nordic Vessel Standard require inclining test, calculation of righting arm and centre of gravity for different loading and operating conditions. It has specific requirements for righting arm and requirement of not more than 10 degree heeling when performing lifting operation.

More recently, the Regulation of Building and Supervision of Smaller Cargo Vessel came into force (FOR-2014-12-19-1853, 2014). This regulation is mandatory for all vessels below 24 m and requires stability documentation for the ship trim and stability during all conditions. It requires that all ship have sufficient stability and a justifiable trim. It is built on the same requirements as in Nordic Vessel Standard, but the requirements for righting arm are more numerous and in some cases stricter. It shall also be checked for more numerous amount of load conditions, than earlier. In addition, it requires that ships, which shall use crane, must be a closed ship and requirements to righting arm is stricter.

It is not normal to have passive or active ballast tanks in order to help improve the stability of the vessel.

Structure: The material used for the construction includes steel and aluminium. Recently, aluminium has been more popular due to its reduced weight compared to steel. The structure normally consists of shell plating supported by longitudinal members and transvers frames. The Regulation of Building and Supervision of Smaller Cargo Vessels gives concrete requirements for the ships structure (FOR-2014-12-19-1853, 2014).

4.1.2 **Generic Floating Net Cage**

A generic net cage system is defined in order to describe the functions and characteristics that are common to all cages of this type. The system will be limited to the floating circular net cages made of high-density polyethylene (HDPE) plastic collars used for salmon and trout farming. This is the industry standard today and by far the most common fish farm design used in Norwegian aquaculture.

The generic floating net collar is, as the generic service vessel, a hypothetical model of any size and type of circular HDPE net cages. It is an appraisal of all the function of operation that is necessary for all floating net collars. The operations are cyclic with following distinct phases of life:

- Design, construction and commissioning;
- Operation;
- Maintenance period;
- Decommissioning and scrapping.

The description of the generic floating net cage can be divided into several aspects for safety analysis purposes, as illustrated in Figure 4.2. As the status of the cage's function changes throughout its phases of life, these aspects will affect the safety and reliability.

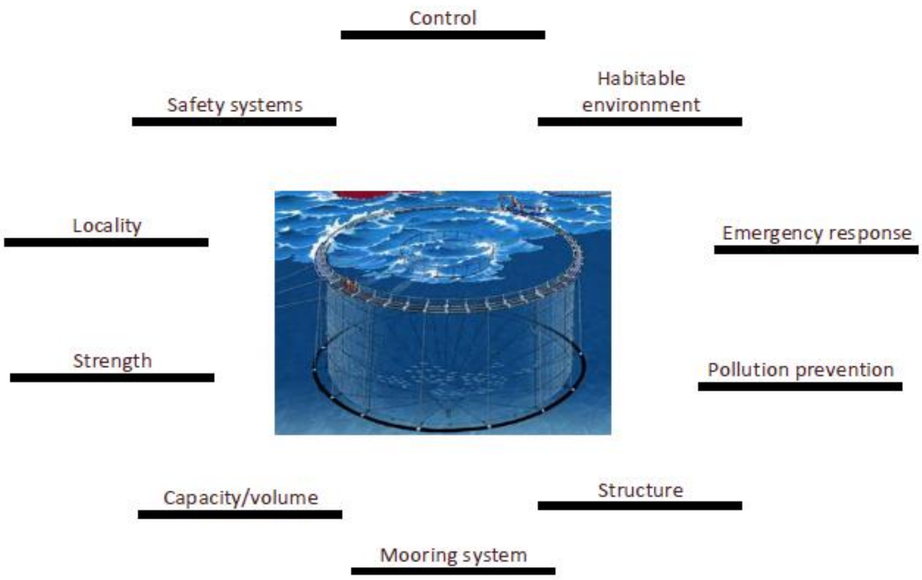


Figure 4.2: Generic floating net collar (ref. picture: Aqualine, 2016)

Strength: Requirements for strength of the different components in the system are given by The National Regulation for Certification and Inspection of Fish Farm Systems (NYTEK) (FOR-2011-08-16-849, 2011). NYTEK has requirements to classification and environmental conditions (wind, current, waves, bottom topography) for the site. It requires that only equipment that have been certified are used. Furthermore, it requires that the mooring analysis of a production unit is controlled by an accredited company. NYTEK points to that the farm components must meet the requirements in the technical standard NS9415 or equivalent. NS9415 has specific strength requirements for the different components like net, floating collar, mooring system (NS9415:2009, 2009).

Structure: The net cage exists of a net attached to the floating collar and stretched out by a bottom ring to ensure the volume of the net. The net cage may have different size and shape of nets. Form, depth, circumferences, material and mesh size varies and there is no given standard. The bottom ring or weights are usually connected to the surface through a rope or chain, while

Aqualine has a patented system where it is tied/sewed directly into the net to prevent abrasion between rope and net. The floating collar may vary in size, but most net cages today have a circumference of 160 meter. The floating collar normally consist of two collars made of elastic pipes welded together and forced into circles. The diameter of the floating collar depends on the load capacity of the system. A complete floating net cage consists of the floating collar, railings, bottom ring, centre bird net frame, bird net/jumping net and a walkway, like illustrated in Figure 4.3.

The structure of a fish farm is strictly regulated through NYTEK and NS9415. All calculations and components used must be certified by an accredited certification company. However, there are no requirements for the integrity of the overall fish farm.

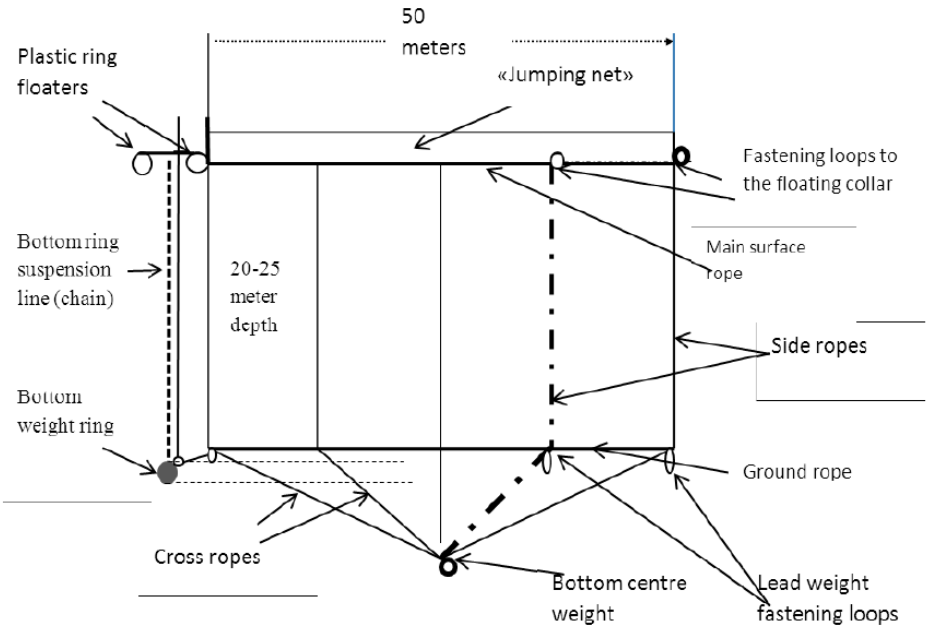


Figure 4.3: Illustration of complete floating net collar (Karlsen)

Mooring system: Anchor frame lines, anchor lines, anchor frame buoys, anchors and bridles build up the mooring system holding the cages in place. A pre-stressed mooring system is used and designed in such ways that the forces acting on the system are equally spread over the entire farm (Lekang, 2013). The main purpose of this mooring system is to have as little vertical force as possible on the net cage, because this force need to be compensated by increased buoyancy capacity on the floating collars. The frame is lowered to around 7 m to allow vessels sailing close to the cages.

The net cages are typically moored in series, as illustrated in Figure 4.4, but the number of net cages and design of system is dependent on how many licences the site has. The mooring system of a fish farm is also strictly regulated through NYTEK and NS9415.

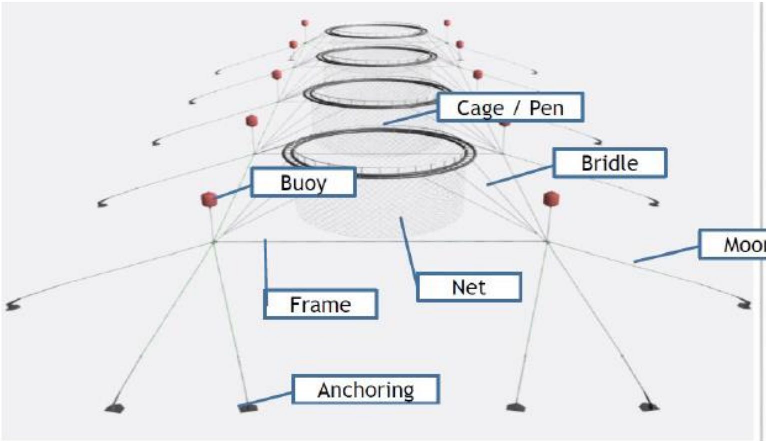


Figure 4.4: Typically mooring system for fish farm (Søreide, 2016)

Capacity/volume: The capacity of one single net cage is by the Aquaculture Act, limited to maximum 200 000 fish (LOV-2005-06-17-79, 2005). The volume of the net will therefore be dependent on number and size of fish in the net cage. The total biomass at on site is determined by the licences. Furthermore, maximum allowable fish density is 25 kg per cubic metre (LOV-2005-06-17-79, 2005).

Pollution prevention: The farm localities are chosen and approved in order to ensure that waste from the fish not is accumulating and harming the environment around the farm. The standard NS 9410," Environmental monitoring of benthic impact from marine fish farms", have requirements on monitoring and controlling the environment around the farm (NS9410:2016, 2016). Furthermore, it is noteworthy to add that the above-mentioned requirements in NS9415 and NYTEK are mainly designed to avoid escapement of fish.

Emergency response: The farms have normally plans for emergency response when accidents happens and plans for how to reduce the consequence of e.g. fish escapement. In addition, the Norwegian Directorate of Fisheries have an emergency preparedness team that will travel to the fish farm in case of an emergency like event of escapement of fish.

Safety systems: The fish farms normally have procedures to use divers or ROV to inspect the net cage after more complicated operations, in order to ensure that the operation did not cause any harm. The fish farmers normally use a communication system with regularly feedback to other personnel or to land, especially when working alone. In addition, the companies are according to the Employment Protection Act, obliged to ensure that the personnel have adequate and correct safety equipment (LOV-2005-06-17-62, 2005). However, the use of safety equipment on the fish farms still varies, although it is becoming better. Further, The Regulation on systematic health, safety and environment work in enterprises (Internal control regulation), ensures that the companies plan and carry out safety procedures (FOR-1996-12-06-1127, 1996).

Habitable environment: This applies to the fish. This may require consideration for motion, oxygen supply, current, temperature, exposure for wind and waves, predators, boat traffic, and a dead fish removal system. Fish welfare is an important issue in fish farming.

Control: The fish farmers are normally equipped with cameras and sensors in order to monitor the feeding and the conditions in the cage. Each farm has a control station on board the feed barge, but it is becoming normal that the farm in addition can be controlled from an external location at land. The farms are starting to get more autonomy, but most operations are still manual.

4.1.3 Locality Classification

NS 9415 classifies fish farm localities into five classes, from little exposure to extreme exposure(NS9415:2009, 2009). The classification depends on significant wave height, wave period and midcurrent speed, as shown in Table 4.1 and 4.2 respectively.

Table 4.1: Wave classes at the site decided by dimensioning, significant wave height and wave period (NS9415:2009, 2009)

Wave classes	H_s m	T_p S	Designation
A	0,0 – 0,5	0,0 – 2,0	Little exposure
B	0,5 – 1,0	1,6 – 3,2	Moderate exposure
C	1,0 – 2,0	2,5 – 5,1	Substantial exposure
D	2,0 – 3,0	4,0 – 6,7	High exposure
E	> 3,0	5,3 – 18,0	Extreme exposure

Wave classes is determined by significant wave height and wave period, while current classes are decided by current velocity. The wave and current classes decides whether the site has little exposure to extreme exposure.

Table 4.2: Classification of site based on midcurrent (NS9415:2009, 2009)

Current classes	V_c m/s	Designation
a	0,0 – 0,3	Little exposure
b	0,3 – 0,5	Moderate exposure
c	0,5 – 1,0	Substantial exposure
d	1,0 – 1,5	High exposure
e	> 1,5	Extreme exposure

Ryan et al. (2004) classifies the sites after geography location, as this is located to wave height, wave period and current speed. Ryan et al. (2004) divide between four different classes, as shown in Figure 4.5. The classes is defined as sheltered inshore site, semi-exposed inshore site, exposed offshore site and open ocean offshore site (Ryan et al., 2004).

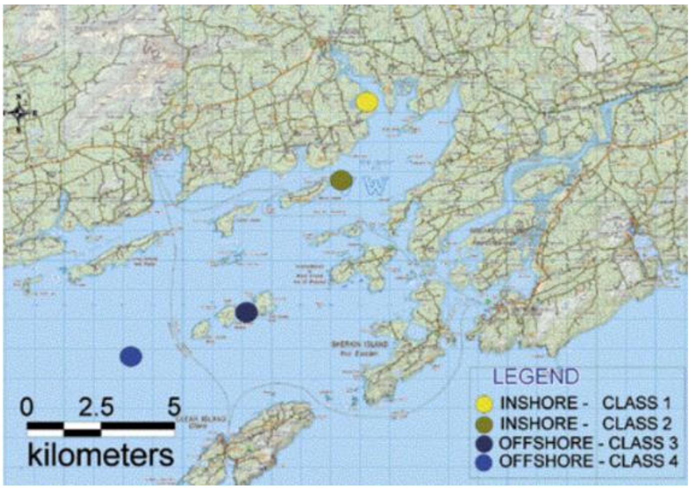


Figure 4.5: Classification of sites according to geography location (Ryan et al., 2004)

The class of exposure indicates which wave, current and wind that can occur at the location, but it says less about the degree of exposure and how many days during a year the site is operational.

4.1.4 Impact of Environmental Loads

Today the fish farm locations tend to lay more exposed to rough sea conditions. Exposed sites will have increased environmental loads with stronger and steadier currents. This increases the water quality and improve the oxygen supply, which is needed to maintain the fish normal vital functions (Jensen et al., 2010). The currents will in addition contribute to transportation of waste away from the cage, which increase the well-being for the fish. Other environmental loads, like wind and waves, are stronger at sites further offshore.

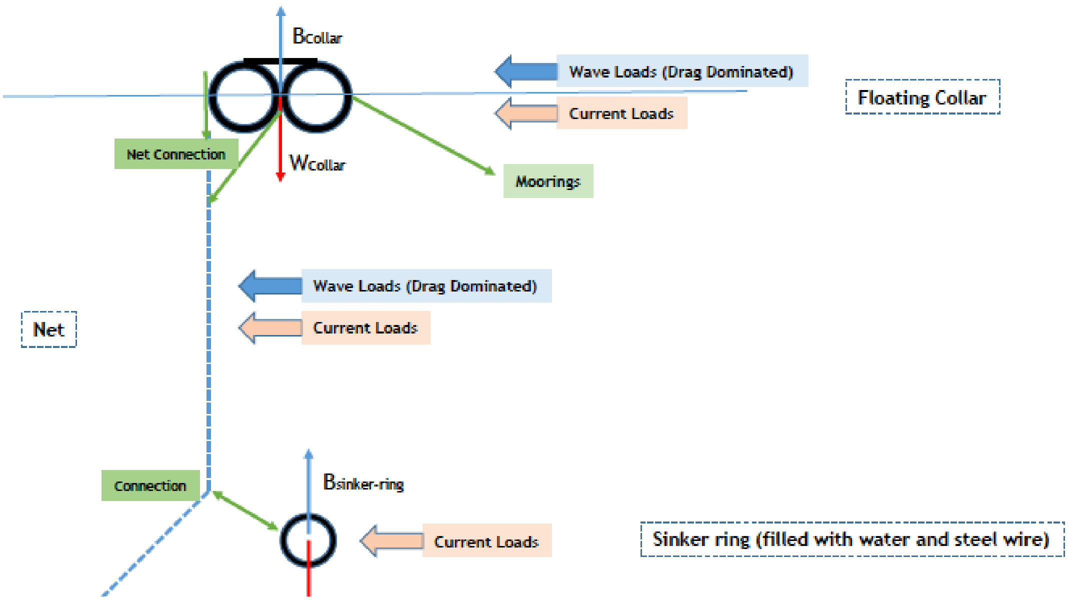


Figure 4.6: Environmental forces on a net cage (Søreide, 2016)

It is mainly the environmental loads from current and waves that affects the net cage, while wind has minimal impact directly on the fish farm. The floating collar and net experience loads from both current and waves. While the current force occurs independent of depth, the wave force decreases exponential with depth. On depth equal to half of the wavelength, less than 1% of the energy from the wave is left (Søreide, 2016). The bottom ring only perceives force from the current. Figure 4.6 shows how the different environmental loads affect the net cage.

Figure 4.7 illustrates the forces acting on a cage system, in a possible 50-year storm which implies 0.5 m/s current speed and 30 m/s wind speed (Berstad and Mürer, 2015). In this example, one of the mooring lines perceives a maximum load of 13.9 ton.

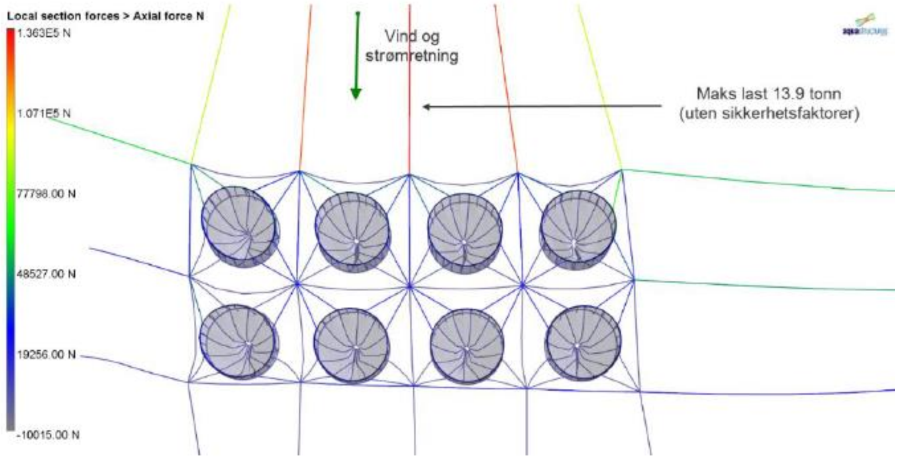


Figure 4.7: Impact from 50-year storm on mooring system (Berstad and Mürer, 2015)

These environmental loads will affect service vessels during an operation as well. Wind, current and waves will cause increased movements in the vessel and make operations more difficult to perform. Especially the forces from wind will give increased impact on the service vessels. Furthermore, as the net cages and the service vessels are getting larger, the risks related to the operations will change, and the consequences of a possible accident more severe. The risk of accidents as falling or being hit by an object may be assumed to increase with sudden vessel movements due to e.g. waves. Waves can also make the net cage unsafe to walk on. Furthermore, bad weather may delay the operations significantly if deemed unsafe of difficult to perform.

A service vessel moored to a net cage can contribute to additional loads to the fish farm and the mooring system. This can be reasoned with the results from an analysis performed in SIMA, with model received from MARINTEK (Aksnes, 2016). The model is used to simulate and illustrates a vessel moored to a net cage, with wind, waves and currents from; windward, in the bow and leeward direction respectively. In Figure 4.8, the vessel is moored to the windward side of the cage. This causes large deformation on the net cage due to additional impact from vessel, as illustrated in the figure. In Figure 4.9, the vessel is moored to the net cage with the environment towards the bow. This cause less deformation on the net cage, as illustrated in the figure. Lastly, in Figure 4.10, the vessel is moored to the leeward side of the cage. As with the environment towards the bow, this cause less deformation on the net cage. However, in the two last cases, a pulling force in the mooring line connected to the net cage will contribute to deformation where the vessel is moored. Furthermore, analysis performed by Berstad and Mürer (2015) shows that large service vessels or well boats, if moored directly to the cage, can cause higher loads on the mooring system than a 50-year storm alone.

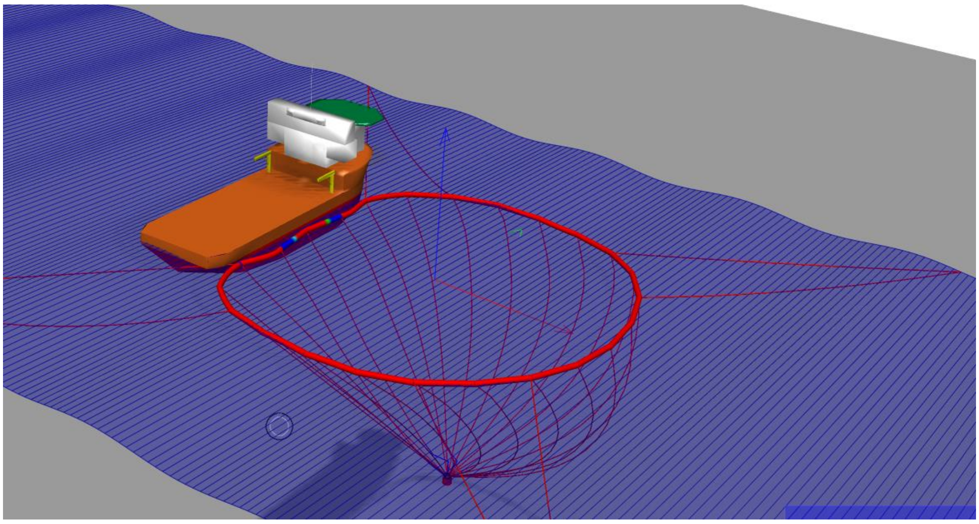


Figure 4.8: Impact on floating collar from vessel moored to the windward side of the cage

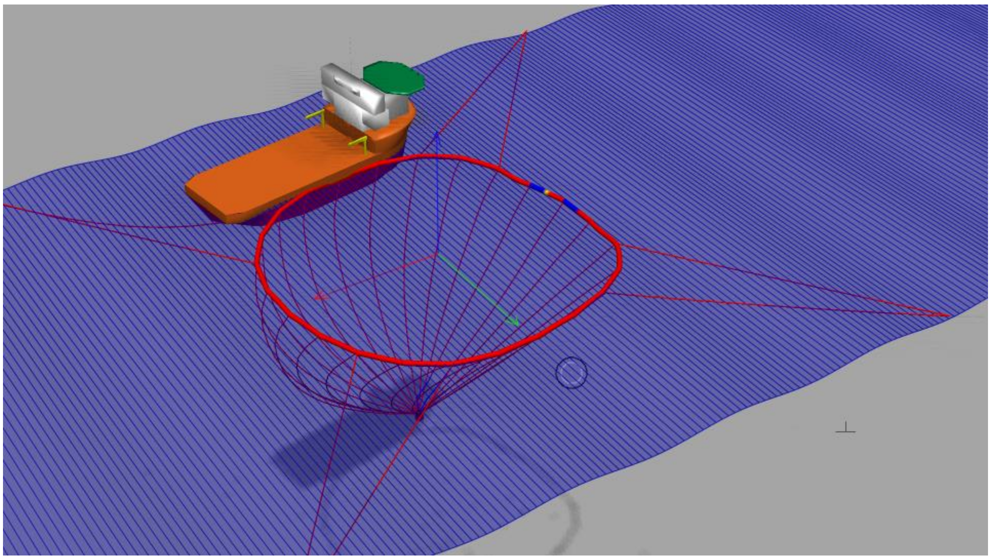


Figure 4.9: Impact on floating collar from vessel moored with the environment towards the bow

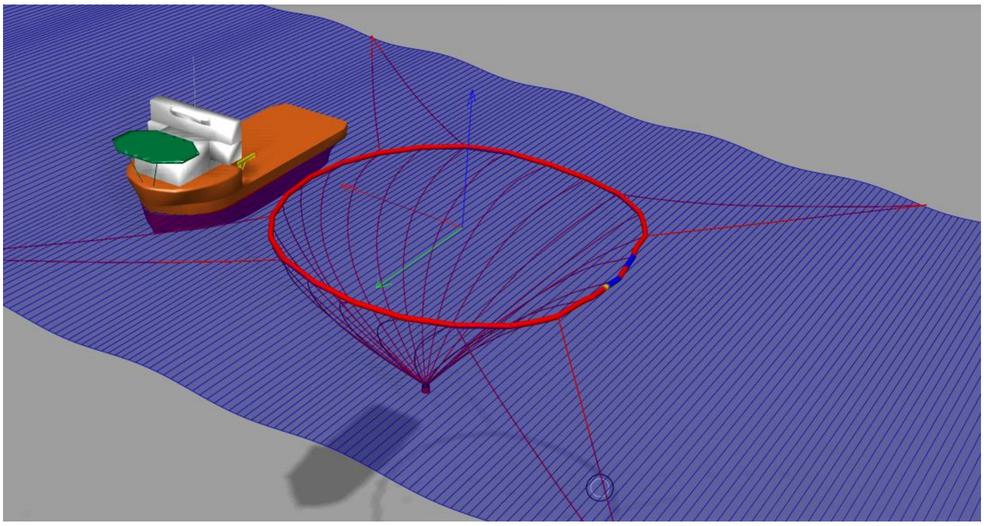


Figure 4.10: Impact on floating collar from vessel moored to the leeward side of cage

4.2 Data Collection

A study performed by Holmen et al. (2016) shows that the aquaculture industry is the most dangerous industry to work in after the fishery industry. The study shows that during 1982 to 2015, there have been 34 fatalities. While during 2001 to 2012, there are registered 761 occupational accidents with personal injuries. The causes of accidents are many, while for the fatalities the main causes are clearer, although it have changed during the period.

For the purpose of this report, an accident is defined according to IMO (2013) FSA guideline:

> "An unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage."

Hence, all kind of unintended events may be regarded as an accident, not only those involving fatalities. The following subchapters present available statistics on accident injuries, occupational deaths and number of fish escapement.

4.2.1 Accident injuries

Accidents that are reported at Norwegian Labour Inspection Authority (NLIA) are most often accidents with serious consequences where the personnel involved is serious injured. It is therefore believed to be a great number of underreporting of accidents in the NLIA database (Salomonsen, 2010, Mostue, 2015). The accident statistics represented in Table 4.3, are accidents registered from 2003 to 2009 (Salomonsen, 2010) and new statistic from NLIA for the period 2011 to 2015 (Mostue, 2015). Unfortunately, it has not been possible to get statistics from 2010. In addition to underreporting, the statistics has 55 unspecified events that decrease the statistics representativeness. The frequency is established based on the accumulated number of employees in the industry in the given period (SSB, 2015).

Table 4.3: Accidents statistics from NLIA and their frequencies and causes (based on: Salomonsen, 2010, Mostue, 2015)

Accident category	Acc. (2003-2009)	Acc. (2011-2015)	2003-2015 (except 2010)	Freq.	Comment
Accumulated employees	17342	20647	37989		
Electrical	-	15	15	3.9E-04	
Fall (slip/trip)	84	13	97	2.6E-03	Falling during boarding/ disembarking, tripping, fall from ladder/ stairs, fall from net cage and falling from quay
Hit by object	77	25	102	2.7E-03	Equipment that slips, and equipment in tension, heavy equipment falling on worker
Squeezed/ trapped	68	17	85	2.2E-03	Between equipment and/or vessel. Squeeze with use of capstan, conveyer belt etc.
Stabbed/ cut by sharp object	62	1	63	1.7E-03	Use of knife, but also sharp equipment or because of lacking protective equipment
Chemicals	19	10	29	7.6E-04	Lacking use of protective equipment, hoses loosens from container. Bad labelling of chemicals etc.
Collision/ crash	8	4	12	3.2E-04	Collision of truck etc. Collision with vessel due to bad visibility (1)
Overturn/ fall	8	5	13	3.4E-04	Capsizing, fall from vessel in strong sea, hit in the head by machine hatch, fall from ladder when the ladder felled
High/ low temperature	4	1	5	1.3E-04	Handling of hot material/ water, hypothermia from fall in sea
Explosion	3	-	3	7.9E-05	
Other	55	14	69	1.8E-03	Unspecified events
Total	388	105	493	1.3E-02	

The Norwegian Maritime Directorate (NMD) collect accident statistics, but for accidents involving vessels. The registered accidents for the period 2006 to 2015 are summarized in Table 4.4. The number of accidents are quite low and underreporting must be assumed. It should further be assumed that double counting between the two databases exist and they should therefore not be directly summed up.

Table 4.4: Accident statistics from NMD and their frequencies (NMD, 2016, adapted)

Accident category	Accidents (2006-2015)	Frequency
Accumulated employees	34672	
Grounding	12	3.5E-04
Fire/explosion	8	2.3E-04
Collision	4	1.2E-04
Environmental damages/ leak	8	2.3E-04
Occupational accidents	10	2.9E-04
Capsize	7	2.0E-04
Engine breakdown	1	2.9E-05
Other accidents	7	2.0E-04
Total	**57**	**1.6E-03**

Sandberg et al. (2012) looked at 20 deviation reports for personal injuries, and divided them into accident categories as presented in Table 4.5

Table 4.5: Accidents registered in deviation reports (Sandberg et al., 2012, adapted)

Accident category	Accidents	Comment
Fall	11	Tripping in objects, missteps, fall in ladder, fall into sea
Hit by object	5	Rope that hits during use of capstan, hit head on equipment
Squeezed/ trapped	2	Squeezed fingers during handling of rope
Stabbed/ cut by sharp object	2	Use of knife dominates

Of these accident categories, Table 4.6 shows where the accident took place and their percentage (Sandberg et al., 2012).

Table 4.6: Distribution of where accidents occur (Sandberg et al., 2012, adapted)

Place of accident	Percentage
Vessel deck	35%
Floating collar	35%
Feed barge	20%
Quay	5%
Workboat/rescue boat	5%

Most of the accidents take place on the floating collar or on the vessel deck. The deviation reports, in contrast to the accidents statistics from NLIA, is often kept internal and is written for all deviations including small injuries and almost-accidents (Sandberg et al., 2012). Sandberg et al. (2012) concluded that the high percentage of falling at exposed localities could be because of high waves making it hard to keep the balance on the vessel deck when operating equipment and moving around on the deck.

4.2.2 Occupational deaths

Overall, there have been 34 occupational deaths in the period from 1982 to 2015 (Holmen et al., 2016). Of these, six are related to “man over board”, five to “hit by object” and “squeeze” and one to “collision” (Holen, 2016). Further, studies shows that deaths earlier have been related to transport accident, while it today is more related to lift operations (Holmen, 2015)

Statistics from NLIA presented in Salomonsen (2010) shows that four people died in the period 2005 to 2009 (ref. Table 4.7). From 2011 – 2015, it was further registered 2 fatalities in NLIA database (Mostue, 2015).

Table 4.7: Statistics on occupational deaths (Salomonsen, 2010, adapted)

Accident category	Number	Comment
Diving accident	2	One of the accidents was caused by broken regulations
Fall from vessel	1	Worked alone. Probably fell from vessel and could not get up again
Collision	1	Two vessels was playing on the stern wave of a third boat

4.2.3 Fish escapement

In the period from 2006 to 2015, data from Norwegian Directorate of Fisheries (NDF), shows that the number of escaped salmon have dropped significantly from above 900 000 and stabilized to approximately 250 000 escaped fish after 2008, as presented in Figure 4.11 (NFD, 2016). The number of accidents have however, varied a lot in the period and in some years been larger than earlier. The total number of fish farms have increased during the period, indicating that overall accidents/total fish farms have decreased. However, the last couple of years have had an increase in number of accident, while the establishment of new fish farms and production growth have been limited. The development in Figure 4.11, also indicates that the accidents are less severe than earlier and the drop after 2006 is connected with the implementation of NYTEK pointing to NS9415 or equal.

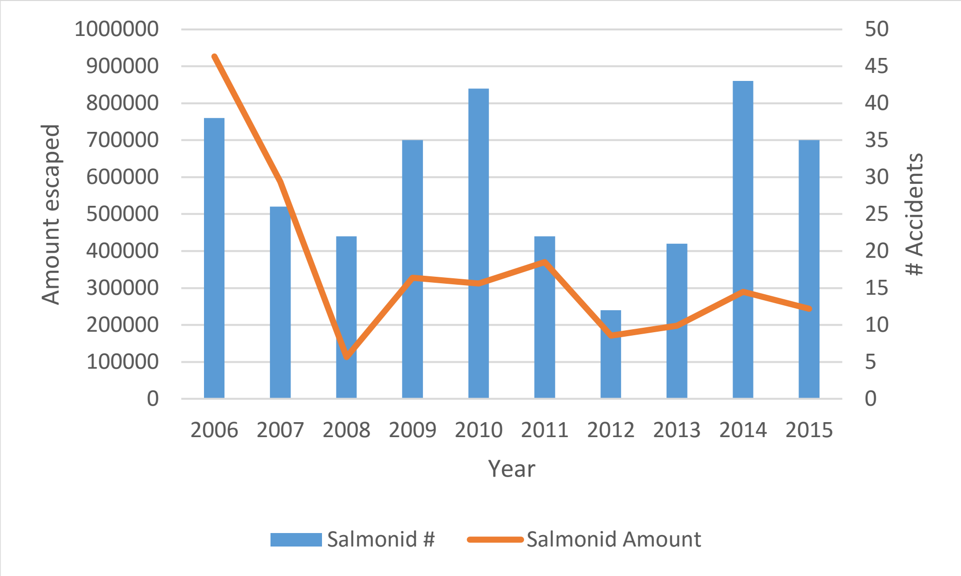


Figure 4.11: Amount of escapement and total number of escaped salmon (based on: NFD, 2016)

Moe and Jensen (2009) have looked at causes of escapement in 152 reported accidents in the period of 2006 to 2009, which resulted in total escapement of 770 000 salmon, 480 000 cod, 120 000 trout and 16 000 halibut. 64% of the escaped fish is caused by hole in net, 22% caused by net under water and 6% of breakdown. The other causes stand for 10% of the total. Of the reported accidents, 67% is hole in net, 5% is net under water. Net under water is caused by wrong fastening of net to floating collar and wear. Their findings is represented in Table 4.8.

Jensen et al. (2010) have identified that structural failures (68%) are the dominating cause of total number of fish escaped in the period 2006 to 2009, while operational related-failure and external factors contribute to 8 % of the total escaped fish each. NFD categorising of fish escapements in 2015 indicates the same trend (NDF, 2015). 66% of total escaped fish is caused by structural failures, while operational related-failures contributes to 34% of the total escaped fish (NDF, 2015). However, of 109 registered incidents in 2015, the main cause of accident was operational related-failures with 42% of the incidents, followed by structural failures and external factors with 27% and 5% of the causes respectively (NDF, 2015). Structural failures often cause larger escapements than operational failures, because they might be harder to discover and thus, causing larger escapement, compared to operation failures (Jensen et al., 2010, Moe and Jensen, 2009). Some few accidents caused by structural failures, therefore cause most of the total amount of escaped fish. The decreasing amount of fish escaped indicates that the number of structural failure accidents are decreasing, while the increasing total number of accidents indicates that the number of operational related-failures are increasing. The increasing number of accident caused by operational related-failures may be a result of more exposed fish farm and harder sites to perform operations. In addition to more demanding operation like delousing and new methods of performing delousing.

Table 4.8: Registered fish escapements, number and amount, in 2006 to 2009 (Moe and Jensen, 2009, adapted)

Hole in net	Amount escaped [%]	Amount escaped salmon [%]	Amount escaped cod [%]	# accidents	Frequency (accumulated # employees = 10 569)	Comment
Total amount of escaped fish	878 000	412 000	449 000			
Total # of accidents		63	36	101	9.6×10^{-3} (6.0×10^{-3})	
External vessel	20	-	39	1	9.5×10^{-5}	Fishing vessel
Predator	15	1	27	23	2.2×10^{-3}	Animal or fish, most common for cod
Tow	2	3	-	3	2.8×10^{-4}	During tow, contact with bottom
Cod biting	2	-	1	9	8.5×10^{-4}	
Service vessel	2	2	-	9	8.5×10^{-4}	Vessel approach, propel
Handling/lift	3	-	1	8	7.6×10^{-4}	Lift of weight, gathering of net
Poor repair	5	8	3	6	5.8×10^{-4}	Fault in net
Feed automat	6	14	-	1	9.5×10^{-5}	
Flotsam	6	15	-	6	5.8×10^{-4}	
Wear	11	23	1	17	1.6×10^{-3}	Contact
Other	2	4	-	6	5.8×10^{-4}	Damage from fish, feed hose, high pressure cleaning, vandalism
Without conclusion	11	27	-	1	9.5×10^{-5}	May have several causes
Unknown	15	4	25	11	1.0×10^{-3}	

Based on the statistics of previous accidents, Figure 4.12 and 4.13, illustrate the total risk for personnel working in the aquaculture industry and for fish escapement.

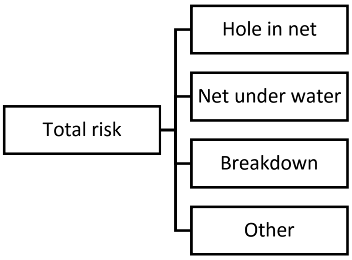


Figure 4.12: Total risk picture, fish escapement

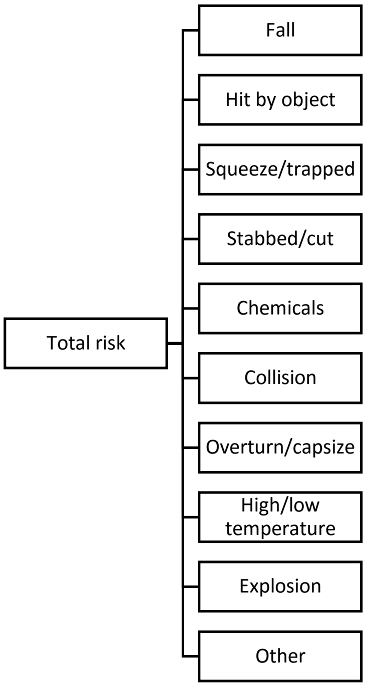


Figure 4.13: Total risk picture, personnel

4.3 Software

4.3.1 AutoCAD

AutoCAD is a software used for computer-aided design (CAD) in 2D or 3D. The software program is used for sketching all 2D and 3D drawings presented in this study.

4.3.2 SIMA

SIMA is a powerful tool for modelling and analysis of marine operations and floating systems within the field of marine technology (SIMA, 2015). 3D and 2D graphics allow users to quickly and intuitively understand the results. The illustrations presented in Section 4.1.4, are modelled with SIMA.

4.3.3 Microsoft Visio

Microsoft Visio is a software used to create diagrams and flow charts. Visio has been used in this report to create STEP-diagrams to document the operations observed, in addition to all other graphical figures.

5 Documentation of Operations

To assess the operational efficiency and HSE aspects in marine aquaculture operations, it is important to observe and understand how the different operations are performed. Based on the problem definition, a desire from collaborators and known dangerous operations that requires many person-hours, the following operations are targeted and later analysed in this report:

- Service and maintenance of floating collars
- Delousing
- Cleaning of the net

These operations may be performed in different ways depending on method and equipment used, which can involve different aspect of hazards and danger for accidents. Based on attended operations, a STEP diagram for each operation is established to easy document and understand course of events of the operation. The STEP diagrams are presented in Appendix A, while observations are summarised in the following subchapters.

5.1 Net Cleaning Operation

Cleaning of net is an important operation and takes place approximately every 10th day, but varies with season. Insufficient cleaning may lead to reduced flow and water exchange, and increased load on the net. The biofouling on the net includes benthic organisms such as blue mussels, seaweed and hydroids. Furthermore, biofouling may become a source for diseases and a good habitat for lice larvae.

Figure 5.1: Location of fish farm at Bjørgan (BarentsWatch, 2015)

The locality during the net cleaning operation was at Bjørgan in Flatanger, Nord-Trøndelag (ref. picture 5.1), classified as offshore class 3 according to Ryan et al. (2004) (ref. Section 4.1.3). The site visited is not classified according to NS9415 because of lack of environmental data, such as current measurements, significant wave height and wave period.

The cleaning equipment normally used is a net cleaning rig driven by a remotely operated vehicle (ROV) or by crane, a remote operated net cleaner (RONC), or a combination of both. The cleaning equipment is attached to a high pressure cleaner (HPC) located on the deck of vessel. The equipment is used on the inside of the net, washing away biofouling and dirt. At the attended operation with AQS Hugin (LOA = 15 m), a combination of both ROV and RONC were used. The equipment was remotely controlled from inside the wheelhouse on the vessel by a crew of two people. The operation was monitored on a computer screen showing video of the ongoing operation.

5.1.1 Observed Challenges

Some of the challenges observed that affects both safety and efficiency can be shortly summarised. During the operation, there was a stop in the HPC system, shown in Figure 5.2, due to a leakage in the oil filter. This delayed the operation as the filter needed to be changed. In addition, the stop caused further delays because the RONC depends on the HPC to keep its buoyancy. Thus, when stopping the HPC, the RONC will sink to the bottom of the net, if not driven to the surface and tied to the railing. Either way this increase the delay, but, if not driven to the surface, it also induce risk of the RONC being stuck to other equipment or the net.

Figure 5.2: Picture of HPC on AQS Hugin

Having an untidy deck with moving hoses laying around may cause a risk of tripping and falling. Furthermore, leakage of liquids such as hydraulic oil was observed to make the vessel deck quite slippery.

A hazard of being crushed might occur when the crew is present on the walkway during mooring of the vessel or other activities. Figure 5.3 illustrates such a scenario. During crane lifts, the accident category of being hit by an object applies.

Figure 5.3: Mooring of vessel to net cage

Strong wind, wave motions in vessel, insufficient fastening or snapping of lifting strops can provoke such an accident. Figure 5.4 shows a lift of the RONC into the net cage, which on a harsher day can be quite difficult and dangerous.

Figure 5.4: Lift of RONC

Handling of equipment requires manual work, such as hauling heavy hoses back on vessel deck after the operation. This is quite ineffective and constitute a risk of getting back injuries.

5.2 Delousing Operation

AQS perform delousing by use of closed tarpaulin as shown in Figure 5.5. The delousing is performed by pulling a tarpaulin around the net and adding a mixture with hydrogen peroxide. The same technique is used when treating for amoebic gill disease (AGD), where fresh water is used to treat the fish instead of peroxide. Normally, four vessels are participating in the operation; one chemical vessel carrying the medicine, one vessel placing out the tarpaulin and two smaller assisting vessels.

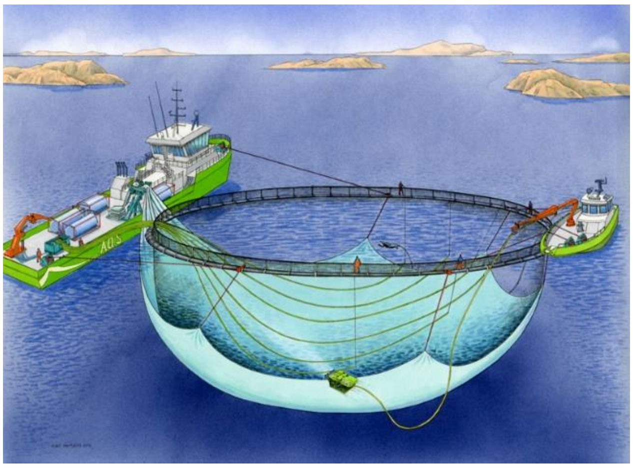


Figure 5.5: Delousing with tarpaulin (AQS, 2016)

The attended delousing operation took place at the locality Steinflesa outside Leka in Nord-Trøndelag (ref. Figure C), classified as offshore class 4 according to Ryan et al. (2004) (ref. Section 4.1.3). The locality is exposed to weather, and during the study trip, strong wind interrupted the

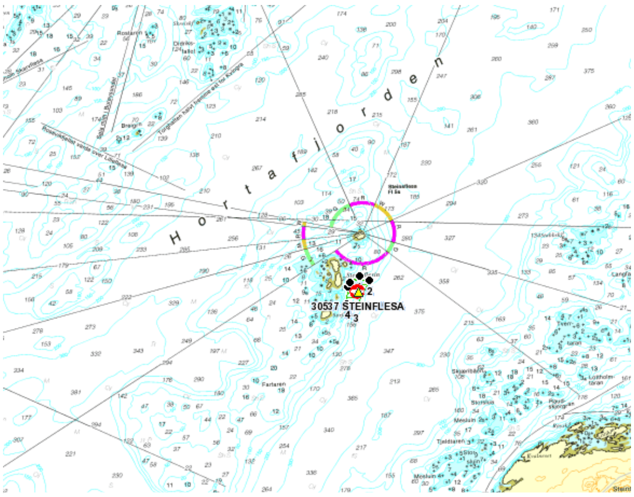


Figure 5.6: Location of fish farm at Steinflesa (BarentsWatch, 2015)

service vessel's ability to perform the operation safe and efficient.

Two main vessels, MS Mariner (LOA = 60 m) and AQS Loke (LOA = 25.5 m), was used during the operation. MS Mariner was hired by AQS to be work as the chemical vessel in this operation. The fish farm company (the customer) assisted the operation with to smaller vessels, MS Heilhornet (LOA = 14.99 m) and MS Vesthav (LOA = 13 m). Furthermore, a veterinary is usually present during delousing to control the welfare of the salmon. Delousing demands good communication between the four vessels.

5.2.1 Observed Challenges

Larger service vessels may sometimes have to lie on the bridles, because of the length of the vessel. This can increase the vertical forces on the cages mooring lines significantly, and the floating collar and net may be deformed and forced downwards. A submerged floating collar can in worst-case lead to escape of salmon. Due to the configuration of the mooring frame system, a vessel with length of 50 meter or more, has to lie on the bridles if moored directly to a standard 160-meter net cage. Furthermore, repeated contact from the vessel on the bridles can lead to wear and tear or failure of the bridles, thus reducing the capability to hold the net cage in place. If the bridles are slack, the risk of getting in contact with the propeller increases. This may damage both the propeller and the bridle.

The weather is often a problem for the service vessels ability to berth to the floating collar. The mooring system of the net cage may be an obstacle for the vessel and can easily come in contact with the vessels hull, propeller or other components. This is especially an issue in bad weather with more movement in both vessel net cage and with poor visibility in the ocean. During the study trip, strong gusts of wind made it difficult for the larger service vessels to moor to the fish farm, and the operation was eventually aborted. Thus, the net cage and mooring system is not adapted to fit each other for larger vessel. Furthermore, the decision of aborting the operation was mainly done by the captain's opinion. There seem to be a need for a decision-support tool based on weather window for when an operation is safe and efficient to be performed.

When a vessel is moored to the net cage, wind, waves and current may push the vessel against the floating collar (ref. Section 4.1.4). The vessel will transfer loads to the floating collar, which can be deformed and oval-shaped. The tarpaulin will not fit around the net cage, if it is too oval-shaped, and the operation must thus be delayed or aborted. In worse case the oval shape can cause collapse due to local buckling. Local buckling appears if the critical bending radius,

R_b, get too high. This relation for local buckling is given in Equation 5 (Janson and Borealis, 1996):

$$R_b > \frac{D}{1.12 * \frac{s}{D_m}} \tag{5}$$

where D is outer diameter of collar, s is wall thickness and D_m is in the middle of the wall (D_m=D-s).

If a floating collar collapses, there is always a risk of other components, like brackets and handrails, fails, which again can cause escape of salmon. Further, progressive collapse of other parts of the fish farm can occur because of loss of integrity (Jensen, 2006).

Furthermore, wind and waves can be hazardous if there are rocks or islands located near the fish farm. If the mooring from the vessel to the net cage fails, the vessel may drift and collide during short time, often in a few seconds in strong wind. This is especially an issue with large and heavy vessels. During the observed operation, the smaller assisting service vessels had problems with wave movements and tended to jump up and down, making contact on the floating cage collar. In some cases, the small service vessels may also jump and land on the walkway on the floating collar. This is not optimal, constitute a risk for both personnel and equipment and might interrupt the working conditions and leading to unwanted accidents.

On localities with strong current, the vessels will avoid laying up against the current when berthed to the cage, as there is a risk of the net drifting into the propeller (Sandberg et al., 2012). However, this is not always possible for larger vessels, as there is restricted space with mooring lines and other vessels. Furthermore, it requires much thruster power to move the vessel away from the net cage after operation, which is a hazard of damaging the net. This is also the case with strong winds.

The net cages and its mooring system is designed to meet the requirements in NS9415, but the standard do not directly account for the forces from service vessels performing marine operations on the net cage. Larger and several vessels are being used in operations, which give a greater load on the net cage and the mooring system. Marine operations in bad weather can therefore give loads on moorings and the net cage that may exceed the capacity of the components (ref. Section 4.1.4). Operations should not be performed when bad weather may endanger human life, property and or environment. However, it is not clearly stated for what environmental conditions operations should be aborted.

5.3 Service and Maintenance of Floating Collar

Figure 5.7: Location of fish farm at Kvitneset (BarentsWatch, 2015)

Service and maintenance of the floating collars should be done between each output of fish in order to secure good conditions of the floating collar and prevent accidents as fish escapement. There are strict requirements for service and maintenance of the net in NS9415. However, there is no requirements for regular service and maintenance of floating collars. Thus, it might occur that floating collars not will be maintained for several years. This increase the risk of accidents and breakdowns.

The attended operation took place at Kvitneset in Nord-Trøndelag (ref. Figure 5.7), classified as inshore class 2 according to (Ryan et al., 2004) (ref. Section 4.1.3). During the operation the floating collars were cleaned for biofouling and dirt, as blue mussels, seaweed and other benthic organisms. Biofouling can become a source for diseases, besides giving extra weight and reducing the buoyancy of the collar. Furthermore, sharp blue mussels can cause cuts in ropes or holes in the net.

Figure 5.8: Picture from service and maintenance operation

The service vessel used was AQS Brage (LOA = 14.98 meter) with a crew of four, in addition to a cleaning barge. The cleaning barge is equipped with several nozzles, which clean the floating collars with high-pressured water from HPC located on the deck of the vessel. Both the floating collar and bottom ring are lifted up onto the barge, which moves around the circular floating collar using rotating hydraulic wheels. The cleaning process occurs by driving the barge two times around the cage. During or after operation, the blue mussels and dirt is manually shovelled away from the cleaning barge. The setup of the operation is illustrated in Figure 5.8.

5.3.1 Observed Challenges

At least one crewmember need to be out on the vessel deck to assist and control the operation during cleaning. The visibility is poor as water and biofouling is sprayed around, as seen in Figure 5.9. Communication with other crewmembers inside the wheelhouse is therefore limited. The blue mussels also have sharp edges and can become a potential hazard for eyes if protective goggles are not used.

Figure 5.9: Poor visibility during operation

Lifting the floating collar is a challenge because of inadequate design and limited crane capacity. The general hazards for crane operations identified during net cleaning operations are also relevant here. Further, the cleaning barge has no securing or railings, and therefore constitute a risk of falling into sea when standing on the barge, especially in bad weather. Further, there is a hazard of height difference that potentially can cause a fall accident when the personnel stands on the lifted collars as shown in Figure 5.10.

Figure 5.10: Potential hazard during operation

6 Formal Safety Assessment

In this chapter, the three first steps of the Formal Safety Assessment are utilised on the marine operations and are presented together with the results along the analysis.

6.1 Hazard Identification

As explained in Section 3.1.3, the aim of hazard identification is to investigate and identify hazards that can affect the marine operation under consideration. The hazard identification corresponds to Step 1 in the FSA.

The objective in this part is to identify hazards in different marine aquaculture operations, to understand the risk involved in the operations and to rank them according to frequency and consequence. By doing this, it is possible to establish generic accident categories that shall provide as input to the risk analysis.

6.1.1 Frequency Classes and Consequence Categories

To be able to rank the hazards identified during the PHA, frequency classes and consequence categories are established. The consequence categories should be enable to cover health, safety and environment in order to suit the problem under investigation. However, the categories proposed in the IMO (2013) FSA Guideline do not cover environmental impact. Thus, the frequency classes and consequence categories are established based on a combination of classes and categories given in Rausand (2011) and in the IMO (2013) FSA Guideline.

The definition of frequency classes is presented in Table 6.1, while the definition of consequence categories is presented in Table 6.2.

Table 6.1: Frequency classes (based on: IMO, 2013, Rausand, 2011)

FI	Category	Class	Description
1	Unlikely	Once per 100th year	Very rare event that will not necessarily be experienced. Likely to occur once in the lifetime of the total fleet of approx. 500 ships in Norway.
2	Possible	Once per 10th year	Rare event, but will possibly occur in a fleet of 100 ships, i.e. likely to occur in the total life of several similar ships.
3	Occasional	Once per year	Event that happens now and then in a fleet of 10 ships, i.e. normally be experienced a few times by the personnel during the ship's lifetime.
4	Frequent	Once per month or more often	Event that is expected to occur frequently on one ship

Table 6.2: Consequence categories (based on: IMO, 2013, Rausand, 2011)

SI	Category	Consequence types		
		People	Environment	Property
1	Minor	Minor insignificant injury. Injury can be treated at site and operation can continue.	Minor environmental damage	Minor insignificant property damage
2	Significant	Significant injury. Medical treatment and lost-time injury up to 7 days.	Local environmental damage of short duration (<1 month)	Minor system damage, minor production influence
3	Major	Major severe injury. Prolonged hospital treatment. Absence more than 7 days.	Time for restitution of ecological resources 2-5 years. Escaped salmon	Considerable system damage, production interrupted for weeks to months
4	Catastrophic	Severe injury causing death or serious injury for rest of life.	Time for restitution more than 5 years. Escaped salmon, large leaks etc.	Total loss of system, fish farm or vessel is wrecked/disabled

6.1.2 Hazard Identification Results

The hazard identification is carried out by performing a Preliminary Hazard Analysis (ref. Section 3.3.2.2) and is based on hazard logs, excursions and observation of operations, follow-up work and discussions. The hazard logs are presented in Appendix B.

A total of 62 hazards were identified and evaluated for their frequencies and consequence within the following operational phases:

- Work on deck/net cage and entering/disembarking vessel/net cage (8 hazards)
- Lift operation (10 hazards)
- Net cleaning operation (5 hazards)
- Vessel berthing to net cage (18 hazards)
- Delousing operation (12 hazards)
- Cleaning of floating collar (9 hazards)

Based on subjective and qualitative estimates of their frequencies and consequences by this thesis authors, the hazards have been ranked to establish a prioritised list of the most severe hazards. The spread of these hazards are graphically illustrated in Table 6.3, while the top ranked hazards are presented in Table 6.4. The complete PHA is given in Appendix C.

Table 6.3: The spread of hazards

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent		3	2	
3	Occasional	3	6	4	5
2	Possible		10	13	11
1	Unlikely			1	4

Table 6.3, shows that many of the identified hazards are located in red area indicating that the risk level is not acceptable and risk reduction is required. The risk level of the hazards in yellow area is acceptable, but use of ALARP principle (ref. section 3.1.4.4) and further analysis should be considered. For those hazards in white area, the risk level is found acceptable.

Table 6.4: Top-ranked hazards

No	Hazard	RPN
2-5	Worker pushing/pulling lifted objects	7
2-7	Workers cannot hear each other and get hit by lifted object	7
4-6	Vessel laying on crowfoot pushing crowfoot and floating cage collar down	7
4-17	Vessel transferring large point-loads to the floating cage collar	7
6-4	Worker fall into sea when standing on lifted floating collar	7
6-5	Lifting strops snaps due to high tension and hits worker	7
6-9	Slip/trip when entering cleaning barge/net cage	7
1-4	Fall into cold water when entering/disembarking vessel	6
1-7	Fall down from level above	6
2-1	Lifted object swing and hit worker	6
2-3	Lifted object falls down and hit worker	6
2-8	Vessel losing stability when lifting object	6
3-1	Wear and tear on net from cleaning equipment	6
3-2	Cleaning equipment tangled in ropes or net	6
3-5	Lifting heavy equipment by hand	6
4-1	Propel in contact or stuck in crowfoot or other ropes	6
4-2	Propel in contact with net	6
4-14	Communication error when approaching and berthing to net cage	6
4-18	Vessel hitting floating collar	6
5-4	Contact between the net and the bottom ring and/or the rope/chain down to bottom ring	6
5-5	Moving vessel hit/squeeze worker on net cage	6
5-9	To strong blending/too long treatment when delousing	6
5-10	O2 fails during delousing	6
5-12	Worker tangled in rope and get pulled down by the rope when lowering the bottom ring	6

By using the information, knowledge and data collected in the PHA, generic accident categories for further work in the risk analysis are developed. A systematic evaluation of the hazards identified in the PHA, with special focus on the top-ranked hazards in Table 6.4, is conducted to develop the accident categories. These, with their belonging causes, are presented in Table 6.5.

Table 6.5: Accident categories and there main causes

Accident categories	**Main causes**
Trip/slip	Wet and slippery surface, untidy deck, inappropriate design, human error, severe weather conditions, unstable vessel, gap between vessel and net cage/quay
Hit by object	Human error, poor/missing sea fastening, severe weather, swinging object, falling object, ropes in tension, snapping object, degradation, pushing/pulling lifted object, lack of crew competence, communication error, moving vessel
Squeeze/trapped	Moving object/equipment, pushing/pulling objects, moving vessel, use of capstan
Collision/contact	Slack crowfoot, strong current, floating ropes, lack of crew competence, communication error, human error, severe weather, technical failure, inappropriate/inadequate design, drifting vessel, mooring line failure
Capsize	Inappropriate design, lack of crew competence, severe weather conditions
Hole in net	Wear and tear from equipment, sharp equipment or organic material, thruster/propeller, human error, lack of crew competence
Other occupational accidents	Inappropriate design, lack of crew competence, heavy lifts, sharp edges
Death of fish	Human error, lack of crew competence, technical failure

The statistics and the top ranked hazards in Table 6.4, indicates that the accident categories involving the occupational accidents; trip/slip, hit by object and squeeze/trapped, should be prioritized in the risk analysis in Step 2. Furthermore, the operational related accident categories; collision/contact and hole in net, should also be prioritized in the risk analysis.

However, in the scope of this study, hole in net is assumed to occur only due to collision/contact accidents. The accident category hole in net is therefore combined into the collision/contact accident category. Other occupational accidents, death of fish and capsize are not believed to be very critical to personnel safety, property and environment, due low overall contribution to the overall risk picture. Other scenarios found in the PHA that are out of scope of this thesis, will not be taken further in this study either.

6.2 Risk Analysis

As elaborated in Section 3.1.4, the purpose of the risk analysis in this part is to perform a thorough investigation of the causes, initiating events and consequences of the more important accident categories identified in the hazard identification. Following this approach, the work in this study can be focused upon high-risk areas and factors that influence the level of risk; can be identified and evaluated. The risk analysis corresponds to Step 2 in the FSA.

By performing a causal and frequency assessment and a consequence assessment, the risk can be modelled.

6.2.1 Accident Categories

The generic accidents scenarios was established in Section 6.1.2, based on a PHA, and is summarised in Figure 6.1. These are selected for further study in the following risk analysis and work as the initiating event/hazardous event used in the Event Tree Analysis later in this report.

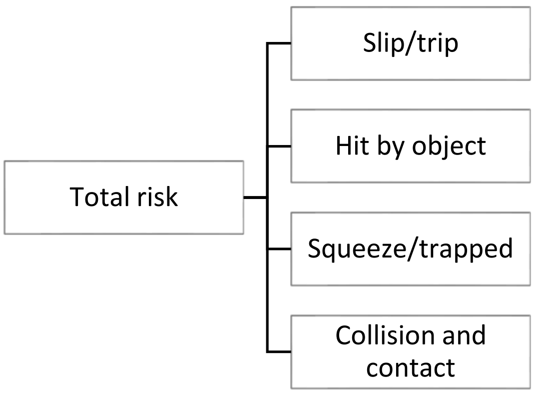


Figure 6.1: Generic accident scenarios

6.2.2 Risk Acceptance Criteria

In order to evaluate the risk estimated in the risk analysis, an appropriate risk acceptance criteria must be established (ref. Section 3.1.4.4).

Most of the accidents in the aquaculture industry involves occupational injuries and damage to environment or property. Except some few accidents with several fatalities, accidents in the aquaculture industry involves accidents with few fatalities. Thus, only individual risk will be assessed in this study.

Individual acceptance criteria adopted for this study is based on recommendations in HSE (2001), and is presented in Table 6.6.

Table 6.6: Individual risk acceptance criteria for personnel in marine aquaculture operations (HSE, 2001)

	To personnel	**To third parties**
Unacceptable risk per year	$> 10^{-3}$	$> 10^{-4}$
ALARP region per year	$10^{-6} – 10^{-3}$	$10^{-6} – 10^{-4}$
Broadly acceptable risk per year	$< 10^{-6}$	$< 10^{-6}$

6.2.3 Causal and Frequency Analysis

A detailed Causal and Frequency Analysis can be modelled by use of e.g. fault tree or Bayesian Belief Networks (BBN). Common for both, are that they have a top event or a main event that represent accident categories in the risk contribution tree. These top events can be calculated based on the causal data. However, due to limited available causal data in this study, the accident frequency are estimated based on available statistics, and therefore not modelled through FTA, BBN or similar.

6.2.3.1 Frequency Analysis

The frequency of an initiating event for each risk sub-model is based on historic accident frequencies presented in Section 4.2, with some adjustments to fit the scope of this study.

70% of all reported accidents occur either on vessel deck or on the floating collar. The remaining 30% are not relevant within the scope of this study. Hench, frequencies for slip/trip, hit by object and squeeze/trapped are reduced accordingly, i.e. slip/trip reduced to 1.8×10^{-3} per year, hit by object to 1.9×10^{-3} per year and squeeze/trapped to 1.5×10^{-3} per year.

For collision and contact accidents, the statistics are more uncertain and NLIA, NMD and NDF are all keeping their own statistics. A total of twelve collision accidents are registered in the NLIA database in the period of 2003 to 2009 and 2010 to 2015. However, this do not only concern collision with vessel, but collision with e.g. a truck. In addition, nine escapement accidents involving service vessel and were reported to NMD in the period 2006 to 2009. These accidents may be referred to as contact accidents. In 2015, NMD presented numbers showing that out of 109 accidents in 2015, 42% were caused by operation related failure. If assuming 30% of these was collision/contact related, about fourteen collision/contact related accidents where registered in 2015. This is by the authors of this study found to be reasonable, as fish farms are being located more exposed and vessel gets larger compared to ten years ago. In scope of this study, only collision and contact accidents between vessel and net cage are modelled. Considering this, it is reasonable to assume that this will lead to escapement of fish and therefore suitable to use the statistics from only NDF. This also prevent the uncertainty regarding double counting when using statistic from different databases. Thus, the frequency of the initiating event collision and contact is estimated to 3.1×10^{-3} per year.

The suggested accident frequencies are represented in Table 6.7.

Table 6.7: Accident frequency for generic accident scenarios

Generic accident scenarios	**Accident frequency (per personnelyear)**
Slip/trip	1.8×10^{-3}
Hit by object	1.9×10^{-3}
Squeezed/trapped	1.5×10^{-3}
Collision/contact	3.1×10^{-3}

No further assessment of causal factors will be performed in thesis. However, Salomonsen (2010) findings of most common triggering causes, independent of accident, was found to be: wrong execution of the task, standing in wrong position, wrong use of equipment, incorrect lifting, defective equipment, insufficient securing protective measures not/partly completed.

6.2.3.2 Consequence Assessment

A systematic approach using Event Tree Analysis on the four generic accident scenarios (defined in Section 6.2.1) is utilised in agreement with the results from previous hazard identification and analysis of available accident data. This section describes the background and modelling of four event trees, where the accident categories are used as initiating event in the event tree.

The models have been established by attending and observing operations, interviews and expert judgement of the authors. Each branch in the event tree has an outcome including an end event description, degree of material damage and frequency. The end frequency of each generic accident scenario is calculated by multiplying the frequency of the initiating event with each branch probability along the pathway to the end event. The risk contribution is calculated by multiplying the end frequency with the consequence of the scenario.

6.2.3.3 Quantifying the Event Trees

As there are limiting published accident information available, several assumptions are made through the quantitative analyses. Several different approaches and techniques have been used in order to assign the branch probabilities for the various escalating events. By doing this, it has been possible to quantify the probabilities and consequences associated with each scenario in the event tree.

The initiating event is based on the results and assumptions made in the frequency analysis. Further, general assumptions by the authors are made where suited, and an expert evaluation based on answers from a team of experts have been utilised in order to arrive at a consequence estimate for each accident scenario. The expert evaluation scheme was established based on the established models, and is attached in Appendix D. The general assumption made by the authors of this paper will be presented in the following paragraphs together with conceptual risk model of each accident category. The modelled event trees are attached in Appendix E.

Slip/trip

A typical slip/trip scenario might develop in the following way. First, the hazardous event of slipping or tripping occurs. The scenario might develop in different way according to where the accident occur. In the scope of this study, accident occurring at vessel deck and at floating collar are of specific interest and will be investigated further. Furthermore, the slip/trip might occur when the weather conditions are bad. If the weather is good, the likelihood of further escalation of the accident is regarded as smaller compared to if the weather is bad. It is regarded in all accidents that if the weather is bad, the impact will most probably be larger, it will be harder to survive and to evacuate. The slip/trip might cause different degree of personal injury and it can cause the person to fall into the sea. Falling into the sea is regarded as worse than not falling into the sea. Cold water will cool down the person and it might cause shock and slow down motions. The person must also stay afloat, swim and get out of the water, to be able to survive. Using life west will increase the probability of surviving, while working alone will decrease the probability, as the person must be able to save himself. The risk model illustrated in Figure 6.2 describes a typical slip/trip accident, which the event tree in Appendix E.1 is based on.

Slip/trip frequency

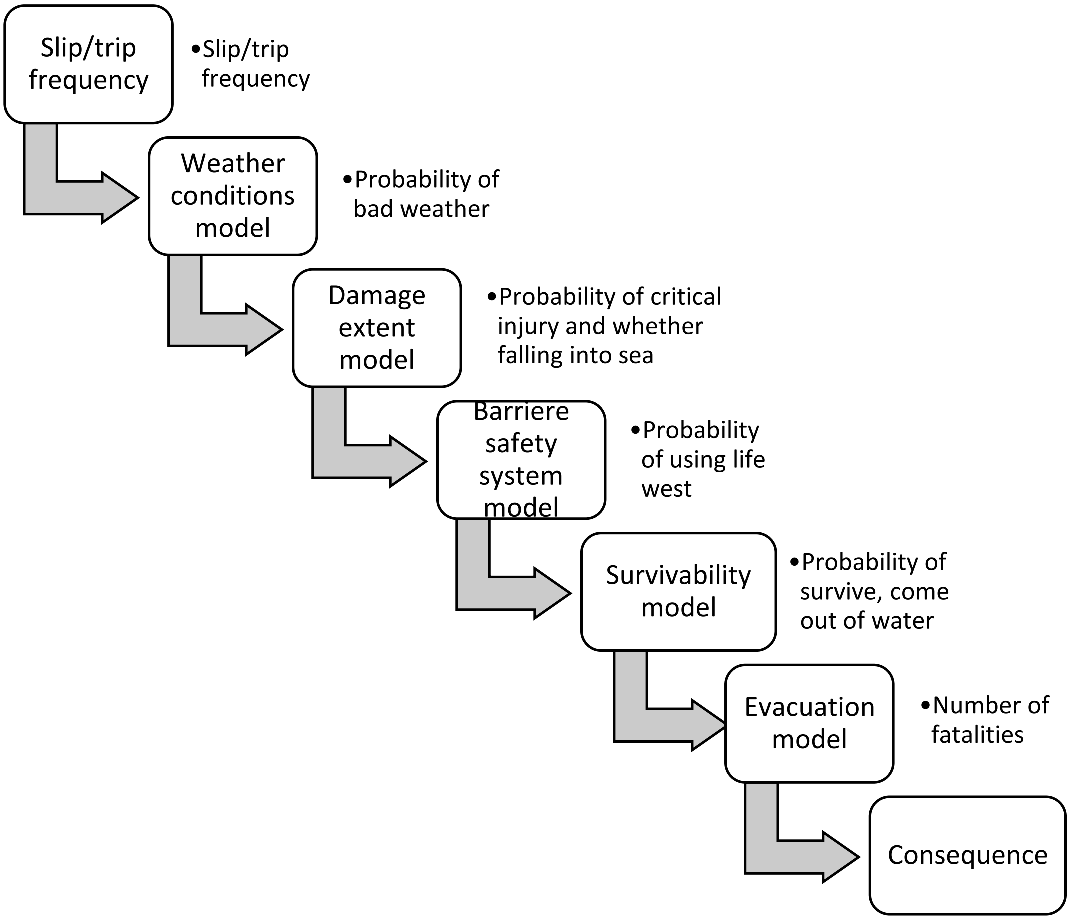


Figure 6.2: Conceptual model of slip/trip accident

The overall frequency for slip/trip incidents estimated in Tabell 6.7, is used, i.e. 1.80E-03 per year (ref Section 6.2.3.1).

Level 1

Slip/trip distribution is based on accident distribution estimated in Tabell 6.7, i.e. 35% of accidents happens on vessel deck, 35% on floating collar and 30% happen on other location not relevant for this study. As the slip/trip frequency already consider this, the distribution is distributed equally between vessel deck and floating collar.

Level 2

The slip/trip accident occur either when the weather conditions are bad or good. If the weather is good, the likelihood of further escalation of the accident is regarded as smaller compared to if the weather is bad. Bad weather increase the motions in vessel and floating collar and it is therefore assumed that most fall accidents occur when it is bad weather. Considering this, the probability of bad weather, given slip/trip accident occurred, is assumed to be 0.7.

Level 3 & 4

There are limiting data available on whether the slip/trip incident cause critical injuries or not and if it results in falling into the sea. However, if the weather is good, the likelihood of further escalation of the accident is regarded as smaller compared to if the weather is bad. Further falling into the sea when slipping/tripping on floating collar is assessed to be higher than when slipping/tripping on vessel deck. On the floating collar, there is limited protection against falling into the sea, while on a vessel there is normally protected with railings. Branch probabilities comes from the expert evaluation and correspond well to the considerations made above.

Level 5

There is no data available on whether crew are using life west or not. However, use of safety and protective equipment have been focus area for several years and have by many companies been integrated in the safety procedures of the company. Use of life west is today more widespread than for only few years ago. Based on this consideration, a probability of not using life west of 0.1 is used.

Level 6

Less and less work is performed alone, and if working alone, it become more normal to have to follow reporting procedures where the worker has to report to fixed times. It is understand that most alone work today is performed in the weekends, when a reduced number of workers are at work and only performing necessary routine work. Most accidents happens when the activity is highest, hence during weekday when less alone work are performed. At the same time, working alone can lead to more stressful situations leading to dangerous incidents. Based on these considerations, a conditional probability of working alone of 0.2 is used.

Level 7

The assessment of whether a person is able to get out of water or not when fallen into sea, is based on expert evaluation. It follows that the probability is largest if it is bad weather, the person is critical injured and bot are not using life west and is working alone.

Hit by Object

Both hit by object and squeeze/trapped scenarios will resemble the slip/trip scenarios as many of the same factors contribute and the impact often result in a fall into sea scenario. Hit by object scenario, might develop in the following way.

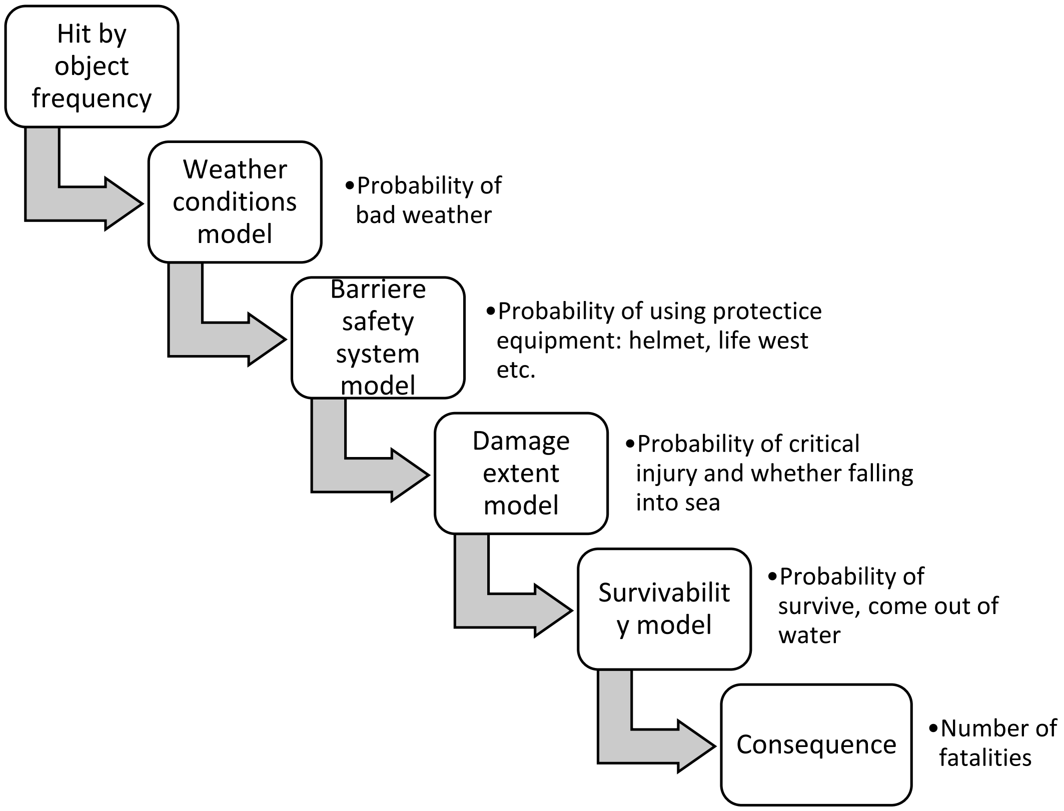


Figure 6.3: Conceptual model of hit by object accident

First, the hazardous event occurs and it will have a distribution between vessel, floating cage collar and other locations. Furthermore, as for slip/trip, the scenario can occur during bad weather, which will have an effect on the further development of the scenario. The damage extent model are dependent on whether the involved part is using protective equipment or not, which is covered in the barrier safety system model. The impact from the object may give different level of damage, which is covered in the damage extent model. Only damage to worker is analysed in this model and damage to property and possible damage to environment is kept outside the model. Significance of damage and injury on worker depends on where the worker is hit and depending on degree of force in the impact. The impact may cause the worker to fall into the sea, which connect this model to previous slip/trip model. The survivability model is therefore connected to this part in the slip/trip model when worker has fallen into the sea due to impact, but it cover the probability of surviving when not fallen into the sea as well. The risk model illustrated in Figure 6.3 describes a typical hit by object accident, which the event tree in Appendix E.2 is based on.

Hit by object frequency

The overall frequency for hit by object incidents estimated in Tabell 6.7, is used, i.e. 1.9E-03 per year (ref Section 6.2.3.1).

Level 1 & 2

Based on the same considerations as for slip/trip, the hit by object distribution is distributed equally between vessel deck and floating collar and the probability of bad weather is assumed to be 0.7.

Level 3

As for slip/trip, it is assumed good use of protective equipment. Still it is considered that use of life west is more common than use of helmet. Based on this consideration, a probability of not using a helmet is set to 0.2.

Level 4 & 5

There are limiting data available on whether the hit by object accident cause critical injuries or not and if it results in falling into the sea. However, if the weather is good, the likelihood of further escalation of the accident is regarded as smaller compared to if the weather is bad. Further falling into the sea when hit by object on floating collar is assumed higher than when hit by object on vessel deck. On the floating collar, there is limited protection against falling into the sea, while on a vessel there is normally protection with railings. Branch probabilities comes from the expert evaluation and correspond well to the considerations made above.

Level 6

Hit by object is normally caused by lifted object or being hit by a snapping object as a rope in tension. As reasoned for slip/trip, less and less work is performed alone. However, to be hit by a lifted object, normally two persons must be involved. One controlling the crane and one assisting the lift or standing close to the lifted object resulting in being hit by the object. It is become more usual to use remote control for the crane, which can lead in more incidents involving hit by lifted object, as the crane operator stand free to move around. Hit by a snapping object can occur independent of working alone or not, but assuming most alone work exist of routine work – the probability of being alone when accident occur is assumed low. Considering this, a conditional probability of working alone of 0.4 is used.

Level 7

The assessment of whether a person is able to get out of water or not when fallen into sea, is based on the same expert evaluation as for slip/trip.

Squeezed/Trapped

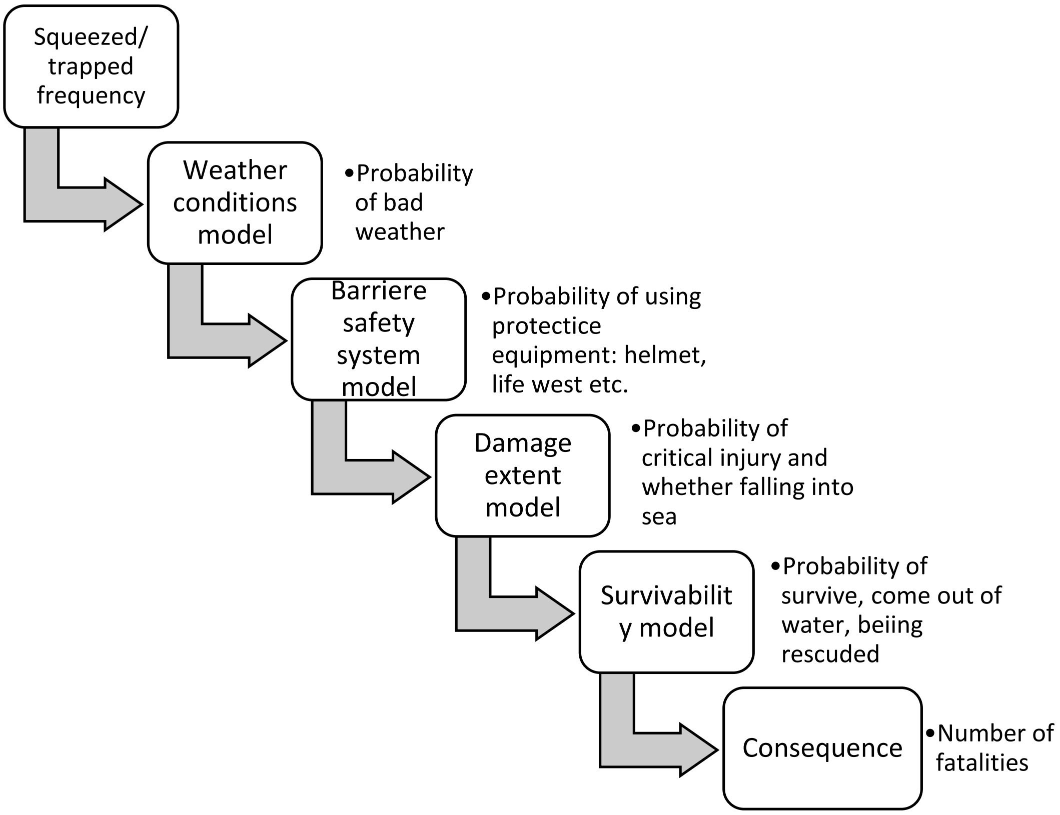


Figure 6.4: Conceptual model of squeeze/trapped accident

Squeeze/trapped scenario, might develop in the following way. First, the hazardous event occurs and it will have a distribution between vessel, floating cage collar and other locations. Furthermore, as for previous models, the scenario can occur during bad weather, which will have an effect on the further development of the scenario. The damage extent model are, as for hit by object scenario, dependent on whether the involved part is using protective equipment or not, which is covered in the barrier safety system model. The impact from being squeezed or trapped may give different level of damage, which is covered in the damage extent model. As earlier, only damage to worker is analysed in this model and damage to property and possible damage to environment is kept outside the model. Significance of damage and injury on worker depends on how the worker is squeezed/trapped and it depends on the degree of force in the impact. The impact may cause the worker to fall into the sea, which connect this model to previous slip/trip model. The survivability model is therefore connected to this part in the slip/trip model when worker has fallen into the sea due to impact, but it cover the probability of surviving when not fallen into the sea as well. The risk model illustrated in Figure 6.4 describes a typical hit by object accident, which the event tree in Appendix E.3 is based on.

Squeeze/trapped frequency

The overall frequency for squeeze/trapped incidents estimated in Tabell 6.7 is used, i.e. 1.5E-03 per year (ref Section 6.2.3.1).

Level 1 & 2

Based on the same considerations as earlier, the squeeze/trapped distribution is distributed equally between vessel deck and floating collar and the probability of bad weather is assumed to be 0.7.

Level 3

Contrary to slip/trip and hit by object accidents, the use of protective equipment against squeeze/trapped is assumed not good. Merely because few good solutions are available, except perhaps safety shoes. Use of life west is considered good. Based on these considerations, a probability of not using protective equipment is set to 0.7.

Level 4 & 5

There are limiting data available on whether the squeeze/trapped accident cause critical injuries or not and if it results in falling into the sea. However, if the weather is good, the likelihood of further escalation of the accident is regarded as smaller compared to if the weather is bad. Further falling into the sea when squeeze/trapped on floating collar is assumed higher than when squeeze/trapped on vessel deck. On the floating collar, there is limited protection against falling into the sea, while on a vessel there is normally protection with railings. Branch probabilities comes from the expert evaluation and correspond well to the considerations made above.

Level 6

The same assumption for working alone in slip/trip accidents is made for squeeze/trapped accidents. A probability of working alone is therefore set to 0.2.

Level 7

The assessment of whether a person is able to get out of water or not when fallen into sea, is based on the same expert evaluation as earlier.

Collision/Contact

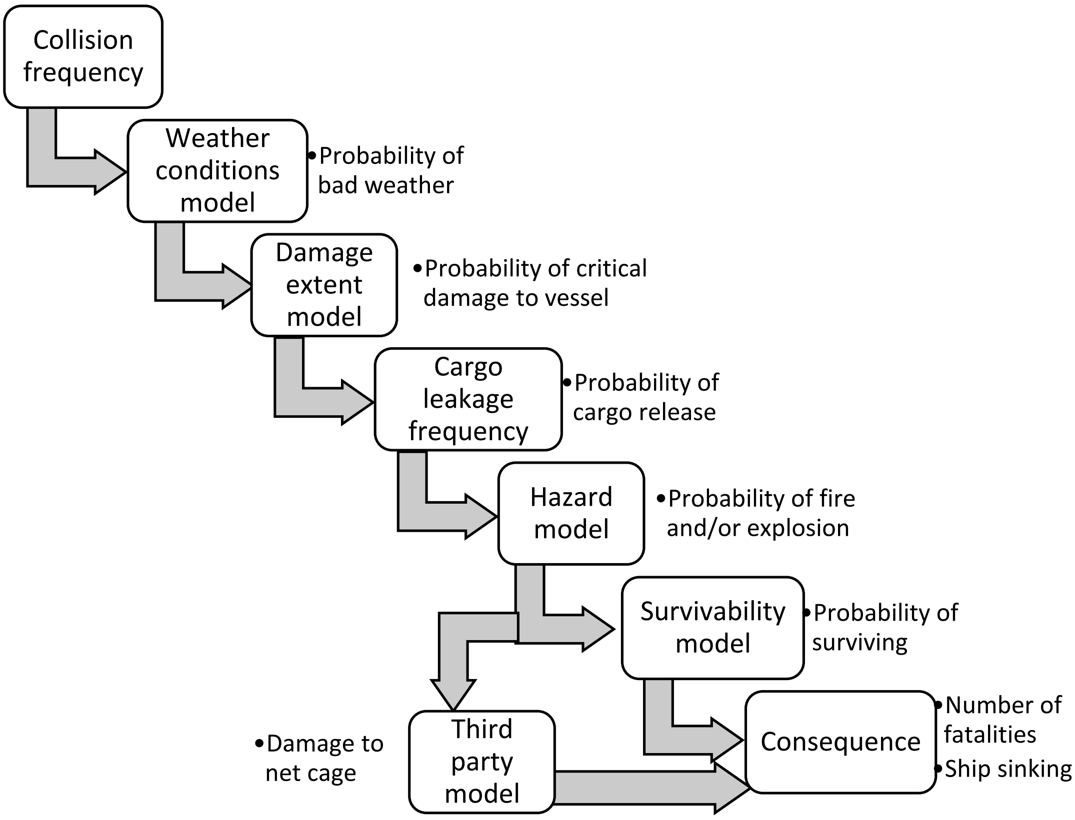


Figure 6.5: Conceptual model of collision/contact accident

A typical collision/contact scenario with an aquaculture service vessel might develop in the following way. First, a collision/contact occur. The collision/contact progress will be affected by whether it is bad or good weather. Similar to the other models, the likelihood of further escalation of the accident is regarded to be higher if the weather is bad compared to if the weather is good. The service vessel may be the striking ship or the ship that is struck. However, in the scope of this study, only collision/contact accidents between vessel and net cage is assessed. Whether the ship is the striking ship or not, is therefore in this model not relevant. Thus, independent of if the service vessel is the struck or striking ship; the damage extent model only covers if the service vessel get critical damage and weather this damage may lead to a leak of fuel or oil. If fuel or oil is released, it can cause hazards model including fire and explosions. Still the probability for this is low; it can cause the ship to sink and potential loss of several human life. Finally, the model includes possible damage and fatalities to any third part crew, including damage to net cage and escapement of fish. The risk model illustrated in Figure 6.5 describes a typical collision/contact accident, which the event tree in Appendix E.4 is based on.

Collision/contact frequency

The overall frequency for collision/contact incidents estimated in Tabell 6.7 is used, i.e. 3.1E-03 per year (ref Section 6.2.3.1).

Level 1

Based on the same considerations as for slip/trip, the probability of bad weather is assumed to be 0.7.

Level 2, 3, 4 & 5

The evaluation of branch probability for critical damage to vessel, leak, fire/explosion and not surviving are based on expert evaluation, as there is limited or none data available to assess it based on historic data.

Level 6

The same assumption, made earlier for working alone, is made for squeeze/trapped accidents. A probability of working alone is therefore set to 0.2.

Level 7 & 8

The third party model including whether net cage are critical damaged or not and the probability of fatalities among other than crew, are based on expert evaluation.

6.2.4 Risk Analysis Results

In this part the results from the risk analysis is presented. A frequency analysis is utilized, based on available statistic, to analyse the frequency of each accident scenario. A consequence analysis existing of an Event Tree Analysis has been utilized, to analyse and display the event sequence that may follow a specific hazardous event.

The results from the frequency analysis is used as input in the consequence analyse. Based on this, together with different assumptions and expert evaluations, can the following results from the consequence analysis be presented. Table 6.8, 6.9, 6.10, 6.11 and 6.12 summarize the consequence spectrum for the hazardous events in each event tree (ref. Section 3.3.2.4).

Table 6.8: Consequence spectrum for event tree, Slip/trip

i	Consequences	Risk contribution per year
FF1.1.1	Drowning, not rescued and not able to get out of water	7.7E-06
FF1.1.2	Able to get out of water, but critical injured	1.0E-06
FF1.2.1	Drowning, not rescued in time and not able to get out of water	2.2E-05
FF1.2.2	Rescued, but critical injured	1.1E-05
FF1.3.1	Drowning, not rescued and not able to get out of water	4.5E-05
FF1.3.2	Able to get out of water, but critical injured	2.8E-05
FF1.4.1	Drowning, not rescued in time and not able to get out of water	5.7E-05
FF1.4.2	Rescued, but critical injured	2.0E-04
FF1.5.1	Drowning, not rescued and not able to get out of water	6.8E-06
FF1.5.2	Able to get out of water, less severe injury	3.4E-06
FF1.6.1	Drowning, not rescued in time and not able to get out of water	1.8E-05
FF1.6.2	Able to get out of water, less severe injury	1.8E-05
FF1.7.1	Drowning, not rescued and not able to get out of water	4.3E-05
FF1.7.2	Able to get out of water, less severe injury	4.0E-05
FF1.8.1	Drowning, not rescued in time and not able to get out of water	7.3E-05
FF1.8.2	Able to get out of water, less severe injury	2.1E-04
FF1.9	Not falling into sea, but critical injured	3.1E-05
...	(Consequences recurring, but with different degree and end frequency. See event tree model for full description.)	...
FV2.9	Not falling into sea, but critical injured	7.3E-06
	Sum frequency	**1.32E-03**

Table 6.9: Consequence spectrum for event tree, Hit by Object

i	Consequences	Risk contribution per year
HF1.1.1	Drowning - not able to get out of water or dies directly from impact.	1.1E-04
HF1.1.2	Seriously injury, head and body damage. Disabled	2.0E-05
HF1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	1.2E-04
HF1.2.2	Seriously injured, head and slightly less body damage. Disabled	7.9E-05
HF1.3.1	Dies directly from impact	2.1E-05
HF1.3.2	Seriously injured, head and slightly less body damage. Disabled	4.9E-05
HF1.4.1	Drowning and not able to get out of water. Do not die directly from impact	2.2E-05
HF1.4.2	Significant injury, cold and wet from falling into sea	1.1E-05
HF1.5.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	2.1E-05
HF1.5.2	Minor injury, cold and wet from falling into sea	1.1E-05
HF1.6.1	Drowning - not able to get out of water	2.1E-04
HF1.6.2	Seriously injury, body damage. Prolonged hospital treatment	1.3E-04
HF1.7.1	Drowning - not able to get out of water or rescued.	1.0E-04
HF1.7.2	Seriously injured, body damage, wet and cold. Prolonged hospital treatment	3.6E-04
HF1.8.1	Dies directly from impact or of the injury from impact	6.1E-05
HF1.8.2	Seriously injured, body damage. Prolonged hospital treatment	1.1E-04
HF1.9.1	Drowning and not able to get out of water. Do not die directly from impact	1.1E-04
HF1.9.2	Minor injury, cold and wet from falling into sea	5.1E-05
HF1.10.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	7.1E-05
HF1.10.2	Minor injury, cold and wet from falling into sea	1.0E-04
...	(Consequences recurring, but with different degree and end frequency. See event tree model for full description.)	...
HV2.10.2	Minor injury, cold and wet from falling into sea	2.7E-05
	Sum frequency	**4.38E-03**

Table 6.10: Consequence spectrum for event tree, Squeeze/trapped

i	Consequences	Risk contribution per year
SF1.1.1	Drowning - not able to get out of water or dies directly from impact.	8.9E-05
SF1.1.2	Seriously injured to body. Prolonged hospital treatment	1.2E-05
SF1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	2.5E-04
SF1.2.2	Seriously injury to body. Prolonged hospital treatment	1.3E-04
SF1.3.1	Dies directly from impact	6.4E-05
SF1.3.2	Seriously injured, body damage. Prolonged hospital treatment	1.6E-04
SF1.4.1	Drowning and not able to get out of water. Do not die directly from impact	4.3E-05
SF1.4.2	Minor injury, cold and wet from falling into sea	1.1E-05
SF1.5	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	1.1E-04
SF1.6.1	Drowning - not able to get out of water or dies directly from impact.	1.8E-05
SF1.6.2	Seriously injured, body damage.	7.4E-06
SF1.7.1	Drowning - not able to get out of water or rescued or dies directly from impact.	2.3E-05
SF1.7.2	Significant injured, cold and wet from falling into sea	5.4E-05
SF1.8.1	Dies directly from impact or of the injury from impact	2.0E-05
SF1.8.2	Significant injured from impact	3.4E-05
SF1.9.1	Drowning - not able to get out of water	1.7E-05
SF1.9.2	Minor injury, cold and wet from falling into sea	8.0E-06
SF1.10	Drowning - not able to get out of water or rescued.	2.9E-05
...	(Consequences recurring, but with different degree and end frequency. See event tree model for full description.)	...
SV2.10	Drowning - not able to get out of water or rescued	5.1E-06
	Sum frequency	**2.24E-03**

Table 6.11: Consequence spectrum for event tree, Collision

i	Consequences	Risk contribution per year		
		Individual	**Environment**	**Property**
C1.1	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	2.0E-06	1.5E-06	2.0E-06
C1.2	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4.9E-07	3.7E-07	4.9E-07
C1.3	Vessel critical damaged, leak and explosion. Vessel sinks due to damage. Workers evacuated	6.9E-06	1.0E-05	1.4E-05
C1.4	Vessel critical damaged, leak of fuel, oil etc. Detected and explosion prevented	3.7E-05	7.3E-05	7.3E-05
C1.5	Vessel critical damaged, but no leak or fatalities	3.7E-04	0.0E+00	7.3E-04
C1.6	Vessel minor damaged	0.0E+00	0.0E+00	1.8E-03
C2.1	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	6.1E-07	4.6E-07	6.1E-07
C2.2	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	1.5E-07	1.2E-07	1.5E-07
C2.3	Vessel critical damaged, leak and explosion. Vessel sinks due to damage. Workers evacuated	2.2E-06	3.3E-06	4.3E-06
C2.4	Vessel critical damaged, leak of fuel, oil etc. Detected and explosion prevented	1.2E-05	2.3E-05	2.3E-05
C2.5	Vessel critical damaged, but no leak or fatalities	1.2E-04	0.0E+00	2.3E-04
C2.6	Vessel minor damaged	0.0E+00	0.0E+00	8.0E-04
	Sum frequency	**5.42E-04**	**1.12E-04**	**3.65E-03**

Table 6.12: Consequence spectrum for event tree, Collision – third parties

i	Consequences	Risk contribution per year		
		Individual	**Environment**	**Property**
C1.1.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	8.4E-07	8.4E-07	6.3E-07
C1.1.2	Net cage critical damaged. Significant escapement of fish	0.0E+00	1.3E-05	9.4E-06
C1.1.3	Net cage minor damaged. Minor escapement	0.0E+00	2.1E-06	7.1E-07
...	(Consequences recurring, but with different degree and end frequency. See event tree model for full description.)	...	...	...
C2.6.3	Net cage minor damaged. Minor escapement	0.0E+00	6.0E-04	2.0E-04
	Sum frequency	**6.24E-04**	**1.18E-02**	**8.10E-03**

The total risk picture within the scope of this study is presented in Table 6.13. Based on the results, it can be concluded that individual risk levels are outside the ALARP region and hence in the unacceptable risk region (ref. Section 6.2.2). Furthermore, the individual third parties risk level is found to be in unacceptable risk region. According to the predefined risk acceptance criteria, the risk calculations suggest that risk reduction measures must be implemented to reduce the overall risk level. Furthermore, the risk level for environment and property are found to be high, especially for third parties environmental risk due to impact from fish escapements. There are not set any risk acceptance criteria for property and environment, but for i.e. fish escapement, it is a zero-request for escapement.

In this respect, the analysis shows that focus must especially be placed on hit by object- and squeeze/trapped- related accidents. Furthermore, to reduce impact on environment, property and individual third parties, focus should be placed on collision/contact accidents.

Table 6.13: Risk picture, individual risk level and individual third parties risk level

Accident Category	Frequency (per year)	Frequency (%)	Individual Risk (per year)	Individual Risk (%)
Slip/trip	0.52E-03	9%	1.32E-03	15.8%
Hit by object	1.53E-03	26%	4.26E-03	50.9%
Squeeze/trapped	0.78E-04	13%	2.24E-03	26.8%
Collision/contact	3.10E-03	52%	0.54E-03	6.5%
Total	**5.93E-03**	**100%**	**8.36E-03**	**100%**
Total third parties	3.11E-03	-	6.24E-04	-

6.3 Risk Control Measures

The objective is, as elaborated in Section 3.1.5, to propose effective and practical risk control measures on activities and systems with high risk. The high-risk areas can be extracted from the results in the risk analysis. Establishment of risk control measures corresponds to Step 3 in the FSA.

6.3.1 Risk Areas Needing Control

The results from the frequency and consequence analysis in the risk analysis form the basis of which area that need control.

The individual risk per year for each of the occupational accident categories (slip/trip, hit by object and squeeze/trapped) is all in area of unacceptable risk according to the risk acceptance criteria (ref. Section 6.2.2). Thus, it follows that the overall risk picture of individual risk per year is, as previous mention, unacceptable. The initiating events established in the frequency assessment (ref. Section 6.2.3.1) are all high as well. This indicates that both pro- and reactive measures must be implemented.

The event tree models raise three lists of areas that need control (ref. Section 3.1.5). Table 6.14 and 6.15 lists the area needing control based on risk level, Table 6.16 lists the area needing control based on high probability regardless of their severity, while Table 6.17 lists the area needing control based on high severity irrespectively of their probability.

Table 6.14: Area needing control based on risk level

HE	i	End of event tree description	Risk
Slip/trip	FF1.8.2	Able to get out of water, less severe injury	2.1E-04
	FF1.4.2	Rescued, but critical injured	2.0E-04
Hit by object	HF1.7.2	Seriously injured, body damage, wet and cold. Prolonged hospital treatment	3.6E-04
	HF1.6.1	Drowning - not able to get out of water	2.1E-04
	HV1.7.2	Seriously injured, body damage, wet and cold. Prolonged hospital treatment	1.6E-04
	HV1.8.1	Dies directly from impact or of the injury from impact	1.6E-04
	HF2.7.2	Seriously injured, body damage, wet and cold. Prolonged hospital treatment	1.5E-04
	HF1.6.2	Seriously injured, body damage. Prolonged hospital treatment	1.3E-04
	HF1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	1.2E-04
	HV1.8.2	Seriously injured, body damage. Prolonged hospital treatment	1.2E-04
	HV2.8.2	Seriously injured, body damage. Prolonged hospital treatment	1.2E-04
	HF1.1.1	Drowning - not able to get out of water or dies directly from impact.	1.1E-04
	HF1.8.2	Seriously injured, body damage. Prolonged hospital treatment	1.1E-04
	HF1.9.1	Drowning and not able to get out of water. Do not die directly from impact	1.1E-04
	HF1.10.2	Minor injury, cold and wet from falling into sea	1.0E-04
	HV1.3.2	Seriously injury, head and slightly less body damage. Disable	1.0E-04
	HF1.7.1	Drowning - not able to get out of water or rescued.	1.0E-04
Squeeze/ trapped	SV1.8.2	Significant injury from impact	2.7E-04
	SF1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	2.5E-04
	SF1.3.2	Seriously injury, body damage. Prolonged hospital treatment	1.6E-04
	SF1.2.2	Seriously injury to body. Prolonged hospital treatment	1.3E-04
	SF1.5	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	1.1E-04
Collision	C1.5	Vessel critical damaged, but no leak or fatalities	3.7E-04
	C2.5	Vessel critical damaged, but no leak or fatalities	1.2E-04
Collision 3.parts	C1.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	3.6E-04
	C2.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	1.5E-04

Table 6.15: Area needing control based on risk level for environment and property

HE	i	End of event tree description	Risk
Collision (property)	C.1.6	Vessel minor damaged	1.8E-03
	C.2.6	Vessel minor damaged	8.0E-04
	C.1.5	Vessel critical damaged, but no leak or fatalities. Minor injuries	7.3E-04
	C.2.5	Vessel critical damaged, but no leak or fatalities. Minor injuries	2.3E-04
Collision 3.parts (environment)	C1.6.2	Net cage critical damaged. Significant escapement of fish	5.5E-03
	C2.6.2	Net cage critical damaged. Significant escapement of fish	2.3E-03
	C1.5.2	Net cage critical damaged. Significant escapement of fish	1.1E-03
	C1.6.3	Net cage minor damaged. Minor escapement	9.3E-04
	C2.6.3	Net cage minor damaged. Minor escapement	6.0E-04
	C1.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	3.6E-04
	C2.5.2	Net cage critical damaged. Significant escapement of fish	3.2E-04
	C1.5.3	Net cage minor damaged. Minor escapement	1.9E-04
	C2.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	1.5E-04
	C1.4.2	Net cage critical damaged. Significant escapement of fish	1.1E-04
Collision 3.parts (property)	C1.6.2	Net cage critical damaged. Significant escapement of fish	4.1E-03
	C2.6.2	Net cage critical damaged. Significant escapement of fish	1.7E-03
	C1.5.2	Net cage critical damaged. Significant escapement of fish	8.5E-04
	C1.6.3	Net cage minor damaged. Minor escapement	3.1E-04
	C1.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	2.7E-04
	C2.5.2	Net cage critical damaged. Significant escapement of fish	2.4E-04
	C2.6.3	Net cage minor damaged. Minor escapement	2.0E-04
	C2.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	1.1E-04

Table 6.16: Area needing control based on probability

HE	i	End of event tree description	Freq.
Slip/trip	FF1.8.2	Able to get out of water, less severe injury	1.0E-04
Hit by object	HF1.7.2	Seriously injured, body damage, wet and cold. Prolonged hospital treatment	1.2E-04
	HF1.10.2	Minor injury, cold and wet from falling into sea	1.0E-04
Squeeze/ trapped	SV1.8.2	Significant injury from impact	1.4E-04
	SF1.3.2	Seriously injured, body damage. Prolonged hospital treatment	1.2E-04
Collision	C.1.6	Vessel minor damaged	1.8E-03
	C2.6	Vessel minor damaged	8.0E-04
	C.1.5	Vessel critical damaged, but no leak or fatalities	3.7E-04
	C2.5	Vessel critical damaged, but no leak or fatalities	1.2E-04
Collision 3.parts	C1.6.2	Net cage critical damaged. Significant escapement of fish	1.4E-03
	C2.6.2	Net cage critical damaged. Significant escapement of fish	5.6E-04
	C1.6.3	Net cage minor damaged. Minor escapement	3.1E-04
	C1.5.2	Net cage critical damaged. Significant escapement of fish	2.8E-04
	C2.6.3	Net cage minor damaged. Minor escapement	2.0E-04

Table 6.17: Area needing control based on severity

HE	i	End of event tree description	Cons.
Slip/trip	Fx.1.1	Drowning, not rescued and not able to get out of water	4
	Fxx.2.1	Drowning, not rescued in time and not able to get out of water	4
	Fxx.3.1	Drowning, not rescued and not able to get out of water	4
	Fxx.4.1	Drowning, not rescued in time and not able to get out of water	4
	Fxx.5.1	Drowning, not rescued and not able to get out of water	4
	Fxx.6.1	Drowning, not rescued in time and not able to get out of water	4
	Fxx.7.1	Drowning, not rescued and not able to get out of water	4
Hit by object	Hxx.1.1	Drowning - not able to get out of water or dies directly from impact.	4
	Hxx.1.2	Seriously injured, head and body damage. Disabled	4
	Hxx.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4
	Hxx.2.2	Seriously injured, head and slightly less body damage. Disabled	4
	Hxx.3.1	Dies directly from impact	4
	Hxx.3.2	Seriously injury, head and slightly less body damage. Disable	4
	Hxx.4.1	Drowning and not able to get out of water. Do not die directly from impact	4
	Hxx.5.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4
	Hxx.6.1	Drowning - not able to get out of water	4
	Hxx.7.1	Drowning - not able to get out of water or rescued.	4
	Hxx.8.1	Dies directly from impact or of the injury from impact	4

	Hxx.9.1	Drowning and not able to get out of water. Do not die directly from impact	4
	Hxx.10.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4
Squeeze/ trapped	Sxx.1.1	Drowning - not able to get out of water or dies directly from impact.	4
	Sxx.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4
	Sxx.3.1	Dies directly from impact	4
	Sxx.4.1	Drowning and not able to get out of water. Do not die directly from impact	4
	Sxx.5	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4
	Sxx.6.1	Drowning - not able to get out of water or dies directly from impact.	4
	Sxx.7.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4
	Sxx.8.1	Dies directly from impact or of the injury from impact	4
	Sxx.9.1	Drowning - not able to get out of water	4
	Sxx.10	Drowning - not able to get out of water or rescued.	4
Collision (individua l)	Cx.1	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4
	Cx.2	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4
	Cx.x.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	4
Collision (Environ ment	Cx.x.1	Net cage critical damaged. Worker hit and dies of impact. Significant escapement of fish	4
	Cx.x.2	Net cage critical damaged. Significant escpament of fish	4
Collision (property)	Cx.1	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4
	Cx.2	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4
	Cx.3	Vessel critical damaged, leak and explosion. Vessel sinks due to damage. Workers evacuated	4

This shows that some scenarios for individual third parties risk have a higher risk level than acceptable. Furthermore, some scenarios have high frequency, but the main contribution seems to come from many scenarios having a high consequence factor. Many of the established scenarios have drowning as a consequence, which is a result from falling into sea. This is, thus, a common worst-case consequence for the accident categories slip/trip, hit by object and sqeezed/trapped. Critical human injury is also recurring, especially for the following accident categories; hit by object and collision/contact. Furthermore, significant fish escapement is a common worst-case consequence that is recurring for collision/contact accident category.

Drowning and critical human injury together with critical damage to net cage are therefore recurring areas that need control.

6.3.2 Potential Risk Control Measures

The aim of the risk control measures are to improve safety in the operations in the aquaculture industry. The measures are established based on the previously risk analysis and identified areas that need control. A brainstorming session has been utilised by the authors, in order to establish the risk control measures. The results from this session is presented in Table 6.18.The solutions are further described in Section 8.2.

Table 6.18: Results from brainstorming session for risk control measures

Problem	Description	Brainstorming solutions
Hit by object	- Critical injured - Drowning	- Service vessel o Mark the safety zones on deck or design safe areas o Automatic/remote hook o Clearly marking of strops/ropes capacity o Equipment/lift beam designed for lifting of bottom ring (reduce number of lifts) o Kongsberg LARS launching system for ROV and other equipment o Moonpool deployment for equipment o Placement of crane o Ballasting system o Warning system (heeling) o Communication system – integrated in bridge o “Clean railings” o Guide pins - Management o Weather window o Safety equipment o Safety training
Slip/trip (fall)	- Drowning - Critical injured	- Service vessel o Safe stairs/ladder from vessel. “Protection” – only one access o Anti-slip deck o Secure all openings in railings on vessel o Tidy workplace o Winches for hoses o Module-based equipment. Every equipment has its place on deck in regard to operation

		- Net cage o Hand rails / railings o Safety line o Emergency climbing ladder if falling into sea - Regulation o Alarm system if fallen into sea. Saltwater-tablet that is activated when in contact with saltwater. - BARGE
Collision/contact	- Damage to net cage/vessel - Hole in net / fish escape - Fatality due to injury	- Service vessel o Automatic-tension mooring system o “Easymoor”, “Hook&Moor”, prevent movement of crew to/from vessel and net cage o Dynamic Positioning o Bridge layout o Thrusters forward and aft. Enough thruster capacity. o Propeller protection o Weather window, decision support system based on environment - Net cage o Hook for fixed mooring line – easy pick-up o Mooring fastening for vessel on net cage o External mooring system - easy pick-up o Floating movable raft o Other net materials o Subsea cage o System for lowering bridles o AUV system for daily check o Requirement to use chains as bridles - Management o Weather window o All components fit to each other, 3. part
Squeeze trapped	-	- Service vessel Use of winches where possible instead of capstan

In order to establish measures that can improve both safety and efficiency, further assessment of these risk control measures is performed together with improvement measures later in this thesis. After establishment of improvement measures, the different measures will be combined into joint control options for further assessment and recommendation for decision-makers. In the following Chapter 7, the Continual Improvement Assessment will be utilised.

7 Continual Improvement Assessment

For Continual Improvement Assessment, the KOSTER III model is selected. The aim of this assessment however, is to improve efficiency in individual marine operations. Thus, only Step 3 of the KOSTER III model will be utilised in this study (ref. Section 3.2.5). However, as this is a continual process, the full KOSTER III model is presented in Section 3.2.2 for the purpose that companies can use this paper for future reference in order to perform a full continual improvement assessment.

7.1 Improvement of Individual Activities

7.1.1 Mapping the Process

As elaborated in Section 3.2.5.1, the purpose of mapping the process is to get a good understanding of the situation in the company. This stage includes four phases; mapping the company, choose processes for further analysis, map the individual processes and draw flow charts. In the scope of this paper, the first phase of mapping the company is not performed. Furthermore, choosing processes for further analysis is executed in matters of three operations targeted by the collaborating companies (ref. Chapter 5).

Mapping of the individual processes is presented in the following sections by analysing what is giving value and further to get knowledge of inputs to and outputs from the operations. SIPOC diagram and KANO Model is used. In addition, there has been established flow charts of each operation.

7.1.1.1 Map the Individual Process

The purpose of this phase is to identify what is bringing value in the process. This is important to understand to be able to separate between activities that adds value and activities that do not add value, and to utilize the operations according to what the customer requires from the product or in this case the operation.

The objective of this phase is therefore to identify what that is bringing value in the different operations, and to understand what the customer is requiring from the operations. By identifying non-value-added activities (ref. section 3.2.1.1), these can be reduced and thus increase the efficiency of the operations. The analysis is carried out by using SIPOC diagram and Kano Model (ref. Section 3.3.3.1 and 3.3.3.2).

SIPOC Diagram Results

The SIPOC diagram identify and characterise the key driving influences in a process without focusing on the process it selves. This give a basic understanding of what outputs the operations process gets from given input. The results from the SIPOC diagram are presented in Table 7.1, 7.2 and 7.3.

Table 7.1: SIPOC Diagram, Net Cleaning

Suppliers	Inputs	Outputs	Customer
	High pressure cleaner	Clean nets, remove organic material growing on the net	Fish farm companies
	ROV/RONC	Better O_2 for the fish and better growth conditions, less drag loads on net	
	Cleaning equipment	Removes lice larva and the organic material they lives in	
	Vessel w/crane	Larger effect for cleaning fish (eat lice not organic material)	
	Workers/ manpower	Do not need to change net (reduced work/risk)	
		Reduced cost for impregnation	

Table 7.2: SIPOC Diagram, Delousing

Suppliers	Inputs	Outputs	Customer
	Vessels w/crane and capstan	Remove/kill lice	Fish farm companies
	Chemicals	Improve the quality of life of the fish	
	Tarpaulin and other equipment	Improve the quality of the fish	
	ROV	Keep the number of lice below requirements (can keep fish until correct size)	
	Fuel	Reduce the danger of infection of other cages and wild stock	
	Workers/manpower	Effective treatment method when working, compared to other methods (in form of time consuming)	
		Minimal stress on salmon, compared to other methods	

Table 7.3: SIPOC Diagram, Service and Maintenance Floating Collar

Suppliers	Inputs	Outputs	Customer
	Vessels w/crane and capstan	Clean floating collar and bottom ring	Fish farm companies
	Cleaning barge	Service and maintained floating collar and bottom ring	
	HPC	Improved lifetime of floating collar	
	Fuel	Reduced risk of breakdown of floating collar	
	Spare parts		
	Tools		
	Workers/manpower		

Kano Model Results

The Kano Model is used to understand the customer's satisfaction. The customer will based on many requirements and decision criteria, buy the option they believe gives the best overall value for them. The Kano Model is used to divide the different requirements into different categories of importance to the customer, thus get a better understanding of what is most important for the customer (ref. Section 3.3.3.2). However, when buying services as net cleaning, delousing or services from well boat companies, it is often negotiated agreements and contracts for a longer duration of time to ensure that the services is available when needed. An important factor is also who operates in the area, and in many cases, the customer cannot choose and pick from a high number of providers. This limits the customers' possibilities to choose freely between suppliers. The results from the Kano Model are presented in Table 7,4.

Table 7.4: Kano model results

Item	Needs	Wants	Delighters
General	Reputation	Price	Service
	Quality	High operability	
	HSE	Good presence in the area	
	Good treatment of the fish	Documentation of work	
Net cleaning	Clean net; good water flow and O_2, less load on net	Regular net cleaning	Efficiency/longer time between each clean operation
	Non-personal involvement	Control of net after cleaning	Collection of organic material
Delousing	Effective treatment	Keep number of lice below requirements	Reduce danger of infection of other farms and wild stock
	Quality of fish and fish welfare	Efficiency of operation	
	Documentation of effect	Degree of personal involvement	
		Minimal stress on fish	
Service and maintenance of floating collar	Cleaning floating collar and bottom ring	Repair damages to floating collar and bottom ring	
	Service and maintain floating collar and bottom ring	Effective operation	

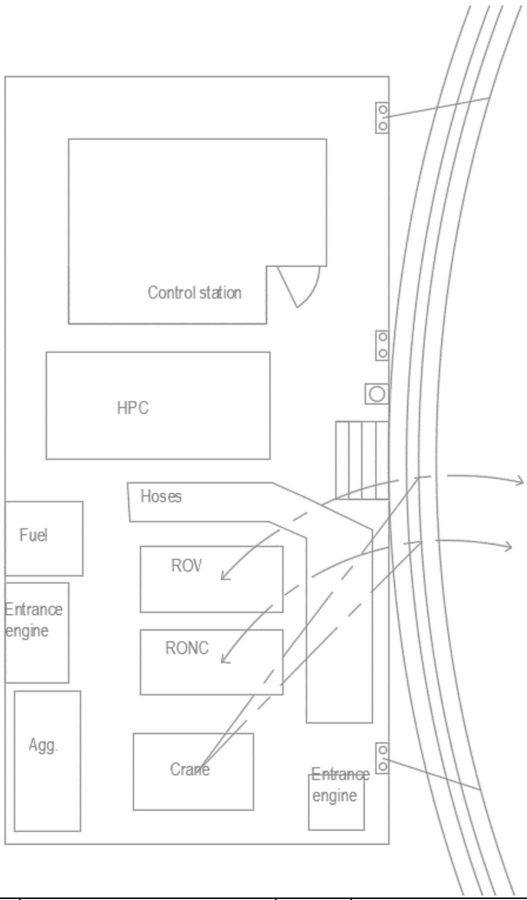
7.1.1.2 Draw Flow Chart of the Individual Process

The purpose of this phase is to visualize the details in the process of the operations. This will be the foundation of the next two steps in the analysis, which is to establish key performance indicators and analyse the process (ref. Section 3.2.5.1).

A flow process chart is the technique chosen to map the process in the different operations in this study (ref. Section 3.3.3.3). This chart includes an overview of the operation and use different symbols to indicate which type of action that are performed in each step of the operation. The analysis is based on attended operations and belonging STEP diagrams. The results from the flow process charts are presented in Table 7.5, 7.6 and 7.7. Each process is summarised in the top of the chart.

Table 7.5: Flow process chart, Net cleaning

Flow Process Chart		Summary				
Process:		Action		Present	Proposed	Difference
Net cleaning operation		○	Operation	12		
Charted by:		⇨	Transportation	4		
Hatlem and Kvamme		□	Inspection	1		
Organization:		D	Delays	1		
AQS		▽	Storage			

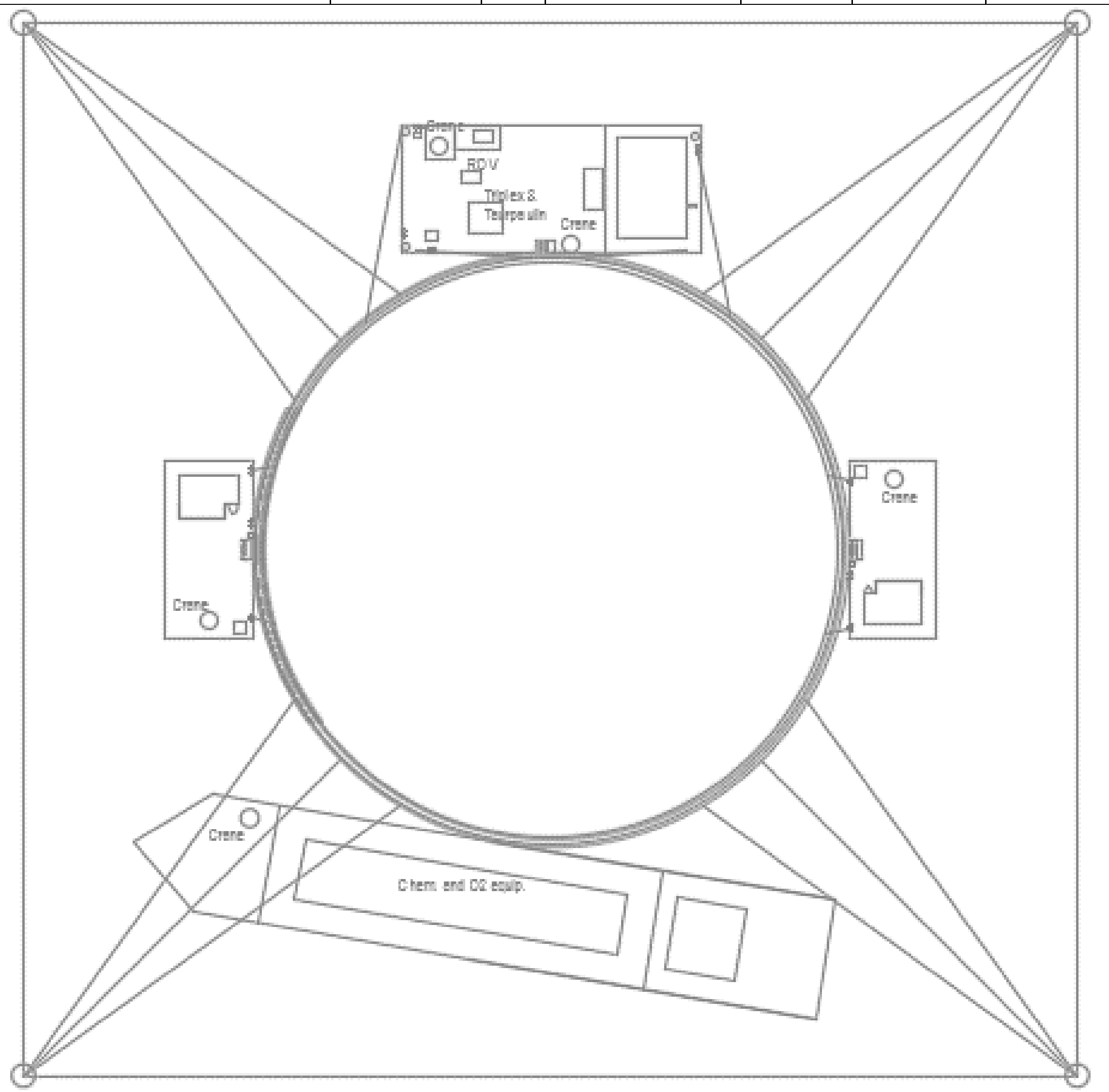


1.	Prepare vessel	● ⇨ □ D ▽	2.	Put off quay	● ⇨ □ D ▽
3.	Transit to site	○ ➡ □ D ▽	4.	Moor to net cage	● ⇨ □ D ▽
5.	Prepare net cage for operation	● ⇨ □ D ▽	6.	Connect hook to ROV	● ⇨ □ D ▽
7.	Lift, turn and lower ROV	○ ➡ □ D ▽	8.	Unhook ROV	● ⇨ □ D ▽

9.	Connect hook to RONC	● ⇨ □ D ▽	10.	Lift, turn and lower RONC	○ ➡ □ D ▽
11.	Unhook RONC	● ⇨ □ D ▽	12.	Release hoses into cage	○ ➡ □ D ▽
13.	Start HPC	● ⇨ □ D ▽	14.	Wait for correct temperature on HPC	○ ⇨ □ ◗ ▽
15.	Release ROV and RONC	● ⇨ □ D ▽	16.	Perform cleaning operation	● ⇨ □ D ▽
17.	Continuously monitor system	○ ⇨ ■ D ▽	18.	Finish operation in lift back equipment in reverse order	● ⇨ □ D ▽

Table 7.6: Flow process chart, Delousing

Flow Process Chart		Summary				
Process:		Action		Present	Proposed	Difference
Delousing operation		○	Operation	22		
Charted by:		⇨	Transportation	5		
Hatlem and Kvamme		□	Inspection	3		
Organization:		D	Delays	1		
AQS		▽	Storage			



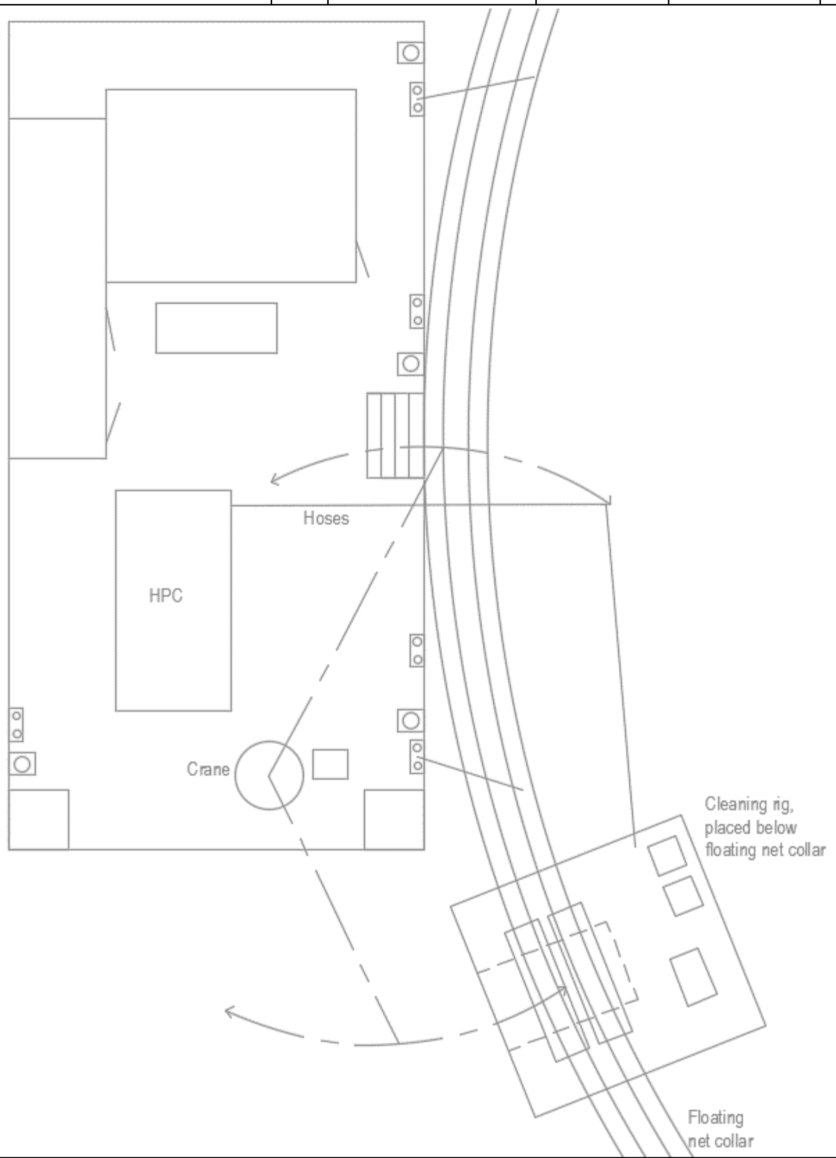
Vessels: Customer x2 (C1 and C2), Tarpaulin vessel (TV) and Chemical vessel (CV)

1.	Prepare vessel (all)	● ⇨ □ D ▽	2.	Put off quay	● ⇨ □ D ▽
3.	Transit to site	○ ➡ □ D ▽	4.	Moor to net cage (C1,C2,TV)	● ⇨ □ D ▽

5.	Prepare lift of bottom ring in steps (to 6-7 meter)	● ⇨ □ D ▽	6.	Pull rope/chain from bottom ring max 5-8 meter using capstan or crane	● ⇨ □ D ▽
7.	Unmoor, move and moor vessel for next rope	○ ➡ □ D ▽	8.	Repeat lift of rope/chain, until lifted to 6-7 m	● ⇨ □ D ▽
9.	Take up slack in net	● ⇨ □ D ▽	10.	Lift up net tip/dead fish equipment	● ⇨ □ D ▽
11.	CV moor to net cage	● ⇨ □ D ▽	12.	CV lift out O2 equipment	● ⇨ □ D ▽
13.	TV prepare ropes for pulling tarpaulin. 7 ropes pulled below crowfoots to position 0’ 45’, 90’ and 135’	● ⇨ □ D ▽	14.	TV mount a weight to the tarpaulin	● ⇨ □ D ▽
15.	Lift and release the ROV for monitoring the operation (TV)	● ⇨ □ D ▽	16.	TV start to release tarpaulin (preferable against the stream)	● ⇨ □ D ▽
17.	CV, C1 and C2 start to pull tarpaulin with capstan	● ⇨ □ D ▽	18.	Use ROV to monitor process (TV)	○ ⇨ ■ D ▽
19.	The tarpaulin is tied to the net cage when pulled on place	● ⇨ □ D ▽	20.	Control O2 level (CV)	● ⇨ □ D ▽
21.	Pump out medicine (CV)	● ⇨ □ D ▽	22.	Continuously control O2 level (CV)	○ ⇨ ■ D ▽
23.	Wait for treatment to be finished	○ ⇨ □ ◗ ▽	24.	Release ropes tied to net cage	● ⇨ □ D ▽
25.	Pull back tarpaulin using triplex (TV)	● ⇨ □ D ▽	26.	Use ROV to monitor process (TV)	○ ⇨ ■ D ▽
27.	Lift back ROV (TV)	● ⇨ □ D ▽	28.	CV disembark and leave net cage	○ ➡ □ D ▽
29.	C1, C2 and TV lower the bottom ring and put cage back in order in reversed order	● ➡ □ D ▽	30.	C1, C2 and TV disembark and leave net cage.	○ ➡ □ D ▽

Table 7.7: Flow Process Chart, Service and Maintenance Floating Collar

Flow Process Chart		Summary				
Process:		Action		Present	Proposed	Difference
Service and maintenance		○	Operation	25		
Charted by:		⇨	Transportation	5		
Hatlem and Kvamme		□	Inspection	1		
Organization:		D	Delays	1		
AQS		▽	Storage			



1.	Prepare vessel	● ⇨ □ D ▽	2.	Put off quay	● ⇨ □ D ▽
3.	Transit to site	○ ➡ □ D ▽	4.	Moor to net cage	● ⇨ □ D ▽
5.	Prepare net cage for operation	● ⇨ □ D ▽	6.	Walk around net cage to check if everything	● ➡ □ D ▽

				is okay; no ropes, bottom ring at 1.5 m, release the bird "cage"	
7.	Lift up floating net collar	●⇨□D▽	8.	Lift the bottom ring up on 2-3 places aft of vessel	●⇨□D▽
9.	Pull cleaning rig below the floating net collar using two capstans	●⇨□D▽	10.	Lower the bottom ring back down	●⇨□D▽
11.	Lower the floating collar back down	●⇨□D▽	12.	Pick up hoses and el-cable from cleaning rig and lift on board vessel	●⇨□D▽
13.	Connect power cable to vessel and hoses to HPC	●⇨□D▽	14.	Drive cleaning rig and control and fit all cleaning nozzles. Ensure that everything is okay	●⇨□D▽
15.	Start and wait for correct temperature on HPC	○⇨□◗▽	16.	Perform cleaning operation by manually driving the cleaning rig	●⇨□D▽
17.	Drive the vessel in front of cleaning rig	○➡□D▽	18.	Continuously monitor system	○⇨■D▽
19.	Clean for a second round	●⇨□D▽	20.	Stop cleaner when finished round 2	●⇨□D▽
21.	Disconnect power and hoses and lift back to cleaning rig	●⇨□D▽	22.	Lift back up bottom ring 2-3 places	●⇨□D▽
23.	Lift up floating collar	●⇨□D▽	24.	Pull out the cleaning rig with capstans and moor to vessel	○➡□D▽
25.	Lower the floating net collar	●⇨□D▽	26.	Lower down the bottom ring to 1.5 m	●⇨□D▽
27.	Connect to manual pumps for cleaning of rig	●⇨□D▽	28.	Lift up one side of rig, to make it easier to clean	●⇨□D▽
29.	Cleaning of rig	●⇨□D▽	30.	Lower down the rig and disconnect the pumps	●⇨□D▽
31.	Disembark and transit to next cage or back to quay	○➡□D▽			

7.1.2 Establish Key Performance Indicators

In order to describe the performance of the process, key performance indicators have to be established by the company before implementing the improvement measures (ref. Section 3.5.2.2). These indicators have been found to be:

- Net cleaning:
  - Time to clean on net
  - Change over time between cages
  - Cleaning efficiency
- Delousing
  - Time of delousing one cage
  - Change over time between cages
  - Effect of treatment
- Service and maintenance of floating collar
  - Time of cleaning floating collar
  - Change over time between cages
  - Time of maintaining one cage
  - Cleaning efficiency

The indicators most suited, should be selected by the company depending on available information, what type of operation and which improvement measures that will be implemented.

7.1.3 Analysis the Process

The purpose of the third stage of analysing the processes is to identify areas of problems in the process and their causes, which can be improved in order to increase efficiency in the process (ref. Section 3.2.5.3). This stage includes three phases:

1. Identify areas of problems
2. What is the cause of the problems
3. Identify possible bottlenecks

The following sections will execute and present the results of this analyse.

7.1.3.1 Identify Areas of Problems

The area of problems in this section are based on the attended operations (ref. Chapter 5) and conversations with the personnel.

Net Cleaning

During the observation of net cleaning, several issues affecting the efficiency of the operation was observed. Some of the issues was regarding stop in machinery, which cause delays in the operation, e.g. after a leak in the oil filter in the HPC. Furthermore, inadequate design can be a problem. An example is with the ROV that has buoyancy control, while the RONC has not. Thus, during a system stop, the RONC will sink to the bottom, if not driven to the surface and tied to the floating collar. The ROV will on the other hand keep its position because of its buoyancy control. Such inadequate design of the RONC makes the operation less efficient when not properly fitted to its purpose. However, the ROV is more costly and require more maintenance than the RONC. Furthermore, driving of the ROV and the RONC might have potential of becoming more autonomous.

An untidy deck can further make operations more difficult and time consuming to perform as well as unsafe concerning tripping over obstacles or slipping in oil leaks. During the operation, hoses were manually pulled back onto deck and equipment were manually assisted during crane lifts. Manual handling of equipment makes the operation physically heavy and less efficient, and at the same time less safe. Solution limiting manual handling can thus increase efficiency and safety in the operation.

Delousing

Delousing with use of a tarpaulin is a demanding operation, and requires good planning and communication with all vessels and personnel participating. During the observation, the operation was delayed several days because of poor planning in respect to the weather. Strong wind was the main problem in addition to currents and waves. Furthermore, the decision on cancelling the operations, were mostly experience based, not knowledge based. By improving planning and according to weather forecasts, it is larger probability for carrying out the operations as planned. Furthermore, if the forecasted weather conditions not allows the operation to be performed, the resources can be used elsewhere.

When several actors and vessels are involved, good communication is essential. Poor communication can lead to misunderstanding causing that necessary equipment is forgotten or that wrong equipment is brought. Furthermore, lack of or poor communication make it hard to give correct orders and to carry out the operation efficiently. Operations with many personnel, many vessels, operations that is carried out at an exposed location or in bad weather, increase these difficulties and the importance of good communication. These issues may among other lead to unnecessary work, unnecessary transit and result in the operation not being optimal executed.

Berth the vessel to the net cage is a recurring problem, especially for larger vessels. The problem increases in harsh weather, where wind, current and waves are making it hard to safely berth to the net cage. There is inadequate design or no good solution for berthing to the net cages in harsh weather condition. Sailing up next to the fish farms can in addition be difficult due to several other reasons like stress, lack of skills and reduced propulsion power. This contribute to make the operation unsafe and inefficient.

Service and Maintenance of Floating Collar

The HPC is placed on the vessel and not the cleaning barge. The vessel must therefore sail in front of the barge during the operation. This makes the operation more demanding and time consuming to perform, than if the cleaning barge could be operated around the floating collar independently of the vessel. Furthermore, the set-up of the process make it necessary to connect and disconnect cables and hoses for each floating collar that are cleaned.

The operation of lifting the floating collar and place the barge below the collar is also demanding, especially in bad weather. If the customer has not properly prepared the floating collars for operation, e.g. with lifting bottom ring to 1.5 m, this will increase set-up time further and might cause additional stops during the cleaning operation. Likewise, lift operations of bottom ring and floating collar have several challenges that should be further looked into.

Further, inadequate design of the cleaning barge, cause accumulation of blue mussels and dirt on the barge deck during operation. This must be manually shovelled away both after, and sometimes during, the operation and causing delays. Manually work is time consuming and might in addition cause back or neck problems for the personnel.

7.1.3.2 Areas of Problems Results

Based on the sections above with observations and talking to personnel, the following main areas of problems have been identified and chosen for further investigation:

- Berth to net cage
- Unnecessary work and transit
- Lift of bottom ring and floating collar
- Inadequate design of cleaning barge

7.1.3.3 What is the Cause of the Problems

The aim of this phase is to identify the causes of the problems identified in previous phase. A Cause and Effect Analysis followed by a Five Whys Analysis are utilized (ref. Section 3.3.3.4 and 3.3.3.5). The main findings from the Cause and Effect Analysis is presented in the following sections.

Berth to Net Cage

The cause and effect diagram established for berthing to the net cages is illustrated in Figure 7.1.

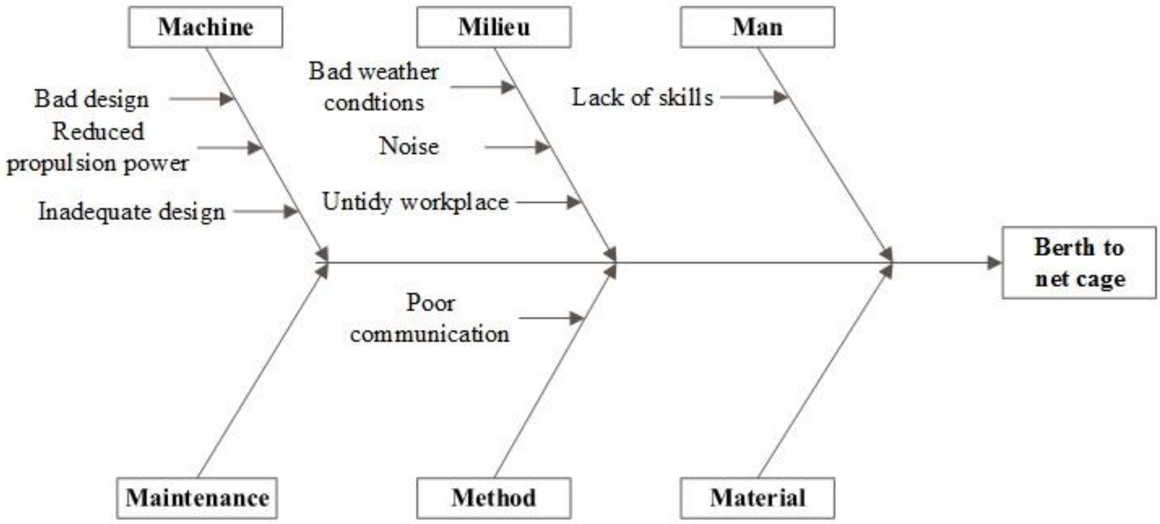


Figure 7.1: Fish bone diagram, Berth to net cage

As observed, there is few adequate solutions to berth to a net cage today, especially for large vessels and during harsh weather conditions. Furthermore, reduced propulsion, poor communication and lack of skills can make berthing difficult.

The root causes for these problems has been further analysed in the Five Whys method presented in Appendix F.1.

Unnecessary Work and Transit

Figure 7.2 shows the cause and effect diagram established for issues regarding unnecessary work and transit.

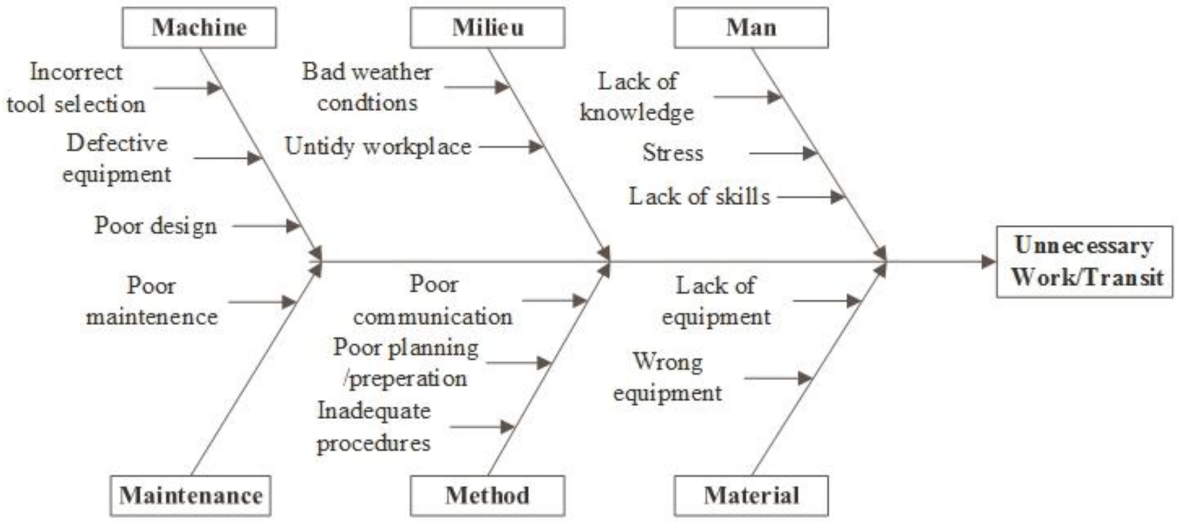


Figure 7.2: Fish bone diagram, Unnecessary work and transit

Unnecessary work, planning and preparing for an operation that is later aborted due to weather conditions, is a recurring problem. This issue will increase in the future as fish farms tends to be located more exposed in harsher weather conditions. Aborted or delayed operations causes a lot of unnecessary transit back and forth to the fish farm. A more effective way of decision-making around performing the operation or not in e.g. bad weather, seems to be missing and only relay on the skipper's previous experience. Furthermore, forgotten or lack of equipment needed for the operation is also an example that leads to unnecessary work.

If equipment and net cages are not properly prepared, it can lead to unwanted delays and stops in the operation. A good dialog with the customer is necessary as they often prepare the cage before the service vessels arrive. Furthermore, poor communication, lack of knowledge and poor maintenance are some of the issues contributing to unnecessary work and transit.

The root causes are identified using Five Why Analysis and are presented in Appendix f.2.

<u>Lift of Bottom Ring and Floating Collar</u>

A cause and effect diagram for issues regarding lift of bottom ring and floating collar is established and presented in Figure 7.3.

Issues with lifting bottom ring and floating collar are mainly concerning limited crane capacity and poor design. Furthermore, lift of bottom ring need multiple lifts and movement of vessel and is a recurring process in several different operations. Thus, reducing the necessary amount needed lifts and movements of vessel, will contribute to increase efficiency in several operations. As for the other operations, lack of skill, bad weather conditions and poor communication, are causes that limits the operation. The issues and their causes are further described in Appendix f.3.

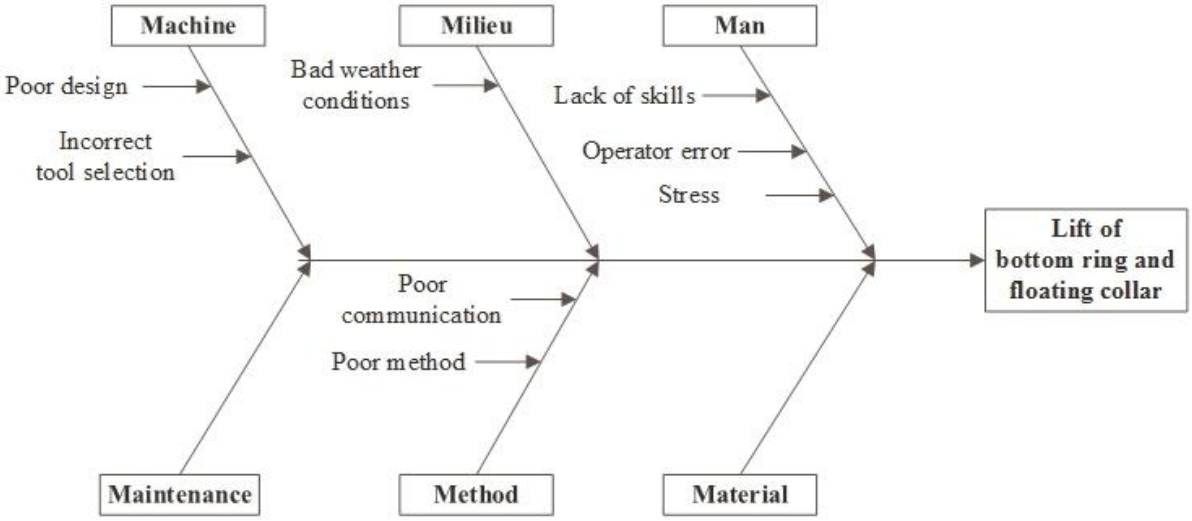


Figure 7.3: Fish bone diagram, Lift of bottom ring and floating collar

Inadequate Design of Cleaning Barge

The cause and effect diagram established for inadequate design of cleaning barge is illustrated in Figure 7.4.

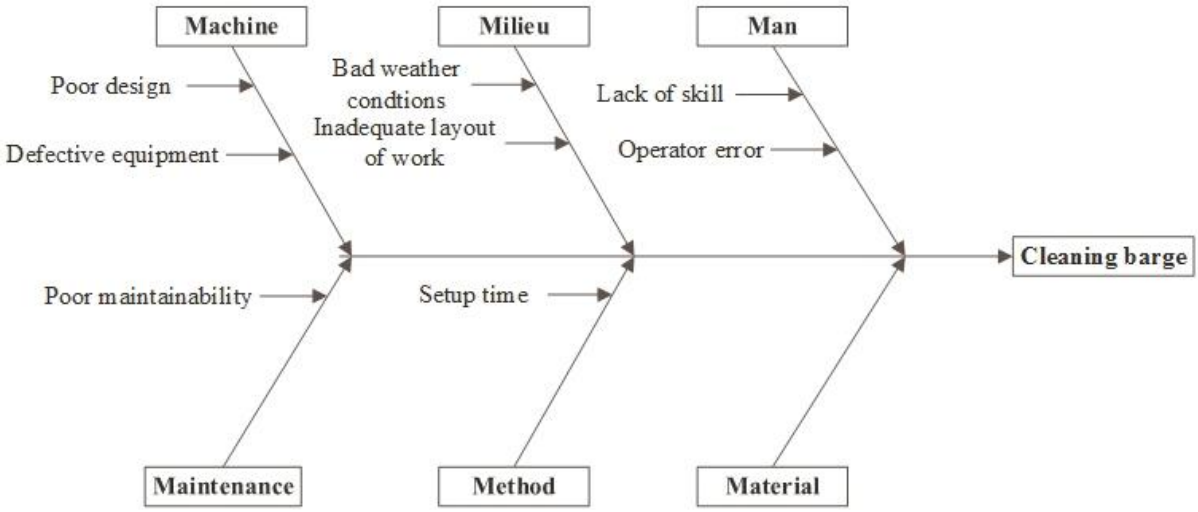


Figure 7.4: Fish bone diagram, Cleaning barge

Issues regarding the cleaning barge are mainly concerning poor or inadequate design. Design of the barge, cause accumulation of blue mussels and dirt on the deck of the barge. Thus, manually removing of the blue mussels and dirt is necessary and causes delays in the operation. Sometime, the operation even need to be stopped before cleaning process is completed in order to remove the bio fouling. Furthermore, the setup of the operation is inefficient and can be improved with better layout of barge. Due to inadequate design, jamming of the bottom ring is also a recurring problem causing delays in the operation.

The root causes have been investigated by performing a Five Why Analysis which is presented in appendix f.4.

7.1.3.4 Identify Possible Bottlenecks

A bottleneck can influence the time of the whole process and can limit the overall performance. There will be little effect from improving the process without considering the bottlenecks (ref. Section 3.2.5.3). Following issues are identified critical for the process and can be described as a bottleneck for the operation.

Poor planning concerning the weather is a bottleneck for all aquaculture operations. As earlier mentioned, the delousing operation is hard to perform in bad weather. The tarpaulin cannot be put out in strong current and wind, and it will be hard for the vessels to berth to the net cages.

During the operation of cleaning the floating collars, the bottom ring often get jammed on the cleaning barge. The operation then have to be stopped in order to get the bottom ring unjammed before the operation can continue. A better design of the cleaning barge might improve this situation.

7.1.3.5 Cause and Effect Analysis and Five Whys Analysis Results

The assessment including Cause and Effect Analysis and Five Whys Analysis shows that the main problems that are recurring are concerning inadequate design, equipment, planning and management.

Inadequate design is one of the challenges that decreases the efficiency of operations most, and needs to be further investigated in order to find possible improvements. The Five Whys Analysis shows that poor design on either net cage or service vessels makes berthing to the fish farm difficult. Today's designs of service vessel and net cage are not appropriately fitted to each other, and proper solutions are lacking. Some fish farms may have a solution with mooring line on the cage that is fitted and ready for the vessel to use. However, each sites may vary in solutions, as there is no good standard today. The increasing demand for larger vessels and the use of several vessels during an operation is clarifying and increasing this challenge.

Poor design of equipment is also considered a challenge. Equipment that are not properly fitted to the operation is a problem. This causes extra work due to fitting before or during operation. Another reason found is that poor design of equipment causes operations to be not optimally performed. Equipment not suited for the tasks can cause delays and cause stops in the system and operation. The cleaning barge has for instance several issues that can be improved. Furthermore, cranes with limited crane capacity and lifting equipment not fitting the crane can be a problem.

An increasing problem as fish farms is tending to be located more exposed, is that bad weather makes operations inefficient and harder to perform. This might lead to delays or abortion of operation that cause unnecessary transit to and from the fish farms. Operations should not be performed when bad weather may endanger human life, property or environment. This applies to all marine operations in Norwegian aquaculture. However, lack of or inadequate procedures make it hard for the responsible to decide whether to perform the operation or not. Thus, this is identified to be an area with great need for improvement. For operations that are limited by weather conditions, there should established a weather window as guidelines for when an aquaculture operation can be performed safely and efficient or not. Improving planning and clearly defining the weather window, can contribute to increase the efficiency in weather-critical operations.

The analysis further shows that lack of skills due to insufficient procedures from leadership or no proper training is found to be a problem in many cases. Likewise, stress due to heavy workload or inadequate procedures is an issue for the efficiency as well as safety.

Incorrect tool selection is also recurring. Likewise, poor maintenance can also cause failure of equipment or stops in the processes. Both is found to be a consequence of lacking procedures or that the crew do not follow the procedures somewhat due to poor planning. This should be followed up by the management

7.1.4 **Generate Improvement Measures**

The purpose of this fourth stage is to identify and develop improvement measures based on the results from the previous analysis of the processes (ref. Section 3.2.5.4). Brainstorming and SMED are used for this purpose.

7.1.4.1 Brainstorming Session

A brainstorming process has been utilised and the results are presented in Table 7.8. Several of the improvements are assumed to also improve safety and decrease the exposure of hazards.

Table 7.8: Results from brainstorming session, Improvement measures

Problem	Description	Brainstorming solutions
Inadequate design	Berth to net cage	- Service vessel o Winch bollards o Automatic tension mooring system o Dynamic position o "Easymoor" system o Sufficient thruster aft and forward - Net cage o Hook to place fixed mooring line on o Addition mooring fastening for vessel o External mooring system - Management o Planning – weather window
Inadequate design	Cleaning barge	- Semi submergible - Demi-hull with hole in deck - Closable hole in deck - HPC on barge - Better design of nozzles and hoses - Wheels for bottom ring - Guide pins - Stairs
Inadequate design and/ or lack of equipment	Lift operations	- Service vessel o Placement of crane o Ballasting system o Automatic/remote hook o Lift beam designed for bottom ring o Launch and recovery system (LARS) for ROV etc. o Moonpool deployment - Net cage o Strengthened area on floating collar for easy lift o Winch system for bottom ring o Air/buoyancy system for bottom ring o Depth indicators marked on bottom ring ropes - Management o Planning – weather window

		o Best practice procedure for operation
Poor planning	- Unnecessary work - Unnecessary transit - Stop in operation	- Increase awareness and culture of use of procedure - Implement procedure into logging system - Regular update procedures according to best practice - Weather window - Clearly procedure for abortion, specific for vessel
Lack of skills		- Training programs specific for operations

7.1.4.2 Improvement of Overall Equipment Effectiveness

In order to streamline and improve the overall equipment effectiveness and hence the overall operation effectiveness, the SMED approach is utilised. The goal of the SMED is as elaborated in Section 3.3.3.6, to streamline the operation in order to increase the overall efficiency either by eliminating activities, make activities external or by reducing time used on activities.

SMED charts are established for each operations and are based on judgement of the authors and by assessing the Flow Process Chart established in Section 7.1.1.2. The established SMED charts are given in Appendix G, while the most important results are presented below.

The result from SMED shows that all operations can improve overall operation efficiency by streamlining the operation. By improving procedures and routines, the time of activities can be reduced. Furthermore, including operation limits regarding weather conditions in the procedures, will as earlier mentioned, reduce delays.

Net cleaning is a repeatedly operation, where several nets are cleaned during one day. It is therefore important to reduce the time used for preparation and completion of each cage. Thus, upgrade of vessel equipment with: remote hook or crane based LARS, storage winch for hoses and installation of buoyancy control on RONC, will contribute to increase efficiency.

Furthermore, if it is possible to start the HPC during transit, several activates can be made external. A future goal for the net cleaning operation should be to make the operation more autonomous. By making the ROV and RONC operate autonomously, e.g. two cages can be simultaneously cleaned without increasing the number of vessel or number of crew. Cleaning of net is, as mentioned, is a repeatedly operation already using remotely operated vehicles and are therefore well suited to be more autonomous.

Delousing operations using a tarpaulin is a demanding operation with several vessels and personnel involved, often from different companies. Thus, good preparation is particularly important for this operation and will contribute to increase the overall efficiency, by eliminating and reducing time spent on different activities. By securing that the operation is not interrupted, good procedures and good dialogue will reduce the time used on each activity further. Making sure that the customer have prepared the cages before the tarpaulin vessel and the chemical vessel arrives, will improve the preparation time. Furthermore, while delousing is in progress, the customer should start preparing next cage, making this activity external. Lift of bottom ring and berthing to net cage are a part of the preparation, and related issues are discussed with suggested solutions earlier in this report. These solutions will decrease the time spent on the preparation process and will therefore contribute to improve the overall operation effectiveness as well.

Service and maintenance of floating collar is today divided into two parts: cleaning of floating collar and maintenance of floating collar. At the attended operation, these parts were performed independent of each other. First, all the floating collars at the site were cleaned, and then all the same collars were maintained. Since the preparation with placing the floating collar on top of the barge is challenging, especially in bad weather, it is suggested to perform these two parts in series. Thus, each floating collar can be completed, before starting on the next. This will add some time in preparation from cleaning to maintenance, but will eliminate many activities and is believed to reduce the overall change overtime significantly.

Furthermore, the design of the barge should be improved, as earlier mentioned. This will contribute to reduce time spent on several activities and remove those activities regarding remove of biofouling. If the HPC can be placed on the barge, several other activities will be reduced and removed as well, and contribute to increase the overall operation efficiency. Furthermore, the operation can be performed independent of the vessel. However, it can be challenging to locate the HPC on the barge for several reasons. The HPC must be located on the inside of the cage, to avoid being an obstacle for the bridle moorings and the barge can pass freely. Placing the HPC onto the barge will most probably make the barge larger and more difficult to handle. Furthermore, it will probably make the barge taller. The floating collar must then be lifted higher in order to place it upon the barge.

In Chapter 8, all the results and suggested improvements from SMED and previous parts, are grouped together to control options for further assessment and recommendation.

7.1.5 Sorting and Prioritising of Measures

In Phase 1 of Stage 5 in the KOSTER III model, the generated measures shall be sorted and prioritised in order to decide which to implement (ref. Section 3.2.5.5). A prioritising matrix is establish for each of the four main problem areas identified in Section 7.1.3.2. The prioritising matrix sort the measures according to the degree of expected efficiency improvement, and to the degree of difficulty of implementation. The matrixes is presented in Figure 7.5 to 7.8.

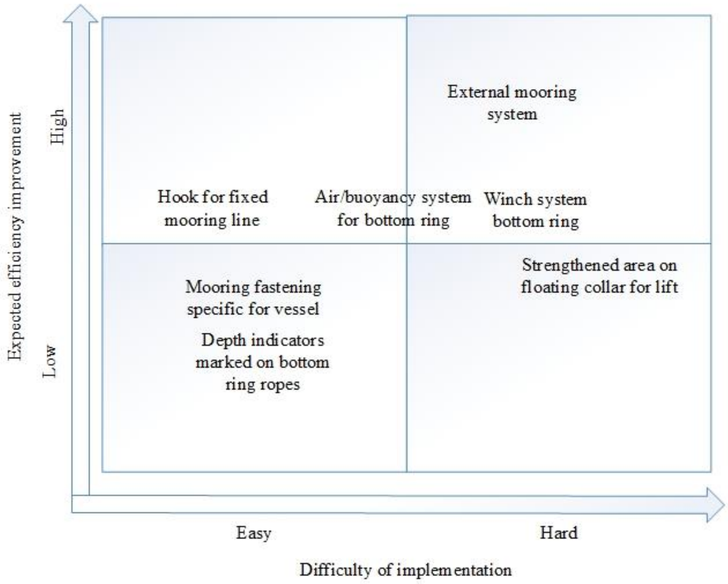


Figure 7.5: Prioritising matrix, Berth to net cage

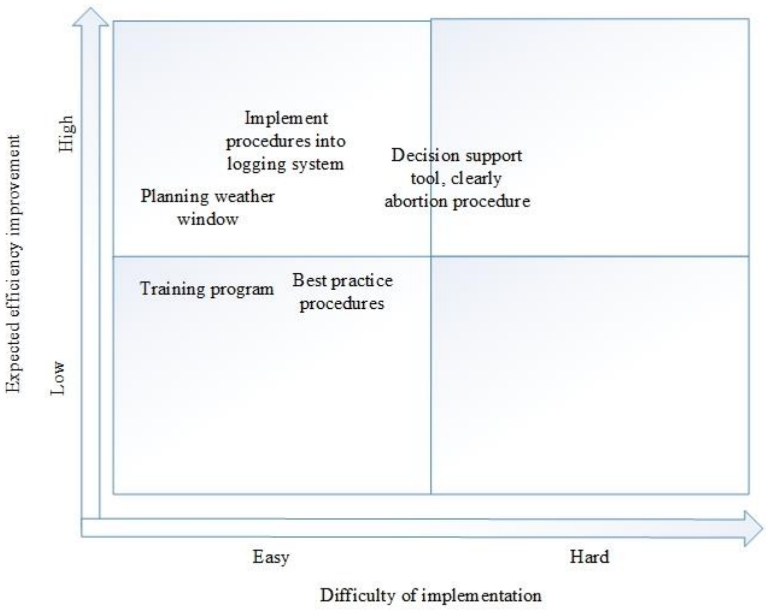


Figure 7.6: Prioritising matrix, Unnecessary work and transit

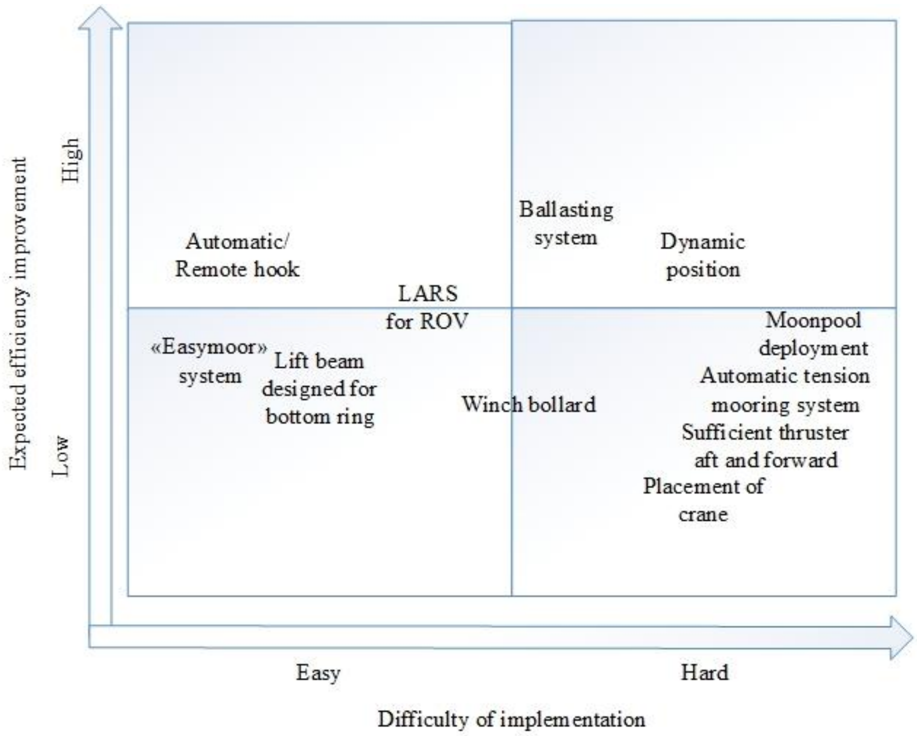


Figure 7.7: Prioritising matrix, Lift of bottom ring and floating collar

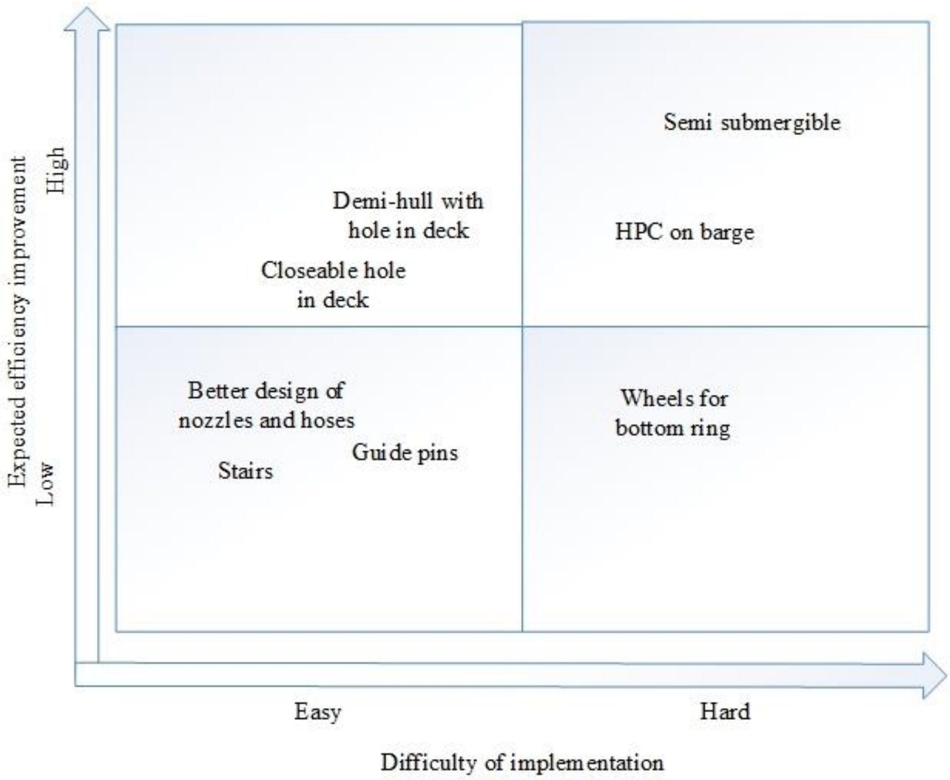


Figure 7.8: Prioritising matrix, Design of cleaning barge

8 Recommendation based on Assessment of Measures

In Chapter 6 and Chapter 7, the first three steps of the Formal Safety Assessment and a Continual Improvement Assessment have been accomplished respectively. The assessments have resulted in introduction of different risk control measures and improvement measures. In this chapter, these measures are assessed and grouped into combined risk and improvement control options. The combined control options will further be detailed explained and the risk analysis will be re-evaluated in order to establish new risk picture and to conclude with recommendation for decision-making.

8.1 Grouping of Control Options

In Section 6.3.2 and 7.1.4 were risk control measures and improvement measures established, based on through assessment of different marine operations. The aim of this section is to group these risk control and improvement measures into different practical categories. In the FSA guideline, this correspond to the grouping of RCMs into RCO(s) (ref. Section 3.1.5, Step 3 – Risk Control Options). However, as a part of this study’s objective is to improve both safety and efficiency in the operations, the different measures are combined into one common risk and improvement control option, hereafter called control option (CO).

The groups of control option shall, as previously mentioned, be well thought and practical in order to be easily implemented. In respect of risk reduction, can the groups be related to controlling the likelihood of initiation of accidents, control of escalation of accidents or a combination. Risk control and improvement measures established in previous assessments form the basis of the grouping of control options presented in Table 8.1.

Table 8.1: Grouping of control options

Control option	Sub-control option	Control measures
CO1: Planning		- Decision support system
CO2: Prevent falling into sea and drowning	CO2a: Improve safety design – net cage	- Safety line - Railing - Emergency climbing ladder
	CO2b: Improve safety design – vessel	- Clearly marking of safety zones - Entrance vessel - Remote gates in railing - Anti-slip deck - Secure, tidy and clean deck area o Storage winch o Dedicated area for equipment
	CO2c: Training and safety system	- Safety and rescue training - Alarm system - Communication system
CO3: Prevent collision and contact	CO3a: Improve mooring system – net cage	- Hook for fixed mooring line - Mooring fastening specific for vessel - External mooring system - System for lowering bridles
	CO3b: Improve mooring system – vessel	- System for easy mooring - Winch bollards - Propeller guard
CO4: Improve vessel stability and crane operation	CO4a: General	- Ballasting system - Remote hook - Clean railing - Launch and recovery system
	CO4b: Improve lift of bottom ring	- Aqualine winch system - Buoyancy system - Lifting beam
CO5: Improvement for new vessels		- Bridge layout - Location of crane
CO6: Operation specific improvement		- Improve cleaning barge - Improve net cleaning operation

8.2 Concept Development

In this part, the control options and solutions found during brainstorming is explained in detail. Where information about cost is available, it is included in the description. Most of the supply industry that have been contacted, have all been interested in giving information and sees the possibility for new market within the aquaculture industry. However, within the available time of this thesis, it has not been time to receive sufficient information to estimate cost for all concepts.

8.2.1 Control Option 1: Planning

A recurring problem for both efficiency and safety is poor or lack of planning. This cause operations to be delayed or even aborted. Furthermore, personnel is exposed for unnecessary risk when operations should have been aborted. Operations are getting more complex, often involves several vessels and workers, performing heavier and more advanced tasks and often in a harsher environment. The need of proper preparation, planning and a decision support system becomes therefore more obvious. Today decision on whether to abort an operation or continue, mostly relay on experience of the leader in charge. This may lead to unjustifiable actions and operations, or it may lead to abortion of operations that should not have been aborted.

Proper planning according to recognised standards will improve both safety and efficiency in marine operation and can function as decision support systems for the leader in charge.

Planning and Decision Support System

Planning of marine operation can be performed according to Veritas Marine Operation (VMO) standard (DNV, 2011) The overall objective of this standard is to ensure that marine operations are performed within defined and recognised safety levels (DNV, 2011). The standard gives general requirements and recommendation for planning, preparation and performance of marine operations. The standard should therefore be used in order to secure good planning and preparation, to establish a good decision support system for the leader in charge and to ensure safe and efficient operations.

The VMO standard (DNV, 2011) recommend that following sequence for the planning and design of the process to be adopted:

1. Identify relevant and applicable regulations, rules, company specifications, codes and standards, both statutory and self-elected.

2. Identify physical limitations. This may involve pre-surveys of structures, local conditions and soil parameters.
3. Overall planning of operation i.e. evaluate operational concepts, available equipment, limitations, economical consequences, etc.
4. Develop a design basis describing environmental conditions and physical limitations applicable for the operation.
5. Develop design briefs describing activities planned in order to verify the operation, i.e. available tools, planned analysis including method and particulars, applicable codes, acceptance criteria, etc.
6. Carry out engineering and design analyses.
7. Develop operation procedures.

The operation must be planned according to if it is a weather restricted or weather unrestricted operation. A weather restricted operation shall be of limited duration where planned operation time normally shall be less than 72 hours (DNV, 2011). A marine operation with defined restrictions to the characteristics environmental conditions can than take place within the limits of a favourable weather forecast. An unrestricted marine operation on the contrary, must be designed and planned for environmental conditions estimated according to long term statistics (DNV, 2011). Hence, statistical extremes for the area and season shall be considered in the design environmental criteria. A weather restricted operation can thus be designed and planned for a considerably lower environmental condition than the seasonal, statistical extremes used for an unrestricted operation.

The duration of the operation shall be defined by an operation reference period, T_R, given by Equation 6 (DNV, 2011):

$$T_R = T_{POP} + T_C \tag{6}$$

Where the planned operation period (T_{POP}) shall be based on a detailed schedule for the operation and a contingency time (T_C) shall be added to cover general uncertainty in the planned operation time and possible contingency situations that will require additional time to complete the operation (DNV, 2011).

Further, the limiting operational environmental criteria (OP_{LIM}) shall be established and clearly described (DNV, 2011). These are used for calculation of design load effects and shall not be taken greater than the minimum of (DNV, 2011):

- The environmental design criteria.
- Maximum wind and waves for safe working- or transfer condition for personnel.
- Equipment specified weather restrictions.
- Any limitation identified based on operational experience with involved vessel(s), equipment etc.

Uncertainty in both monitoring and forecasting of the environmental conditions shall be considered by defining an operational criterion, OP_{WF}, which define the maximum weather condition for execution of the marine operation (DNV, 2011):

$$OP_{WF} = \alpha \times OP_{LIM}$$

The α-factor shall be based on the planned operation time. Other important parameters for the α-factor are the operational criteria and the quality and level of the weather forecast (DNV, 2011). The operation is than safe to be performed when the weather window – the period of time, which is sufficient in length to safely carry out a marine operation, is below the operational criterion for the whole length of the period.

The connection between weather forecast, planned operation time, operation reference time, contingency time, operation criterion, operation environmental criteria and α-factor are illustrated in Figure 8.1

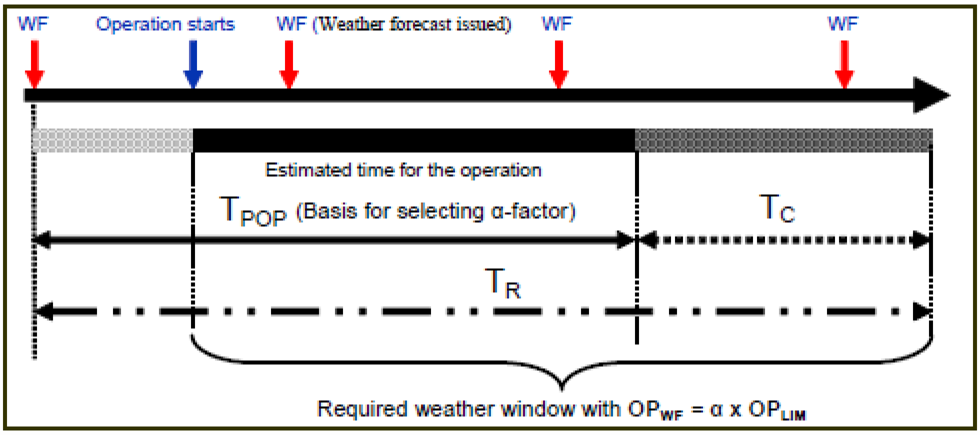


Figure 8.1: Operation periods (DNV, 2011)

By including this approach into the planning process, ensures the operation to be safely, efficient and successfully carried out. Unnecessary delays, transit and hazardous actions is minimized and the leader in charge gets a tool to relay his or hers decisions on. For further reference, see the VMO standard (DNV, 2011).

- Advantages: The operation will be thoroughly thought through, which will increase both safety and efficiency. The operation will be planned and design according to design criteria and only carried out when a favourable weather forecast is within the operational criterions. Work as a decision tool for the leader in charge. Do not need any investment in vessel or net cage.

- Disadvantages: Require more from the management and the responsible for planning. Safety factors might be set too high. Quality of weather forecast and hindcast data bases.

8.2.2 Control Option 2: Prevent Falling into Sea and Drowning

This control options is to prevent against personnel falling into sea and to prevent drowning. The control option is divided into three sub-options divided between net cage, vessel and training and safety systems

CO2a: Improve Safety Design – Net Cage

This section will present different solutions on the net cage that will improve safety. Both proactive barriers against falling into sea and hence possibly drown and reactive barriers to prevent drowning if already fallen into sea are suggested.

Safety Line

In the construction industry, use of safety line is mandatory when working at vulnerable locations. The Employment Protection Act (LOV-2005-06-17-62, 2005) instruct the companies to supply the workers with necessary safety equipment. Several operations expose the worker for falling, including the risk of falling into the sea and drown. However, use of safety line is not particularly widespread in the aquaculture industry, if at all. A safety line can be used to attach the worker to the net cage while walking on it. In case of an accident like slipping or get hit by an object, the safety line will prevent personnel of falling into the sea.

Figure 8.2: Safety line by Hvalpsund Net (Grindheim, 2016)

A good solution for net cages is newly developed by the Danish company Hvalpsund Net who offers a safety line system for both circular and quadratic cages (Grindheim, 2016). The system is installed around the entire net cage, and consists of a wire with a glider that ensures the possibility of free movement around the entire cage, as illustrated in Figure 8.2. The actual safety line is a standard safety line already used in many occupations like in the construction industry.

This solution has recently been introduced and for a regular 160 meter circumference cage costs around NOK 30 000 (Grindheim, 2016).

- Advantages: Easy and low-priced system that can be implemented on existing or new cages.
- Disadvantages: Noe securing while entering or leaving net cage from vessel, and when personnel is fastening himself or herself to the safety line.

Railing

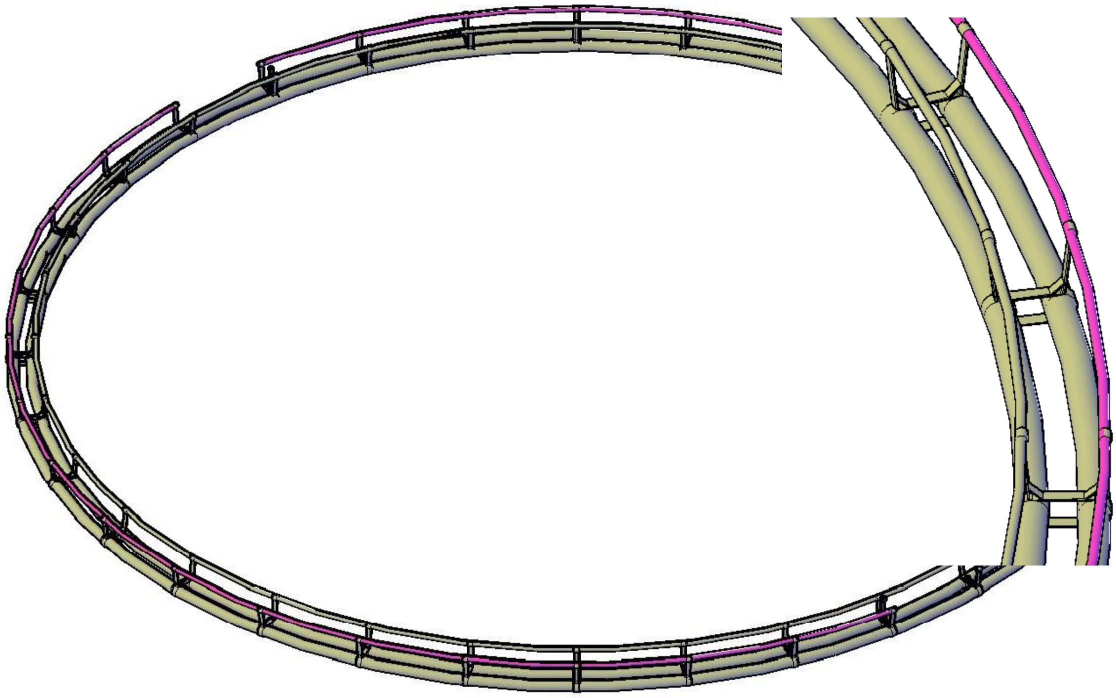


Figure 8.3: Outer railing concept

The safety line may limits the movability of the worker. The worker is not either protected when entering or leaving the net cage/vessel, or when connecting the safety line. Furthermore, it might been seen as unnecessary by the worker. An alternative solution to the safety line is therefore to install outer railings on the net cage. The suggested concept is to install railings around the entire net cage with a couple of openings for entering and leaving the net cage effectively from vessel. The material of the railings can be the same as the existing material used on the floating collars. For new cages, the outer railing can be integrated together with existing brackets. For existing cages, the outer railing can be design to fit and be mounted on existing brackets. The cost for the railing is assumed higher than the system with safety line, but preferred by the workers, as it does not require any extra work from them. Handrails on both sides of the walkway is assumed by the authors to improve safety on equal terms as the safety line concept. The concept is illustrated in Figure 8.3.

- Advantage: Do not require any extra effort from the worker. No limitation in movability. Can be implemented both on existing and new cages. Prevent squeeze hazard between floating collar and vessel.
- Disadvantage: Assumed to be more expensive as more materials is needed. No securing against falling into sea while entering and leaving the net cage or moving past opening in railing.

Emergency Climbing Ladder

In case of a crewmember has fallen into sea, today's net cage design includes poor possibilities to climb back onto the net cage. The floating collars may be slippery or often partly covered with sharp blue mussels. With no climbing solutions available one regular net cages, it is difficult to climb back up. Especially if the person who has fallen is cold or injured and if it is bad weather.

A suggested solution is to implement emergency ladders on several clearly marked locations around the net cage. In addition, the procedures and guidelines should, if not already, ensure that all personnel wear a life west, which makes is easier to swim or move towards the emergency ladders.

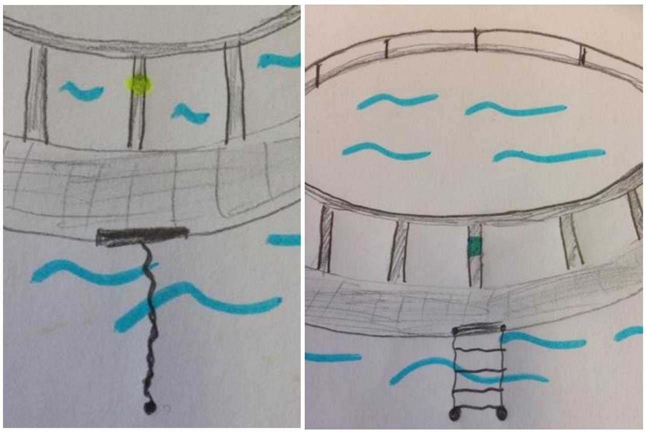


Figure 8.4: Concept emergency climbing ladder

The conceptual design of the emergency ladder is a folded ladder installed on the edge of the walkway. The folded ladder has a wire hanging out in the water that can be used to pull down and release the ladder. It will have weights at the bottom to ensure that it is hanging straight in the ocean and is reachable and easy to climb. The handrail should have a clear stick-on label where the ladders are installed. By have it folded when not used, it will not be of any obstacle to anyone or neither will it grow biofouling on it. Figure 8.4 illustrates the emergency climbing ladder with green emergency mark sign.

- Advantages: Easy and cheap and can be fastened on both existing and new net cages.
- Disadvantages: Has to swim towards ladder if not fallen exactly where it is mounted

CO2b: Improve Safety Design – Vessel

This section will present different solutions on the service vessels that will improve safety and efficiency. The suggested solutions will work as proactive barriers against different accident scenarios and some will contribute to increase the efficiency.

Clearly Marking of Safety Zones

The suggested solution, is to show the workers clearly where it is safe or not during operation, by marking safety zones in the deck of vessel. This will always show the worker where it is safe or not during hazardous operations. For being able to mark the vessel, it is necessary to perform a comprehensive job safety analysis to identify where the safe zones are. This will in addition, ensure good knowledge of dangerous operations performed on and with the vessel. If the vessel is used for different operations, different marking can be used to indicate the zones.

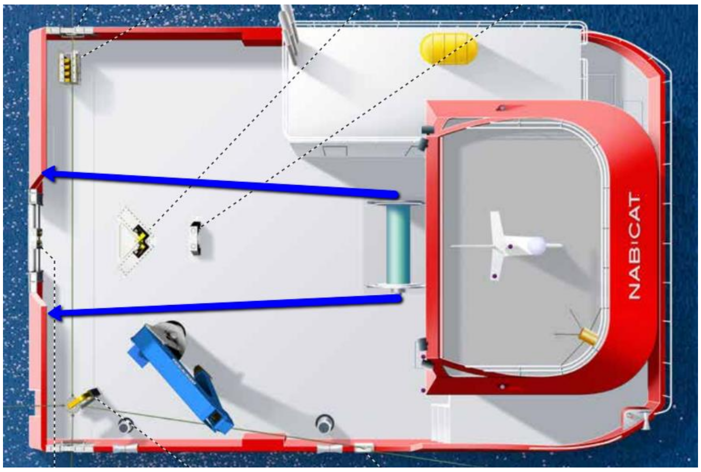


Figure 8.5: Example of safety zone marking (MoenMarin, 2015, adapted)

Figure 8.5 illustrates an example of marking on a vessel deck for operation using winch, chain lock and guide pin. Additional marking for other operations should be included as well.

- Advantages: Clearly shows safe zones on vessel deck ensures safe and efficient operation
- Disadvantages: Hazardous area not identified, false safety.

Entrance Vessel

Vessels today usually have large freeboard and it is normal to have stairs built into the vessel side to get easy access to the net cage. Many of these stairs are steep, do not have any good handrails and are not protected against falling down. Sudden movement in vessel might therefore cause worker to slip and fall when entering or leaving the vessel. An example of hazardous stairs typically used in service vessels is illustrated in Figure 8.6.

Inspired by solution on AQS Loke, the suggested solution is to reduce the open spaces from vessel deck to the ocean by only have one opening from deck. The other sides should be covered by proper railings and the opening should point away from the main area of the deck.

Furthermore, the stairs should be less steep and have a planting at the bottom where the opening in vessel side is. The stairs should be going from forward to back, to make it easier to walk in when the vessel is rolling. This will prevent personnel in falling when entering/leaving vessel/net cage and prevent personnel from falling into sea if slipping/tripping or hit by object when located on vessel deck.

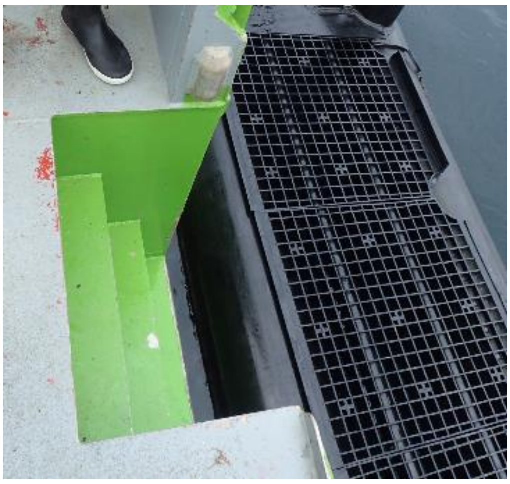


Figure 8.6: Example of hazardous stair

On existing vessels, railings and handrails should at least be implemented. The concept is illustrated in Figure 8.7.

- Advantages: Easier to enter/leave vessel/net cage, easy to be implement in new vessel designs.
- Disadvantages: Take more deck area. Difficult to implement on existing vessels.

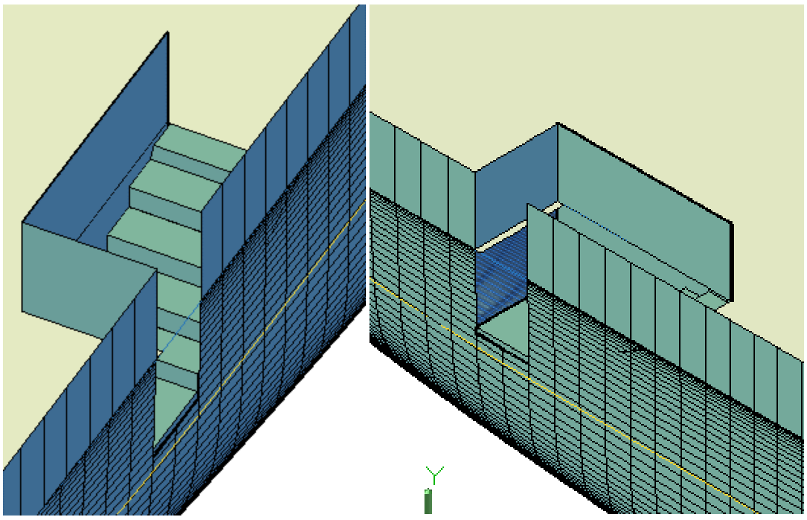


Figure 8.7: Concept design of stairs

Remote Gates in Railing

All openings in the railing should be secured in order to prevent fall through the openings. This regards opening aft for e.g. anchor handling and other openings in the railing used during operation. Manuel solution often exist, but are usually not used. The suggested solution is to install gates into the railing where needed. The gates should be remotely control to easily open it when starting operation and automatically close when the operation is finished. Technology is available in sliding gates used at industry areas today and can be adapted for vessel without being too expansive. Illustration of concept is shown in Figure 8.8.

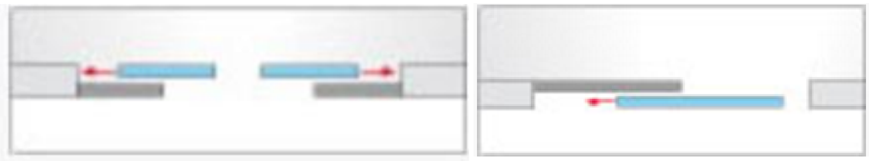


Figure 8.8: Concept remote gates for railing

- Advantages: Prevent falling through openings in the railing. Easy with remote control.
- Disadvantages: Might take some more deck area than ordinary railing.

Anti-Slip Deck

Suggested solution is to treat slippery decks with anti-slip coatings and that all vessels should have available absorbent mats for oil- and other spills. There are several options on the marked for both anti-slip coating and absorbents. Anti-slip coating are available for approximately NOK 50 per square meter (Westsystem, 2016). Several providers supply absorbents kits that easily can be placed on a vessel and that have all necessary products. These kits are available from approximately NOK 1200 and upwards (AcoKjemi, 2016). Figure 8.9 shows example of one kit delivered by AcoKjemi.

Figure 8.9: Absorbent kit (AcoKjemi, 2016)

- Advantages: Prevent slipping and falling. Prevent oil spill and pollution.
- Disadvantages: None found.

Secure, Tidy and Clean Deck Area

The solutions chosen to look further into are winches for ropes and hoses and dedicated area for equipment.

<u>Storage Winch</u>

Suggested solution is to install storage winches on deck for specific tasks in order to secure a tidy deck area. Storage winches can be used to store cables, hoses and ropes and can be delivered with different capacity. They can be installed with distribution device, tension control, they can be electric or hydraulic driven and remotely controlled. This will reduce the risk of tripping over hoses and ropes, which again can lead to falling. Especially cleaning operations using hoses are suited for use of a storage winch. This will not only reduce the risk of tripping, but also increase the efficiency when handling the hoses by eliminating the manual work with pulling of hoses.

There are many providers of winches and they vary in price according to specification. Winches for storing purpose, can be installed on both existing and new vessel. The illustrated storing winches in Figure 8.10 can be delivered by Palfinger.

Figure 8.10: Storing winches delivered by Palfinger (Palfinger, 2016b)

- Advantages: One-man operated and requires no manual work. Efficient and store the hoses and cables in a good way.
- Disadvantages: Do not stop pulling if hose/cable is stuck (if no tension control) and can damage equipment or net. Take up some deck area when not used.

Dedicated area for equipment

Service vessels have often much equipment, tools, chains, spare parts etc. laying on deck. This increase the risk of tripping and eventually fall into sea. In addition, it may not be particularly organised and lead personnel to use time on looking for correct equipment. The suggested solution is to organise the deck area and if bringing much equipment and spare parts, it should be secured in dedicated storage spaces or boxes. This will in addition prevent equipment, tools and spare parts of any movement and hence prevent any risk of personnel to get hit or squeezed. This solution can easily be integrated into new and existing vessel with low costs.

- Advantages: Tidy deck and secured equipment prevents tripping and squeezing accidents. More efficient work.
- Disadvantages: Take up deck area when not used.

CO2c: Training and Safety Systems

This section will present different solutions for personnel knowledge and safety systems that will improve safety. The suggested solutions will work as proactive barriers against different accident scenarios and some will contribute to increased efficiency.

Safety and Rescue Training

In the offshore industry, it is mandatory for all employees to take a safety and rescue course. Different suppliers arrange a basic safety course for sailors including rescue techniques, preventive fire protection and firefighting, basic first aid and personal safety and care for human life and environment. These course can be done during 5 days, cost between NOK 15 000 and 20 000 and should be updated every 5th year (RS, 2016). However, s similar course custom-made for aquaculture should be established to fit the needs in the industry. Such course is just barely started to be delivered by among others Norsafe Academy who can adapt each course to specific location and fish farm to ensure best possible training (Soltveit, 2016).

In addition, to arrange safety and rescue training, the employees should start with regular practical training to ensure good HSE. This will improve safety both through making the personnel more aware of possible hazards and as well increase the knowledge if the accident first happen and thus increase the probability of surviving.

Furthermore, the aquaculture education must adapt to the change in the industry. With many new specialised companies performing only the service operations, the industry is started to be divided between daily operations and caring of the fish and companies performing the advanced operations. This must be reflected in the aquaculture education, as the two segments need different type of knowledge in order to perform their task optimal. E.g. crew on a service vessel need to have more knowledge and competence in driving vessel, crane etc. and how environmental loads affected this in different weather conditions, while a fish keeper need to have more knowledge about the biology of the fish.

- Advantages: Awareness of hazards, awareness of what to do if accident happen
- Disadvantages: Time consuming

Alarm System

When an accident first has occurred and a worker has fallen into sea, an alarm system should be used independent of working alone or not. This will increase safety by alarming co-workers and ensure fast rescue if fallen into sea. The suggested solution is that all workers should bring a sensor that automatically can alarm both co-workers and a base if an accident happen. Figure 8.11 shows how an alarm system can be built up.

Figure 8.11: Alarm system delivered by DeltaSafe AS (DeltaSafe, 2016)

- Advantages: Easy to install, increase safety for drowning accidents.
- Disadvantages: False safety if not working

Communication System

Good communication in an operation might be hard because it often involves several workers, workers on both vessel and net cage, several vessels and larger vessels. If the operation in addition is performed in harsh weather conditions, it even harder to have good communication and hear each other. The industry has access to radio communication systems, but these is often located in the vessel wheelhouse or is handheld. Handheld radio communication system is not a good solution when working and moving around. Some has taken in use two-way intercom system that can be integrated in the helm. 3M Peltor LiteCom Headsets, as shown in Figure 8.12, seems to be leading supplier of these systems and their system is available from approximately NOK 6000 (Univern, 2016).

Figure 8.12: 3M Peltor LiteCome Headset (Univern, 2016)

Use of communication system integrated in the helmet will ensure good communication without disturbances. This will contribute to decrease the possibilities for accidents if all workers in an operation is using the system. The system should also be integrated and easy accessible in the wheelhouse and on several locations if the wheelhouse is large.

- Advantages: Easy to use, do not need to interrupt work for using it, improve communication and increase efficiency and safety.
- Disadvantages: If too many users and too much talking at same time, it can be unclear and work against its purpose.

8.2.3 Control Option 3: Prevent Collision and Contact

This control options is to prevent against collision and contact accidents. The control option is divided into two sub-options divided between net cage and vessel. The options will contribute to increase both safety and efficiency.

CO3a: Improve Mooring System – Net Cage

This section will present different design solutions on the net cage that will reduce the risk of collision and contact and at the same time improve the efficiency of the operations.

Hook for Fixed Mooring Line

Inspired by one of the attended sites, the suggested concept is a pole with a hook that can be mounted to existing bracket. The hook can be used for placing a fixed mooring line on it, in order to easily pick it up from the vessel and use it to moor the vessel to the cage. The mooring line is then easy and fast to reach and it is not necessary to leave the vessel in order to moor it. An example of the concept is shown in Figure 8.13.

- Advantage: Easy and fast to access from vessel, do not need to enter cage before vessel is proper moored.
- Disadvantage: Most suited for smaller vessel.

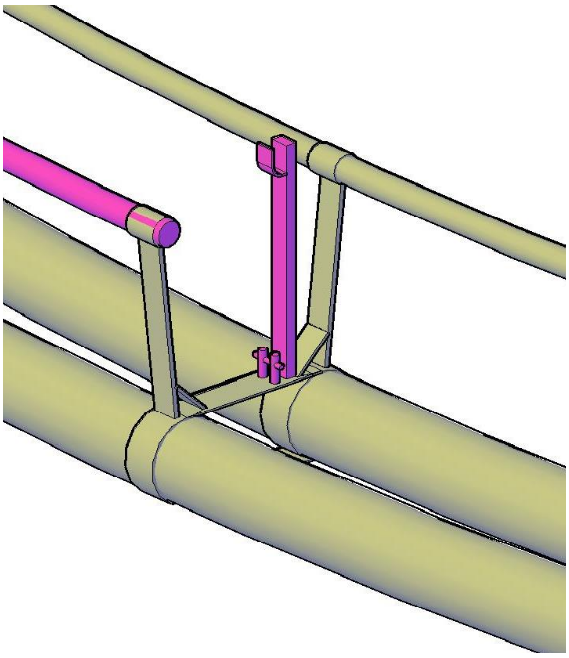


Figure 8.13: Concept with hook for fixed mooring line

Mooring Fastening Specific for Vessels

There are several locations on a net cage where a mooring line from a vessel can be fasten. However, none is specific for the vessel and it might therefor be challenging to find a suitable location as there are many other ropes tied on a cage also. Using time to find suitable location during mooring, increase the risk of collision and contact damage because the vessel has to manoeuvre alongside the net cage as long as it not is proper moored. The suggested solution is to have several mooring fastenings on the floating collar that is specific for

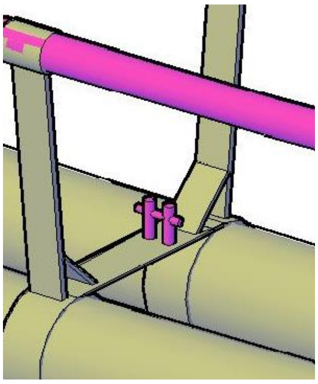


Figure 8.14: Concept mooring fastening specific for vessel

the vessels. The fastenings can be made of steel, fitted to exiting brackets and do not need to be very costly. The concept is illustrated in Figure 8.14.

- Advantage: Easier, faster and safer to moor to cage. Do always know where to fasten the mooring line from the vessel
- Disadvantage: Might still be used for other purposes. Might suit smaller vessel best. If it shall be suited for larger vessels; the bracket, floating collar and the cages mooring system must be designed for this purpose.

External Mooring System

One recurring challenge is for larger vessel to moor to the net cage. It is challenging to manoeuvre close up to the net cage and the net cage is not either designed for large vessels to moor to it. As elaborated in Section 4.1.4, a large vessel moored to a net cage in normal weather conditions, can transfer loads larger than a 50-year storm. Furthermore, as shown in Figure 4.8 to 4.10 in Section 4.1.4, mooring a large vessel to a floating collar can cause large deformation in the floating collar.

In the offshore industry, dynamic positioning (DP) system is used during challenging operations. Such systems are available for vessels in the aquaculture industry, but few vessels have it installed today. A DP system shall control forces from thrusters and propellers to counteract the mean weather forces and provide stiffness and damping forces for the limitation of low-frequency motions (Larsen, 2016). However, the system is not as reliable as use of mooring systems, and loss of position due to drive-off and drift-off occurs. Another problem is that use of thrusters and propellers close by the net cage are not wanted, as this is a hazard for bridles and net. Thus, a DP system can be preferable for vessels that are not performing operations close by the net cage, e.g. well boats if technology from transfer fish from net cage to well boat is improved, or service vessels performing anchor-handling operations.

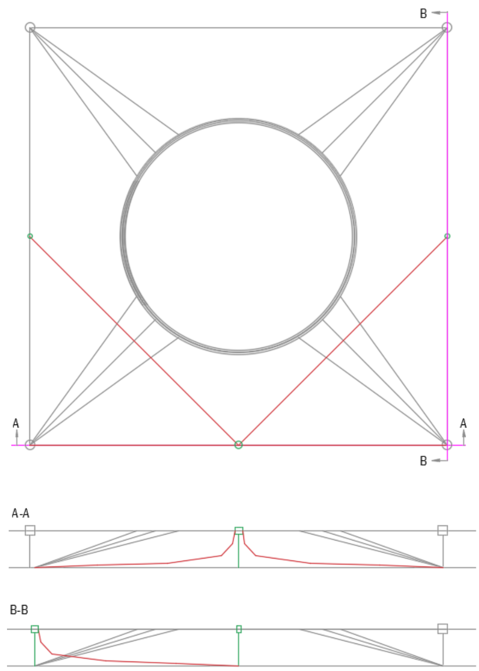


Figure 8.15: Concept of external mooring system

Still many operations need the vessel to be close to or next to the net cage, as the operation is performed on the net cage it selves. For such operation, the suggested solution is to install an external mooring system as illustrated in Figure 8.15. The proposed system contains of a buoy connected to four mooring lines. The buoy is located between the outer main buoys, for easy access and pick up by vessel in safe distance from net cage. The buoy is connected to four mooring lines, where two of the lines are connected to the connection plate below the main buoy on the main frame and two are connected to the centre of the main frame between the main buoys (Illustrated with red lines in Figure 8.15). The buoy for pick up, where the mooring lines are connected, is fasten to the frame to keep its position when not used. A vessel can use capstan or winch to locate the vessel into wanted position by pulling or releasing the four mooring lines safely and efficient without use of thrusters and propellers (As illustrated in Figure 8.16).

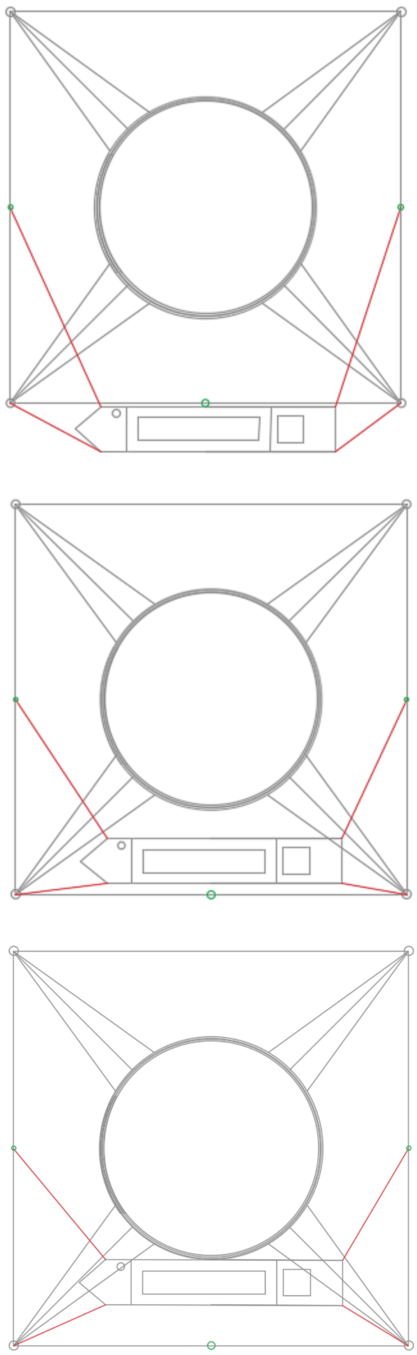


Figure 8.16: Illustration of how external mooring system can be used

From dialog with personnel on AQS Loke, it is known that some vessels are already fastening their mooring lines to the connection plate below the main frame. However, this is not a permanent system and must therefore be placed out every time, which implies an operation with lifting the main buoy to be able to fasten the mooring line.

Whether the existing mooring frame system has capacity to such a system has to be analysed. However, it will not transfer any larger load to the frame system than it already does when moored directly to the net cage. Such system must be characterised as a weather restricted mooring system, but with higher operation limits than a system moored directly to the net cage.

- Advantages: The vessel do not need to moor to net cage directly. Therefore, there will be no force/loads transferred from vessel to net cage. Forces are absorbed in the mooring system. This system is always easily accessible. Furthermore, the vessel does not need to use thrusters or propeller risking damaging net or ropes.

- Disadvantages: Additional ropes close to net cage. In addition, there is still a problem regarding contact with bridles for large vessels if moored next to cage

System for Lowering Bridles

When large vessel moor to the net cage, it has to lay upon the bridles to get access to the cage. This transfers large loads to the bridles, pulling them down and may eventually pulling down the floating collar. In addition, this cause much wear and tear on the bridles, which decrease the lifetime, especially if the bridles are of polyester and not of chain.

When such large vessels are used in operation, it occur that the bridles are lowered by extending the rope/chain from the connection plate to the buoy to make the bridles steeper. This involves lifting up the buoy and extend the rope manually by use of crane. The suggested solution is to make buoys with an internal cylinder in the middle of the buoy, as illustrated in Figure 8.17. With this solution, the connection plate and bridles can be lowered without needing to lift the buoy itself.

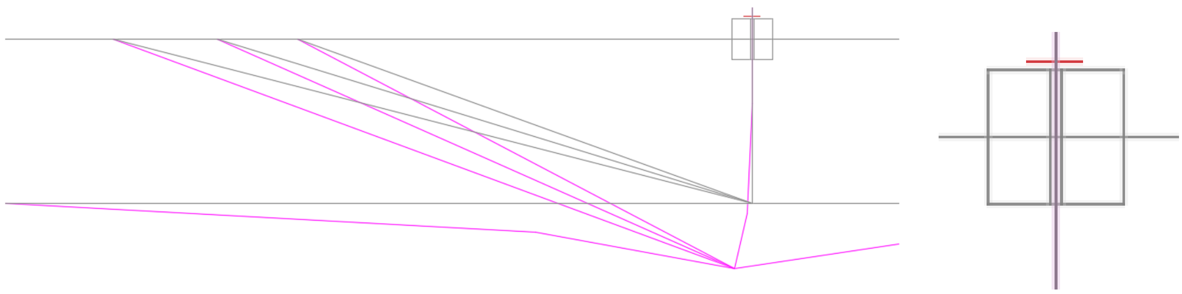


Figure 8.17: Concept of system for lowering bridles

- Advantages: Prevent hazardous lift of buoy. Easy and efficient method for lowering bridles. Prevent contact between vessel and bridles.
- Disadvantages: Buoy has to be larger to have same buoyancy capacity. Solution might be in conflict with other equipment on buoy, e.g. light.

<u>CO3b: Improve Mooring System – Vessel</u>

This section will present different design solutions on the service vessels that will reduce the risk of collision and contact accidents and at the same time improve the efficiency of the operations.

System for Easy Mooring

There is existing technology on the market that allows the personnel on vessels to moor lines without leaving the vessel. EasyMoor and Hook&Moor, as shown in Figure 8.18 and 8.19, are example of such systems (Easymoor, 2016, Hook&Moor, 2016). The concepts is a hook on a pole that can connect a mooring line around or through a mooring fastening. A modified version should be developed to fit the aquaculture industry.

Figure 8.18: Solution from Easymoor (Easymoor, 2016)

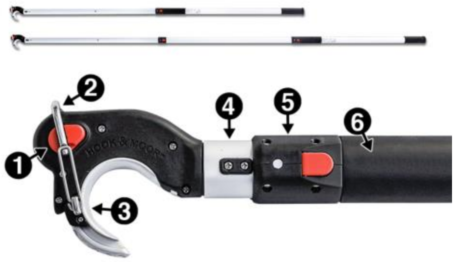


Figure 8.19: Solution from Hook&Moor (Hook&Moor, 2016)

Use of such system, let the personnel fast and easy moor the vessel from a short distance from the net cage – reducing the probability of collision and contact accidents. The personnel do not either need to leave the vessel exposing himself or herself for additional danger. The existing systems are available from NOK 500 to 1500 (Easymoor, 2016, Hook&Moor, 2016).

- Advantages: Easy and cheap system. Can be used on existing cages. Do not need to leave the vessel.
- Disadvantages: Can be challenging to use in bad weather conditions.

Winch Bollards

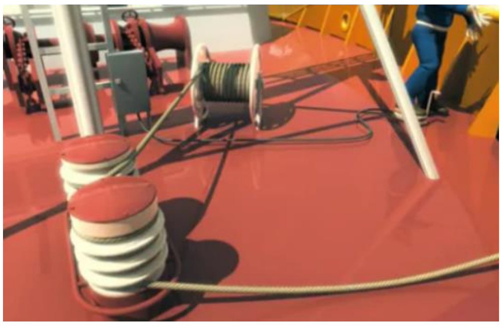


Figure 8.20: Winch bollards delivered by TTS Marine AS (TTSMarine, 2016)

When moor to quay or net cage, it is important to be able to quickly secure and fasten the mooring lines in order to reduce the exposure time and hence decrease the risk of collision and contact accidents. This is especially important in harsh weather conditions when there will be more movement in the vessel. Traditionally capstan is used to tighten the mooring lines, before they are fasten to a bollard. This is a cumbersome method and it involves danger of getting fingers and hands squeezed. TTS Marine AS has developed a winch bollard mooring system, as shown in Figure 8.20. This system can replace mooring winches, capstans, warping drums, bollards etc. (TTSMarine, 2016). The system is one man operated, can be prepared in advanced and is fast and safe to use.

- Advantage: Winch bollards are safer than conventionally use a capstan. It is possible to prepare the ropes before mooring and it is one man operated. Remove the danger of getting body parts injured and reduce the risk of collision and contact accidents. The system can in addition be used as an alternative to capstan in other operations.
- Disadvantage: Might suit larger vessel best and takes up more deck area than a capstan. The winch bollard are sold to the offshore industry and need to be scaled for aquaculture vessels. Cannot be used for other purposes when already used to moor the vessel.

Propeller Guard

Navigation close to a net cage impose a danger of getting rope and net into the propeller. This can in worst-case cause significant material damage and escapement of fish. Thrusters are normally protected, while the propellers are normally not protected. The suggested solution is therefore to install a propeller guard on the service vessels. This will reduce the danger of contact accidents between propeller and ropes/nets. It will in addition protect the propeller against other objects in the water that can damage the propeller. In addition, a propeller guard lead the water towards the propeller, which increase the water pressure. This contribute to reduction in cavitation and vibration, and increase the manoeuvrability and thrust (Progress, 2016).

Figure 8.21: Example of propeller guard (Seatronic, 2016)

Different type of propeller guards are available on the market or can be custom built on place. A propeller guard can easily be mounted on existing vessel during docking. Example of propeller quard is illustrated in Figure 8.21.

- Advantages: Increase both safety and efficiency. Can be installed on existing vessel during docking. Contribute to reduction in cavitation and vibration, and increase the manoeuvrability and thrust
- Disadvantages: None found

8.2.4 Control Option 4: Improve Vessel Stability and Crane Operation

This control options suggests solutions for improving vessel stability and crane operations in order to prevent against mainly hit by object accidents. The suggested solution will in addition improve the working conditions and contribute to increased efficiency in operations. Furthermore, increased vessel stability will decrease the risk of capsizing which have occurred, but is not a part of this scope.

<u>CO4a: General Improvement</u>

Ballasting System

Use of ballasting and anti-heeling systems are well known technology used in the offshore industry to make the vessel more stable in roll motion. The systems are available from simple passive systems as bilge keels and passive roll tanks to active systems pumping water from one tank to another in order to stabilise the vessel in waves and during operations. The systems provides significantly motion reduction and expand the allowable weather window for operations and making it safer to work on deck.

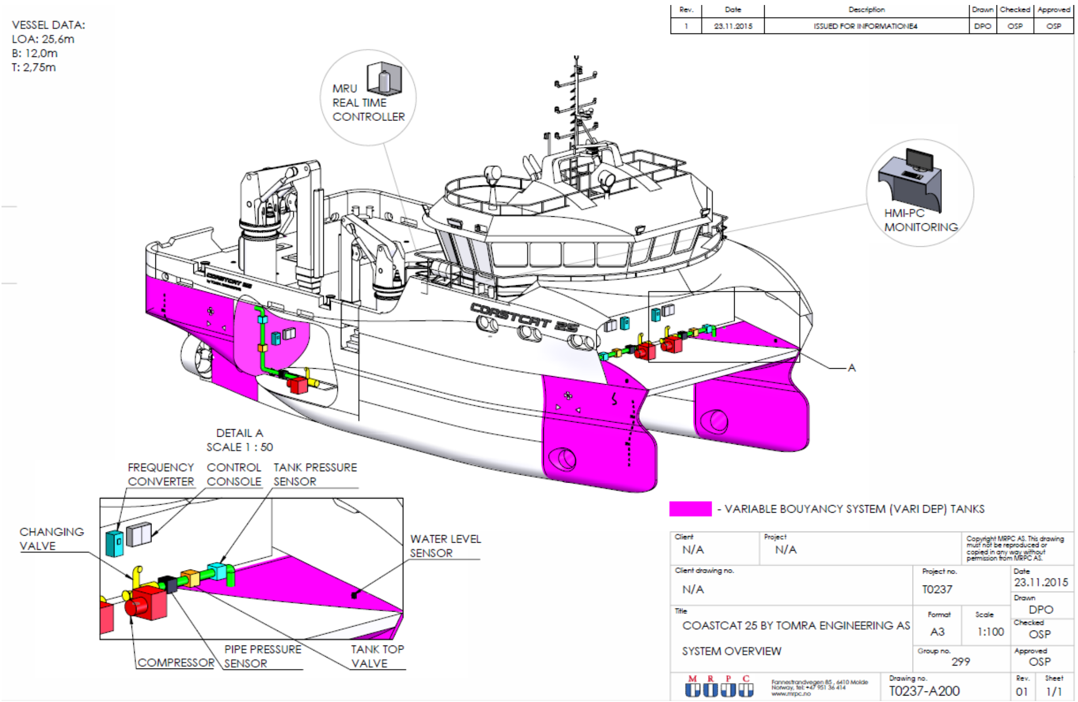


Figure 8.22: Ballasting system delivered by MRPC (Sporsheim, 2016)

Marine Roll & Pitch Control (MRPC) AS has delivered the only system that is installed in an aquaculture service vessel. This system actively stabilize both roll- and pitch motion and ensures safe and efficient operations. Contrary to traditional systems pumping water from one tank to another, this system use ballast tanks that are open to the sea and control water level by making overpressure or vacuum in the tanks (Sporsheim, 2016). This ensures fast response and a reduction of roll/pitch movement of 75-85% (Sporsheim, 2016). The system is available for NOK 1.2 – 1.5 million depending on size of vessel (Sporsheim, 2016). Layout and system overview is illustrated in Figure 8.22.

Use of such ballasting system will increase the vessels operability by increasing the weather window for critical operations. The ballasting system will secures the stability of the vessel, even under demanding and heavy lifting operations. This will secure a safe working deck and reduce the risk of slipping or tripping. Furthermore, it will decrease the movement of the lifted object, which will increase the control during lift and reduce the risk of damaging or being hit by the lifted object.

- Advantages: Ensures good stability of the vessel, increasing the operability and reducing the risk of accidents.
- Disadvantages: Expensive installation cost. Require space for ballast tanks.

Remote Hook

A significant hazard is to move around lifted objects. Especially on vessels, objects can suddenly move and hit worker due to vessel motions from environmental conditions. Because of such sudden vessel movements, this can even happen when object is though safe on deck or in sea. A suggested solution is to use a remote hook and adapting equipment to fit this hook without personnel involvement other than the crane operator. Thus, a remote hook makes it possible to perform crane lifts without having to stand near or assist the object before, during and after the lift. The hook can be remotely attached to the object and detached after lift, reducing the risk of being hit.

The technology already exists, but maybe most used in the construction industry. An example of a remote operated hook is Elebia Remote Operated Hook. The hook is available with different lifting capacities from 2 500 to 25 000 kg and has a price ranging from approximately NOK 30 000 – 70 000 depending on the capacity (Cranepartner, 2016).

Figure 8.23: Elebia Remote Operated Hook (Elebia, 2016)

To improve safety and efficiency, the hook can be fitted with a magnetic system and weighing scale with overload alarms (Elebia, 2016). The magnetic system make it fast and easy to attach and release objects without personnel involvement. The weight scale and overload alarm increase safety since it informs the crane operator of the weight of the object (Elebia, 2016). The hook from Elebia is shown in Figure 8.23.

- Advantage: The hook increase productivity and makes lift operation safer. Lifts can be one-man operated and no one need to assist the operation. Personnel can stand in a safe zone on vessel deck during the whole lift in safe distance from the lift object. There are no need of movement on deck and/or entering the net cage, which reduce the risk of other accidents. The weight scale ensures that the lifted object are not heavier than the capacity of hook, the crane and the lifting strops.
- Disadvantages: Expansive compared to traditionally hooks. Max lifting capacity of 25 000 kg.

Clean Railing

Many lifts are performed by the side and over the railing of the vessel. The railings should therefore be free of obstacles that lifted objects can hook onto during lift operations. It is therefore recommended that guide pins, bollards and other equipment that often are located on top of the railing, should be integrated into the railing.

SHM Solutions AS delivers guide pins that are remotely operated and that are either integrated or can be driven out of the railing when needed (SHM, 2016). Figure 8.24 shows an example of existing solutions from SHM Solution, while Figure 8.25 shows how bollards can be integrated into the railing reducing unwanted hooking incidents.

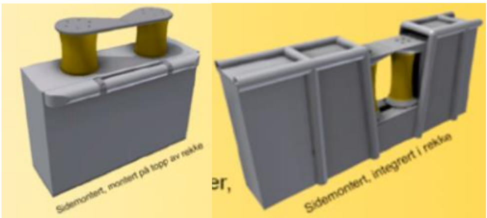


Figure 8.24: Deck equipment solutions delivered by SHM Solution AS (MoenMarin, 2015)

- Advantage: Reduce risk of unwanted hooking incidents during lifting operations. Equipment and solutions provided by SHM Solutions AS gives in addition increased safety and efficiency when used, by being remotely controlled and lockable.
- Disadvantages: Equipment that is remotely controlled is more expensive than traditionally equipment.

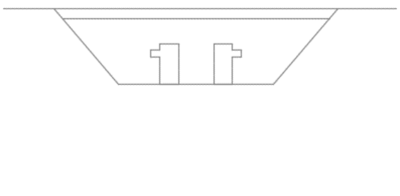


Figure 8.25: Suggested solution for integrated bollards

Launch and Recovery System

Use of remotely operated underwater vehicles in the aquaculture industry is growing and will continue to grow in the future. This will increase the necessity to deploy ROV safe and effective in all weather conditions. A Launch and Recovery System (LARS) is designed to withstand dynamic forces, increase the allowable weather window and hence increase safety related to lift of ROV. Such systems can thus be used to safely and effectively launch and recover ROVs.

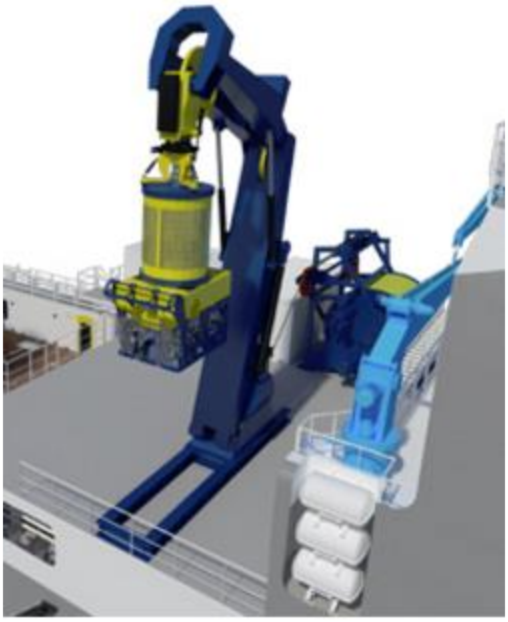


Figure 8.26: Crane based LARS delivered by Palfinger (Palfinger, 2016a)

Several suppliers delivers LARS to the offshore industry and the system is available as both A-frame based and crane based, and can be delivered together with a winch for storing of umbilical. Palfinger is an example of supplier of crane based LARS for ROVs, which can use existing crane (Palfinger, 2016a). Price depends on required capacity of system. Figure 8.26 shows an example of LARS delivered by Palfinger.

- Advantage: Increase weather window, ensure effective launch and recovery and reduce risk of lifting-related accidents. Can use existing cranes.
- Disadvantages: A-frame based use extra deck area. Crane cannot be used for other purposes when ROV is deployed.

CO4b: Improve Lift of Bottom Ring

Many operations require the bottom ring to be lifted. This involves, on a standard 160-meter floating collar, to lift around 20 individual ropes 5-8 meter at a time in order to hoist the bottom ring. If it shall be hoisted to the surface, this involves that the operation has to be performed two to three times at each ropes. A total of around 60 lifts with crane together with movement of vessel three times around the cage, are therefore necessary in order to complete the task. At the same time, the slack of the net has to be manually hoisted.

In the following, it will be presented alternative solution that will contribute to increase safety and efficiency in operation involving lift of bottom ring.

Aqualine Winch System

Aqualine delivers a newly developed winch system, as shown in Figure 8.27, where winches are used to raise and lower the bottom ring (Aqualine, 2016). The system effectively hoist the bottom ring evenly around the entire floating collar with full control and without use of crane or capstan. The system is available for both existing and new cages. The system need however sufficient power supply from shore, feed barge or vessel.

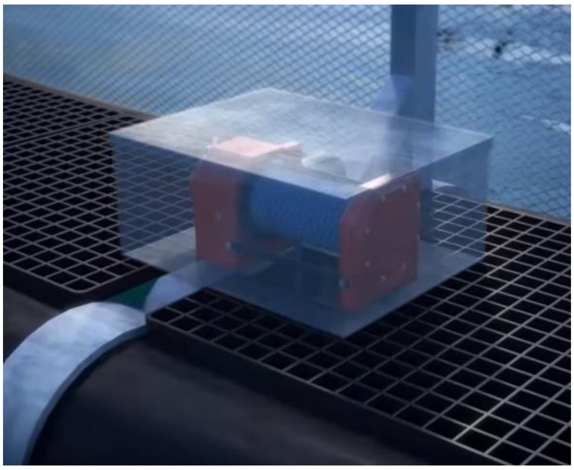


Figure 8.27: Aqualine Winch System (Aqualine, 2016)

- Advantages: No need for crane lift, increase efficiency and decrease risk of unwanted accidents.
- Disadvantages: Need sufficient power supply.

Buoyancy System

Where sufficient power supply is a challenge, a suggested alternative to raise and lower the bottom ring – is with a buoyancy system controlled by compressed air. Existing bottom rings can be fitted with a system containing a bladder. By adding or releasing air from the bladder, the buoyancy of the bottom ring can be controlled in order to raise and lower the bottom ring. The concept is illustrated in Figure 8.28. For new bottom rings, syntactic foam can be used internally in order to make the system more robust. This concept is illustrated in Figure 8.29. The functions are the same as the suggested external bladder, and both can be controlled with air supply from a compressor at vessel or feed barge.

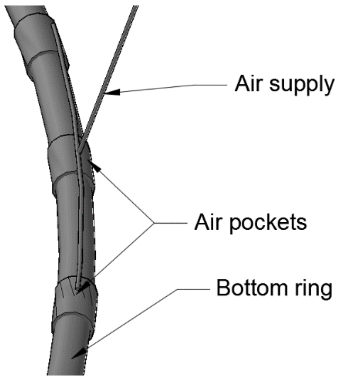


Figure 8.28: Concept of external buoyancy system for bottom ring

- Advantages: No need for crane lifts, increases the efficiency and decreases risk of unwanted accidents. Might be a cheaper system than a system with winches.
- Disadvantages: Can be difficult to control the depth in water

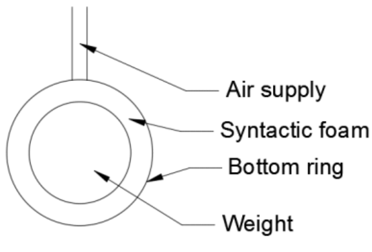


Figure 8.29: Concept of internal buoyancy system for bottom ring

Lifting Beam

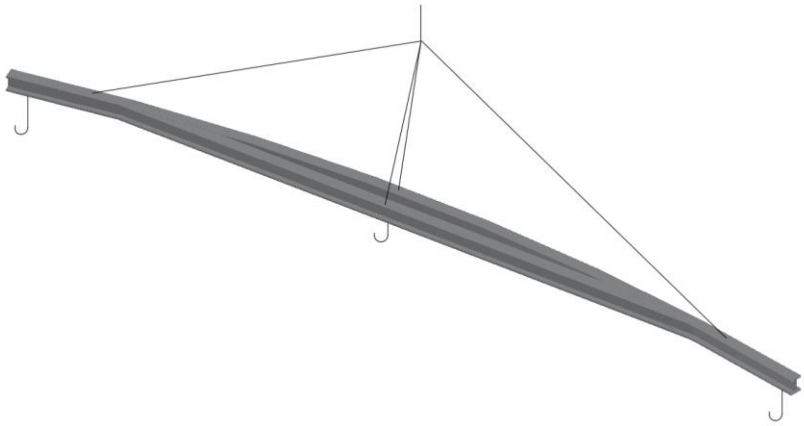


Figure 8.30: Concept of lifting beam

The winch and buoyancy system are an effective system eliminating all lifts with crane when raising and lowering the bottom ring. However, this will only be available for cages where the system is installed. Where such a system is missing, a suggested solution is to use a special designed lifting beam as illustrated in Figure 8.30. The lifting beam is designed for lifting three bottom ring ropes simultaneously, reducing the total number of lifts to 20. This will make the operation much more effective and reduce the risk of accidents to occur. Furthermore, it is important that the beam is light, stable and efficient to use in order to not introduce new hazards.

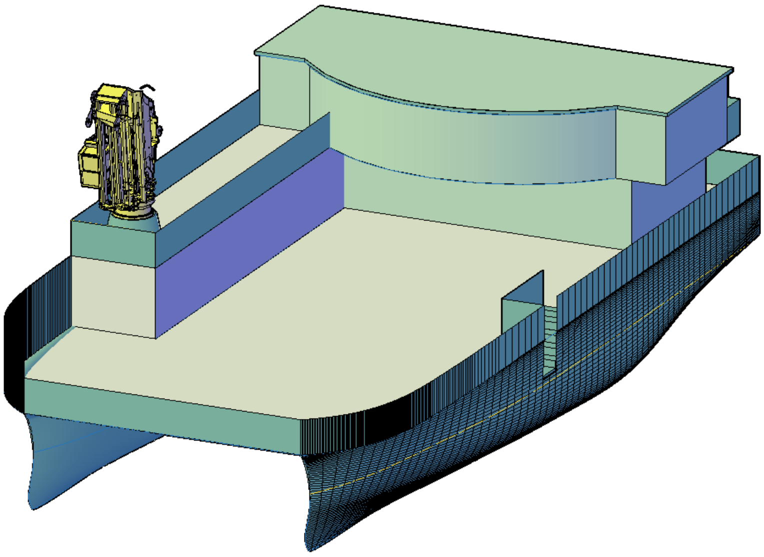
- Advantages: Increased efficiency and decreased risk of unwanted accidents by being able to lift three points simultaneously and hence decreasing overall number of lifts.
- Disadvantages: Lift of extra object during operation can introduce new hazards and contribute to decrease safety.

8.2.5 Control Option 5: Improvements for New Vessels

The following suggested solutions are most suited for new vessels, as it will require large changes to the structure of vessel if to be implemented on existing vessels. The suggested solutions will increase both efficiency and safety.

Bridge Layout

A service vessel in the aquaculture industry is a working boat performing different type of operations. A common development is that the vessels are getting larger and performing heavier and more advanced operations. All vessel has a large deck area where different operations take place, including lifts of the side of the vessel. Traditionally the skipper has contributed to the work performed on the deck. With the development of larger vessel, being a skipper is becoming a fulltime occupation, and often involves ensuring the safety of the crew during operation through leading and/or having full overview from the wheelhouse. It is therefore important for the skipper to have good overview of the vessel deck from the bridge. In addition, it is important to have good overview of the whole side of vessel especially during manoeuvring and berthing next to net cage.



For larger vessel, suggested solution is therefore to move the wheelhouse to the aft of the vessel as illustrated in Figure 8.31. By having the wheelhouse aft and lifted up one deck, there will be a good overview of the whole deck during transit and operation. By not having pathways on the outside of the wheelhouse, the overview of the side of the vessel will increase, and hence contribute to improve the berthing process. In addition, having access below the wheelhouse on port side of the vessel allows easy access to all four corners of the vessel, which is important among others during berthing. The front and the port side of the vessel can be equipped with glass floor to increase visibility of the passage below the wheelhouse and the deck area close to the front of the wheelhouse. Only one control station including one wing station is necessary by having the wheelhouse aft. This will reduce necessary movement within the wheelhouse and give the skipper an opportunity to have constantly overview of the deck. The authors of this thesis believe this will lead to safer and more efficient operation and contribute to reduce risk of both contact and collision accidents and other accidents leading to occupational injuries.

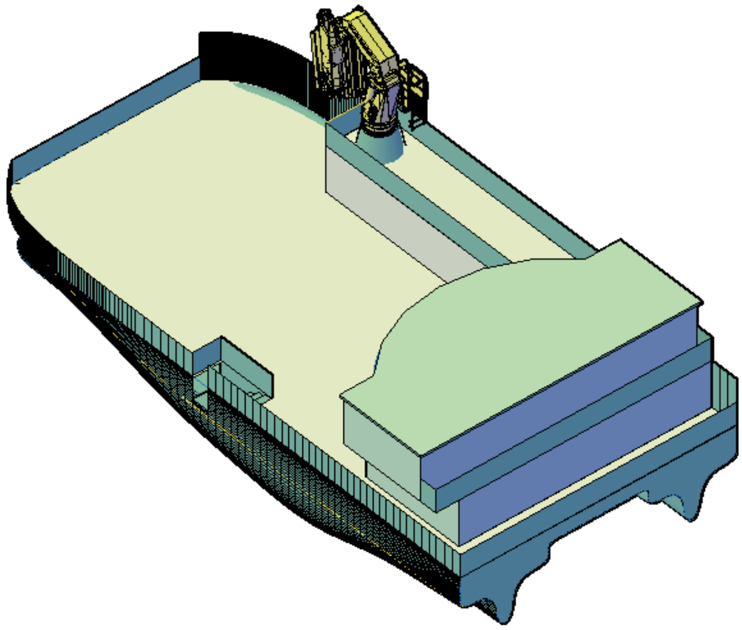


Figure 8.31: Concept of bridge layout for larger vessels

- Advantages: Increase both safety and efficiency by ensuring good overview of the deck and vessel side. Decrease necessary movement inside the wheelhouse, as the skipper only need to have his attention to the forward and the sides of the vessel.
- Disadvantages: Only suited for new vessel. Possible, but expensive for existing vessels. Deck area less protected during transit.

Location of Crane

On vessels in the aquaculture industry, the crane has traditionally been placed on the starboard aft end of the vessel deck. This has allowed the crane to have good range of application both forward side and aft of vessel, performing lifts in safe distance to the superstructure. However, the crane tip motion is connected to vessel motion and increase with distance from the vessel's centre of gravity (COG). Thus, to minimise the crane tip motion and hence increase safety in lifting operations, the crane should be placed in centre amidships. However, this might decrease the range of application, limit or conflict other equipment and take up more deck area. A good alternative placement can therefore be on the side amidships or close to amidships. This will also give less motion, compared to having the crane placed aft on the vessel.

On new vessels, it is therefore recommended to locate the crane as close as possible to amidships in order to minimise the crane tip motions and expand the allowable weather window. This will increase both efficiency and safety in operations using crane.

- Advantage: Increase weather window, reduce risk of lifting related accidents.
- Disadvantages: Only suited for new vessel to be built

8.2.6 Control Option 6: Operation Specific Improvement

These control options are specific suggested solutions for problems identified on the attended marine operations in this study. The solution will contribute to solve challenges identified earlier in this study.

CO6a: Improve Cleaning Barge

For service and maintenance of floating collar several issues were identified with respect to both efficiency and safety. The suggested solution in Figure 8.32, tries to solve many of these issues. The suggested solution is to use a semi-submergible instead of a barge. The semi-submergible can be raised and lowered with use of ballast. Thus, by ballasting the semi-sub, it will be easier to place it below the floating collar. Furthermore, the opening in the deck ensures that biofouling can fall directly into the sea and not be accumulated on the deck during operation. The opening can be fitted with a remote hatch in order to close it when performing maintenance on floating collar.

Furthermore, the deck is equipped with railings to secure personnel from falling into the sea. However, it should be possible to lower the outer railing during operation, in order for the semi-sub to pass the bridles freely. The hydraulic wheels are upgraded with one wheel for the bottom ring, in order to prevent jamming. In Figure 8.32, the HPC is included on deck. This will reduce setup time, but this can, as previous mentioned, be difficult due to the height.

- Advantage: Prevent accumulation of biofouling, prevent jamming of bottom ring, can be easily raised and lowered, shorter setup time, increase safety with railings and no free hoses/cables
- Disadvantage: Expansive, height problem with HPC on deck

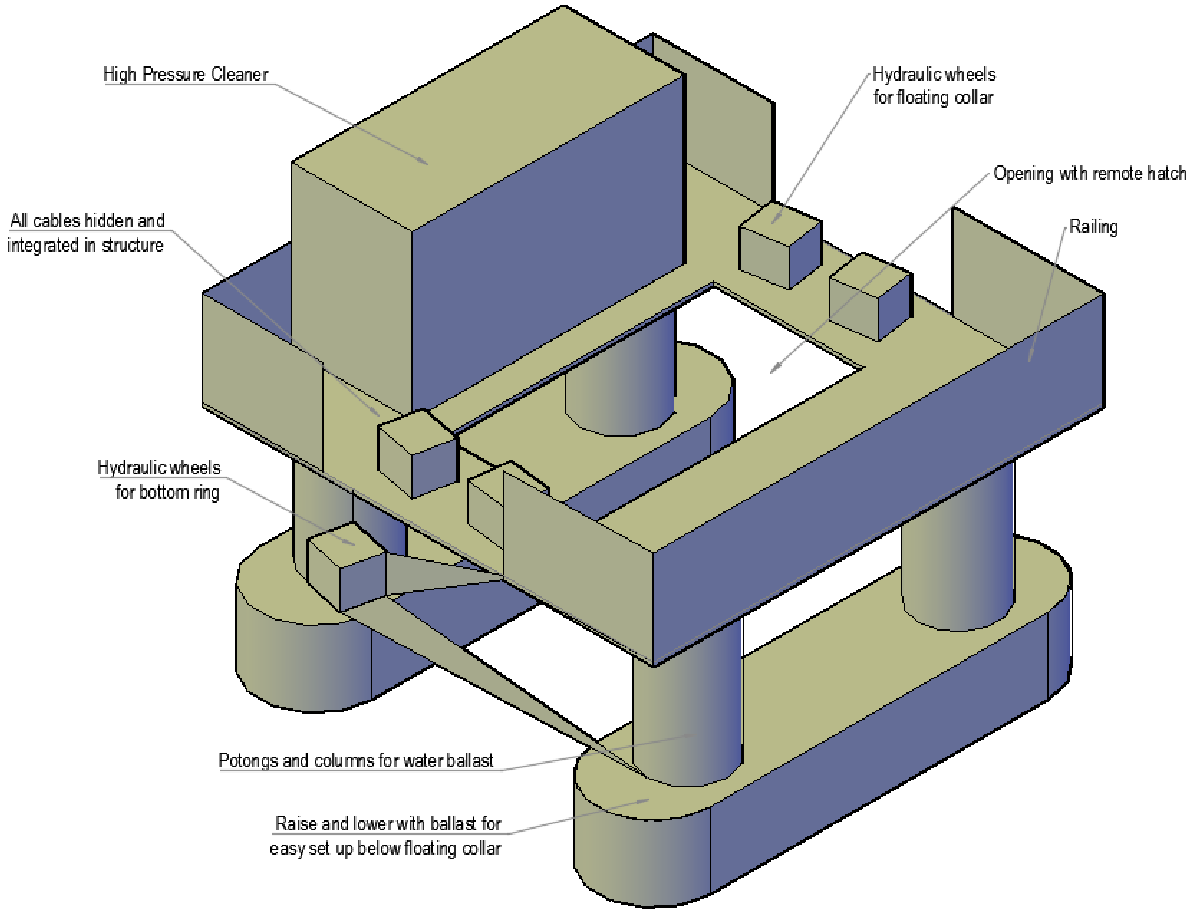


Figure 8.32: Concept cleaning barge

CO6b: Improve Net Cleaning Operation

RONC buoyancy

Multi Pump Innovation delivers the RONC system as shown in Figure 8.33. As elaborated earlier, the RONC has not buoyancy control like the ROV. This cause increased delays if the HPC system is stopped. Furthermore, this can cause hazardous situations and potentially cause fish escapement.

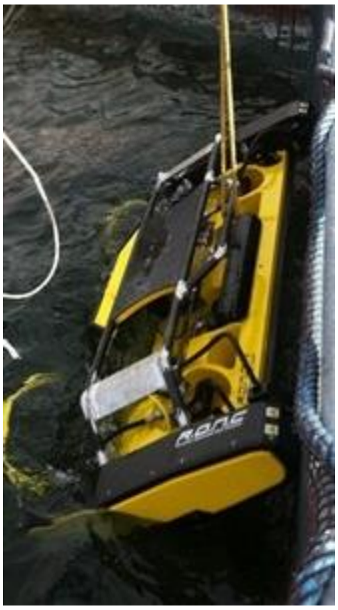


Figure 8.33: RONC delivered by Multi Pump Innovation (MPI, 2016)

The supplier of the RONC has not been contacted, but it should be possible to upgrade the RONC with a fixed ballast system. The technology and control system can be adopted from ROVs. Thus, by controlling the specific gravity of the RONC with such a fixed ballast system, the RONC is no longer dependent of the HPC.

- Advantage: Do not sink when HPC is stopped, do not need to be controlled to surface during stops in operation, reduce the risk of damaging equipment and net.
- Disadvantage: Make RONC heavier, need more software, more expensive.

Storing tank with water for RONC and ROV:

In order to reduce preparation time, suggested solution is to start the HPC during transit. The concept includes a storing tank with water on deck, which will make it possible to start HPC during transit. Thus, the HPC will be ready when ROV and RONC are deployed into the cage. During transit, the HPC can get its water supply from a tank, in order to secure constantly access to water. Furthermore, the ROV and the RONC has a proper storage place submerged in water. The concept is illustrated in Figure 8.34.

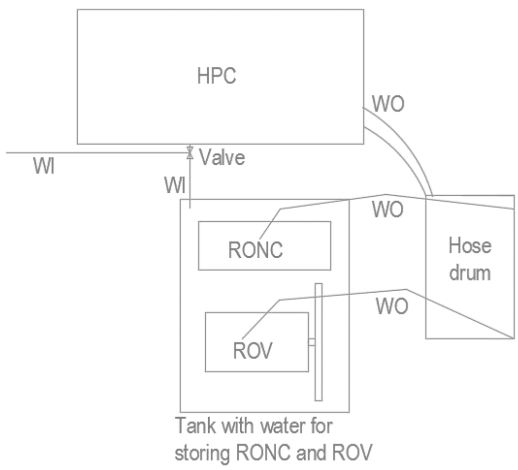


Figure 8.34: Concept of storing tank for ROV/RONC

- Advantage: Better storage of ROV/ RONC. Start process earlier (during transit). HPC ready to use when equi**pm**ent is deployed. Better securing of equipment on deck.
- Disadvantage: Free surface effect

8.3 Assessment of Control Options and Re-evaluation of Risk Picture

In the following sections, the risk reduction of implementing the control options are assessed together with an evaluation of interdependencies between control options. Control option 1 to 4 will be further investigated in the continuation of this assessment. Control option 5 and 6 are more specific control options that will improve both safety and efficiency, but will not be further investigated. These options are more specific to operation and hence difficult to include in a re-evaluation of the generic accident categories.

The impact on specific branches of the event trees are estimated based on expert evaluation by the authors of this thesis. It will be too comprehensive to give a detailed description on every branch, thus the impact is indicated as percentage in belonging tables only, without further explanation.

8.3.1 Control Option 1: Planning

Control option 1 involves proper planning, ensuring good preparation and that the operation is carried out safe and efficient. Furthermore, it can work as a decision support tool for the leader in charge. This will contribute to operations are performed in more safe conditions and will mitigate the effect of failures and prevent accidents from occurring. The impact of control option 1 is presented in Table 8.2, while belonging risk-reduction result is presented in Table 8.3.

Table 8.2: Impact of CO1

Accident category	ET	ET branch probability		
		Basis	**Reduced by CO1**	**New**
Slip/trip	Initiating frequency	1.8E-03	30%	1.26E-03
	Floating collar/bad weather	0.7	21.4%	0.55
	Vessel/bad weather	0.7	21.4%	0.55
Hit by object	Initiating frequency	1.9E-03	50%	0.95E-03
	Floating collar/bad weather	0.7	21.4%	0.55
	Vessel/bad weather	0.7	21.4%	0.55
Squeeze/ trapped	Initiating frequency	1.5E-03	30%	1.05E-03
	Floating collar/bad weather	0.7	21.4%	0.55
	Vessel/bad weather	0.7	21.4%	0.55
Collision/ contact	Initiating frequency	3.1E-03	50%	1.55E-03
	Bad weather	0.7	21.4%	0.55

Table 8.3: Risk reduction of implementing CO1

CO1	Frequency (per year)		Ind. Risk (per year)		ΔR (%)
	Original	New	Original	New	
Slip/trip	0.52E-03	0.34E-03	1.32E-03	0.82E-03	37.9%
Hit by object	1.53E-03	0.75E-03	4.26E-03	2.08E-03	51.2%
Squeeze/trapped	0.78E-03	0.52E-03	2.24E-03	1.48E-03	33.9%
Collision/contact	4.60E-03	1.55E-03	0.54E-03	0.26E-03	51.9%
Total	**7.43E-03**	**3.16E-03**	**8.36E-03**	**4.64E-03**	**44.5%**
Total 3 parities	3.11E-03	1.56E-03	6.24E-04	3.08E-04	50.6%

8.3.2 Control Option 2: Prevent Falling into Sea and Drowning

Control option 2 is a combination of measures for preventing falling into sea and of preventing drowning if accident first has occurred and worker has fallen into sea. Measures in control option 2a are related to net cage, measures in control option 2b are related to vessel, while measures in control option 2c are related personnel training and safety. The impact is presented in Table 8.4, 8.6 and 8.8 respectively. Belonging risk-reduction results are presented in Table 8.5, 8.7 and 8.9 respectively.

Table 8.4: Impact of CO2a

Accident category	ET	ET branch probability		
		Basis	Reduced by CO2a	New
Slip/trip	Floating collar/bad weather/fall into sea	0.45	70%	0.135
	Not bad weather/fall into sea	0.3	80%	0.060
	Floating collar/bad weather/fall into sea/critical injury/no life west/working alone/unable to get out of water	0.85	20%	0.680
	Not working alone/unable to get out of water	0.6	15%	0.510
	Life west/working alone/unable to get out of water	0.55	25%	0.413
	Not working alone/unable to get out of water	0.175	17.5%	0.144

	Not critical injury/no life west/working alone/unable to get out of water	0.5	25%	0.375
	Not working alone/unable to get out of water	0.325	17.5%	0.268
	Life west/working alone/unable to get out of water	0.35	30%	0.245
	Not working alone/unable to get out of water	0.15	20%	0.120
	Floating collar/not bad weather/fall into sea/critical injury/no life west/working alone/unable to get out of water	0.7	25%	0.525
	Not working alone/unable to get out of water	0.45	20%	0.360
	Life west/working alone/unable to get out of water	0.35	30%	0.245
	Not working alone/unable to get out of water	0.1	22.5%	0.078
	Not critical injury/no life west/working alone/unable to get out of water	0.4	35%	0.260
	Not working alone/unable to get out of water	0.3	25%	0.225
	Life west/working alone/unable to get out of water	0.15	45%	0.083
	Not working alone/unable to get out of water	0.075	30%	0.053
	Assume same development for vessel			
Hit by object	Floating collar/bad weather/no helmet/critical injury/fall into sea	0.825	70%	0.248
	Not bad weather/no helmet/critical injury/fall into sea	0.725	80%	0.145
	Assume same development for "unable to get out of water" as for slip/trip			
Squeeze/ trapped	Floating collar/bad weather/no protective clothes/critical injury/fall into sea	0.65	70%	0.195
	Not bad weather/ no protective clothes /critical injury/fall into sea	0.5	80%	0.100
	Assume same development for "unable to get out of water" as for slip/trip			
Collision / contact	Probability of fatalities other than crew on vessel	0.0625	10%	0.056

Table 8.5: Risk reduction of implementing CO2a

CO2a	Frequency (per year)		Ind. Risk (per year)		ΔR (%)
	Original	New	Original	New	
Slip/trip	0.52E-03	0.26E-03	1.32E-03	0.66E-03	50.0%
Hit by object	1.53E-03	1.30E-03	4.26E-03	3.77E-03	11.5%
Squeeze/trapped	0.78E-03	0.70E-3	2.24E-03	1.93E-03	13.8%
Collision/contact	3.10E-03	3.10E-03	0.54E-03	0.54E-03	0%
Total	**5.93E-03**	**5.36E-03**	**8.36E-03**	**6.90E-03**	**17.4%**
Total 3 parities	3.11E-03	3.11E-03	6.24E-04	5.62E-04	9.9%

Table 8.6: Impact of CO2b

Accident category	ET	ET branch probability		
		Basis	Reduced by CO2b	New
Slip/trip	Distribution – vessel (reducing initiating frequency)	0.5	50%	0.250
	Vessel/bad weather/fall into sea	0.15	30%	0.105
	Not bad weather/fall into sea	0.1	30%	0.070
Hit by object	Distribution – vessel (reducing initiating frequency)	0.5	30%	0.350
	Vessel/bad weather/no helmet/critical injury/fall into sea	0.45	25%	0.338
	Not bad weather/no helmet/critical injury/fall into sea	0.35	25%	0.263
Squeeze/ trapped	Distribution – vessel (reducing initiating frequency)	0.5	10%	0.450
	Vessel/bad weather/no protective clothes/critical injury/fall into sea	0.25	25%	0.188
	Not bad weather/ no protective clothes /critical injury/fall into sea	0.15	25%	0.113

Table 8.7: Risk reduction of implementing CO2b

CO2b	Frequency (per year)		Ind. Risk (per year)		ΔR (%)
	Original	**New**	**Original**	**New**	
Slip/trip	0.52E-03	0.43E-03	1.32E-03	1.09E-03	17.4%
Hit by object	1.53E-03	1.29E-03	4.26E-03	3.63E-03	14.8%
Squeeze/trapped	0.78E-04	0.74E-03	2.24E-03	2.14E-03	4.2%
Collision/contact	3.10E-03	3.10E-03	0.54E-03	0.54E-03	0%
Total	**5.23E-03**	**5.56E-03**	**8.36E-03**	**7.40E-03**	**11.5%**
Total 3 parities	3.11E-03	3.11E-03	6.24E-04	6.24E-04	0%

Table 8.8: Impact of CO2c

Accident category	ET	ET branch probability		
		Basis	**Reduced by CO2c**	**New**
Slip/trip	Floating collar/bad weather/fall into sea/critical injury/no life west/working alone/unable to get out of water	0.85	30%	0.595
	Not working alone/unable to get out of water	0.6	20%	0.480
	Life west/working alone/unable to get out of water	0.55	40%	0.330
	Not working alone/unable to get out of water	0.175	30%	0.123
	Not critical injury/no life west/working alone/unable to get out of water	0.5	40%	0.300
	Not working alone/unable to get out of water	0.325	25%	0.244
	Life west/working alone/unable to get out of water	0.35	50%	0.175
	Not working alone/unable to get out of water	0.15	40%	0.090
	Not bad weather/fall into sea/critical injury/no life west/working alone/unable to get out of water	0.7	35%	0.455
	Not working alone/unable to get out of water	0.45	25%	0.338
	Life west/working alone/unable to get out of water	0.35	45%	0.193
	Not working alone/unable to get out of water	0.1	35%	0.065

	Not critical injury/no life west/working alone/unable to get out of water	0.4	50%	0.200
	Not working alone/unable to get out of water	0.3	30%	0.210
	Life west/working alone/unable to get out of water	0.15	60%	0.060
	Not working alone/unable to get out of water	0.075	50%	0.038
	Assume same development for vessel			
Hit by object	Initiating frequency	1.9E-03	25%	1.43 E-03
	Assume same development for "unable to get out of water" as for slip/trip			
Squeeze/ trapped	Initiating frequency	1.5E-03	25%	1.13E-03
	Assume same development for "unable to get out of water" as for slip/trip			
Collision /contact	Initiating frequency	3.1E-03	20%	2.48E-03
	Not surviving	0.15	25%	0.113
	Probability of fatalities other than crew on vessel	0.0625	25%	0.047

Table 8.9: Risk reduction of implementing CO2c

CO2c	**Frequency (per year)**		**Ind. Risk (per year)**		**ΔR (%)**
	Original	**New**	**Original**	**New**	
Slip/trip	0.52E-03	0.52E-03	1.32E-03	1.25E-03	5.3 %
Hit by object	1.53E-03	1.15E-03	4.26E-03	3.03E-03	28.9 %
Squeeze/trapped	0.78E-03	0.57E-03	2.24E-03	1.57E-03	29.9 %
Collision/contact	3.10E-03	2.48E-03	0.54E-03	0.43E-03	20.4%
Total	**5.93E-03**	**4.72E-03**	**8.36E-03**	**6.28E-03**	**24.9%**
Total 3 parities	3.11E-03	2.49E-03	6.24E-04	3.74E-04	40.1%

8.3.3 Control Option 3: Prevent Collision and Contact

Control option 3 is a combination of measures for preventing collision and contact accidents. Measures in control option 3a are related to net cage, while measures in control option 3b are related to vessel. The impact of control option 3a and 3b is presented in Table 8.10 and 8.12 respectively, while belonging results for risk reduction are presented in Table 8.11 and 8.13 respectively.

Table 8.10: Impact of CO3a

Accident category	ET	ET branch probability		
		Basis	Reduced by CO3a	New
Slip/trip	Initiating frequency	1.8E-03	20%	1.44E-03
Squeeze/ trapped	Initiating frequency	1.5E-03	15%	1.28E-03
Collision /contact	Initiating frequency	3.1E-03	30%	2.17E-03
	Bad weather/critical damage to vessel	0.1875	40%	0.113
	Not bad weather/critical damage to vessel	0.1375	40%	0.083
	Bad weather/critical damage to net cage	0.825	40%	0.495
	Not bad weather/critical damage to net cage	0.75	40%	0.450

Table 8.11: Risk reduction of implementing CO3a

CO3a	Frequency (per year)		Ind. Risk (per year)		ΔR (%)
	Original	New	Original	New	
Slip/trip	0.52E-03	0.42E-03	1.32E-03	1.05E-03	20.5%
Hit by object	1.53E-03	1.53E-03	4.26E-03	4.26E-03	0%
Squeeze/trapped	0.78E-03	0.66E-03	2.24E-03	1.91E-03	14.7%
Collision/contact	3.10E-03	2.17E-03	0.54E-03	0.23E-03	57.4%
Total	**5.93E-03**	**4.78E-03**	**8.36E-03**	**7.45E-03**	**10.9%**
Total 3 parities	3.11E-03	2.17E-03	6.24E-04	2.62E-04	58.0%

Table 8.12: Impact of CO3b

Accident category	ET	ET branch probability		
		Basis	Reduced by CO3b	New
Slip/trip	Initiating frequency	1.8E-03	15%	1.53E-03
Squeeze/ trapped	Initiating frequency	1.5E-03	20%	1.20E-03
Collision /contact	Initiating frequency	3.1E-03	20%	2.48E-03
	Bad weather/critical damage to vessel	0.1875	10%	0.169
	Not bad weather/critical damage to vessel	0.1375	10%	0.124
	Bad weather/critical damage to net cage	0.825	15%	0.701
	Not bad weather/critical damage to net cage	0.75	15%	0.638

Table 8.13: Risk reduction of implementing CO3b

CO3b	Frequency (per year)		Ind. Risk (per year)		ΔR (%)
	Original	New	Original	New	
Slip/trip	0.52E-03	0.44E-03	1.32E-03	1.12E-03	15.2%
Hit by object	1.53E-03	1.53E-03	4.26E-03	4.26E-03	0%
Squeeze/trapped	0.78E-03	0.62E-03	2.24E-03	1.79E-03	20.1%
Collision/contact	3.10E-03	2.48E-03	0.54E-03	0.39E-03	27.8%
Total	**5.93E-03**	**4.78E-03**	**8.36E-03**	**7.45E-03**	**9.6%**
Total 3 parities	3.11E-03	2.49E-03	6.24E-04	4.24E-04	32.1%

8.3.4 Control Option 4: Improve Vessel Stability and Crane Operation

Control option 4 is a combination of measures for improving vessel stability and crane operations. Measures in control option 4a are related to general vessel improvements, while measures in control option 4b are related to improvement of lifting of bottom ring. The impact of control option 4a and 4b is presented in Table 8.14 and 8.16 respectively, while belonging risk-reduction results are presented in Table 8.15 and 8.17 respectively.

Table 8.14: Impact of CO4a

Accident category	ET	ET branch probability		
		Basis	Reduced by CO4a	New
Slip/trip	Distribution – vessel (reducing initiating frequency)	0.5	20%	0.4
Hit by object	Initiating frequency	1.9E-03	40%	1.14E-03
	Floating collar/bad weather	0.7	14.3%	0.6
	Vessel/bad weather	0.7	14.3%	0.6
	Floating collar/bad weather/no protective clothes/critical injury	0.75	15%	0.638
	Has protective clothes/critical injury	0.55	15%	0.468
	Good weather/no protective clothes/critical injury	0.7	15%	0.595
	Has protective clothes/critical injury	0.55	15%	0.468
	Vessel/bad weather/no protective clothes/critical injury	0.65	15%	0.553
	Has protective clothes/critical injury	0.45	15%	0.383
	Good weather/no protective clothes/critical injury	0.55	15%	0.468
	Has protective clothes/critical injury	0.4	15%	0.34
Squeeze/ trapped	Distribution – floating collar (reducing initiating frequency)	1.5E-03	15%	1.28E-03

Table 8.15: Risk reduction of implementing CO4a

CO4a	Frequency (per year)		Ind. Risk (per year)		ΔR (%)
	Original	**New**	**Original**	**New**	
Slip/trip	0.52E-03	0.49E-03	1.32E-03	1.24E-03	6.1%
Hit by object	1.53E-03	0.88E-03	4.26E-03	2.32E-03	45.5%
Squeeze/trapped	0.78E-34	0.66E-03	2.24E-03	1.91E-03	14.7%
Collision/contact	3.10E-03	3.10E-03	0.54E-03	0.54E-03	0%
Total	**5.15E-03**	**5.13E-03**	**8.36E-03**	**6.01E-03**	**28.1%**
Total 3 parities	3.11E-03	3.11E-03	6.24E-04	6.24E-04	0%

Table 8.16: Impact of CO4b

Accident category	ET	ET branch probability		
		Basis	**Reduced by CO4b**	**New**
Slip/trip	Initiating frequency	1.8E-03	10%	1.62E-03
Hit by object	Initiating frequency	1.9E-03	20%	1.52E-03
Squeeze/trapped	Initiating frequency	1.5E-03	5%	1.43E-03
Collision/ contact	Initiating frequency	3.1E-03	10%	2.79E-03

Table 8.17: Risk reduction of implementing CO4b

CO4b	Frequency (per year)		Ind. Risk (per year)		ΔR (%)
	Original	New	Original	New	
Slip/trip	0.52E-03	0.47E-03	1.32E-03	1.18E-03	10.6%
Hit by object	1.53E-03	1.22E-03	4.26E-03	3.40E-03	20.2%
Squeeze/trapped	0.78E-03	0.74E-03	2.24E-03	2.13E-03	4.9%
Collision/contact	3.10E-03	2.79E-03	0.54E-03	0.49E-03	9.3%
Total	**5.15E-03**	**5.13E-03**	**8.36E-03**	**6.01E-03**	**13.9%**
Total 3 parities	3.11E-03	2.80E-03	6.24E-04	5.62E-04	9.9%

8.3.5 Sorting of Control Options

A sorting matrix is establish in order to assess how difficult the different control options are to implement against their expected combined efficiency and safety improvement. The result is presented in Figure 35. This shows that control option 1, control option 2a and control option 2c are assessed to be easiest to implement.

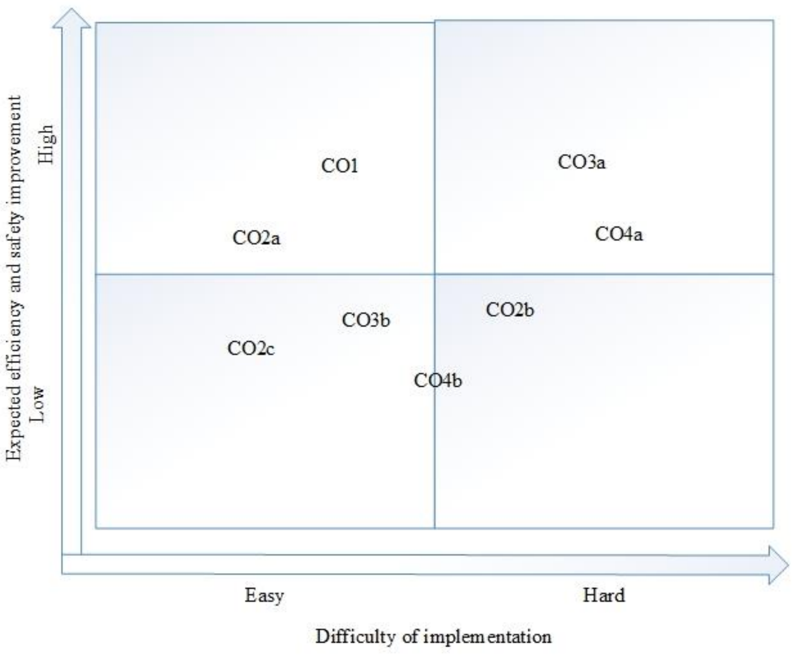


Figure 8.35: Sorting of control options

8.3.6 Evaluation of Interdependencies

In the matrix shown in Table 8.18, the interdependencies between the different control options are assessed (ref. Section 3.15). The matrix is read horizontally, indicating the dependencies between e.g. control option 1 and each of the other assessed control option 2 to 4. The practically meaning of the dependencies is that either it is no dependencies, it is weak dependencies indicating that re-evaluation may not be necessary, or it is strong dependencies indicating that the control option need to be re-evaluated before adopted in conjunction with the control option in question (IMO, 2013).

Table 8.18: Interdependencies of COs

CO	1	2a	2b	2c	3a	3b	4a	4b
1		No	No	No	No	No	No	No
2a	Strong		No	Weak	No	No	No	No
2b	Strong	No		Weak	No	No	Weak	No
2c	Strong	No	No		No	No	No	No
3a	Strong	Weak	Weak	No		Strong	No	No
3b	Strong	No	Weak	Weak	Strong		No	No
4a	Strong	No	Weak	Weak	No	No		Weak
4b	Strong	Weak	No	Weak	Weak	Weak	Weak	

8.4 Recommendations for Decision-Making

The purpose of this step is to define recommendation for the relevant decision makers, which in this case are fish farm companies, service companies, equipment suppliers and authorities (ref. Section 3.1.7).

As the results from the risk analysis showed, the overall individual risk associated with marine operations involving service vessels and floating collars was found to be in unacceptable risk area. Contrary to risk found to be in the ALARP area, measures must be implemented independent of cost-effectiveness (ref. Section 3.3.2.2). Thus, no cost benefit analysis has been utilised in order to present recommendations for decision-makers in this study. An implicit evaluation of cost-benefit are although given in Section 8.2 where the control options are described in detail. However, within the available time of this master thesis, it has not been successfully to invite tenders for all proposed control options.

The risk analysis shows that three of four accident categories investigated, are found to be in unacceptable individual risk area, hence reduction of risk level in all these three categories are necessary in order to sufficient decrease the overall risk level to an acceptable level. Neither of the proposed control options will by itself be sufficient to decrease the overall individual risk level to an acceptable level. Thus, a combination of control options need to be implemented. In implementation of several control options, the dependencies between them must be assessed (ref. Section 3.1.5). The evaluation of dependencies are given in Table 8.18 in Section 8.3.6.

The overall individual risk for third parties are as well found to be in unacceptable risk area. Thus, control options must be implemented in order to reduce the individual risk level for third parties independent on cost-effectiveness. Furthermore, the risk level for environment and property are found to be high, especially for third parties environmental risk due to impact from fish escapements. There are not set any risk acceptance criteria for property and environment, but for i.e. fish escapement, it is a zero-request for escapement. Thus, control options reducing environmental and property risk should be assessed.

The risk reduction potential for the control options evaluated in the present study is summarised in Table 8.19. Third parties risk reduction potential for control options evaluated is summarised in Table 8.20. Environmental and property risk reduction potential is summarised in Table 8.21.

Table 8.19: Summary of Results of Risk Reduction Estimation

CO	Description	Risk reduction ΔR	Priority
CO1	Measures related to better planning and decision support system	44.5%	1
CO2a	Measures on net cage related to prevention of falling into sea and drowning	17.4%	4
CO2b	Measures on vessel related to prevention of falling into sea and drowning	11.5%	6
CO2c	Measures for personnel training and safety related to prevention of falling into sea and drowning	24.9%	3
CO3a	Measures on net cage related to prevention of collision and contact	10.9%	7
CO3b	Measures on vessel related to prevention of collision and contact	9.6%	8
CO4a	General measures related to improving vessel stability and crane operation	28.1%	2
CO4b	Measures related to improving lift of bottom ring	13.9%	5

Table 8.20: Summary of Results of 3.parties Risk Reduction Estimation

CO	Description (3.parties)	Risk reduction ΔR	Priority
CO1	Measures related to better planning and decision support system	50.6%	2
CO2a	Measures on net cage related to prevention of falling into sea and drowning	9.9%	5
CO2c	Measures for personnel training and safety related to prevention of falling into sea and drowning	40.1%	3
CO3a	Measures on net cage related to prevention of collision and contact	58.0%	1
CO3b	Measures on vessel related to prevention of collision and contact	32.1%	4
CO4b	Measures related to improving lift of bottom ring	9.9%	5

Table 8.21: Summary of Results of Environmental and Property Risk Reduction Estimation

CO	Environment risk		Property risk		Environment Risk 3.parties		Property risk 3.parties	
	Risk	ΔR	Risk	ΔR	Risk	ΔR	Risk	ΔR
Org	1.12E-04		3.65E-03		1.18E-02		8.10E-03	
CO1	5.37E-05	52.1%	1.81E-03	50.4%	5.90E-03	50%	4.02E-03	50.4%
CO2c	8.98E-05	19.8%	2.92E-03	20%	9.46E-03	19.8%	6.48E-03	20%
CO3a	4.72E-05	57.9%	2.40E-03	34.2%	7.57E-03	35.8%	4.27E-03	47.3%
CO3b	8.09E-05	27.8%	2.87E-03	21.4%	9.16E-03	22.4%	5.88E-03	27.4%
CO4b	1.01E-04	9.8%	3.28E-03	10.1%	1.06E-02	10.2%	7.29E-03	10%

Based on individual risk reduction potential, the following recommendations can be made:

- Control option 1: Measures related to better planning and decision support system
- Control option 4a: General measures related to improving vessel stability and crane operation
- Control option 2c: Measures for personnel training and safety related to prevention of falling into sea and drowning

Based on third parties individual risk reduction potential, the following recommendations can be made:

- Control option 3a: Measures on net cage related to prevention of collision and contact
- Control option 1: Measures related to better planning and decision support system
- Control option 2c: Measures for personnel training and safety related to prevention of falling into sea and drowning

Based on environmental and property risk reduction potential, the following recommendations can be made:

- Control option 1: Measures related to better planning and decision support system
- Control option 3a: Measures on net cage related to prevention of collision and contact

In relation to the above recommendations, the following points are noteworthy:

- Control option 1 is recurring for all recommendation categories and has therefore the overall best HSE risk reduction potential. Likewise, this control option answer to one of the main challenges found in the Continual Improvement Assessment and will contribute to improve operational efficiency, by ensuring proper preparation through good planning and to limit unnecessary delays and abortions (ref. section 8.2.1). The control option can easily be implemented without any investment of new equipment or upgrade of vessel and net cage. Furthermore, the option can be implemented independent of other decision-makers. E.g. in a service company’s point of view, implementation of this control option will improve efficiency and safety in their operation independent on the facilities of the fish farm they are performing operation on.
- Control option 2c is improving safety for both personnel on vessel and potential third parties on net cage. Likewise, this control option contribute to improve communication during operation and can thus contribute to improve the efficiency of the operation. As

for control option 1, this option can be implemented independent of other decision-makers.

- Control option 3a improves individual third parties risk and environmental and property risk. At the same time, it will improve the berthing process to net cage and increase the operational limit allowing vessel to moor to cages in rougher weather conditions. This option is depending on each fish farm to install the control option. Thus, safety and efficiency will only be increased on fish farm where the option is available.

Although none cost benefit analysis are utilised on the control options, some recommendations can be made based on implicit cost-effectiveness consideration and how difficult they are to implement:

- Control option 1: Measures related to better planning and decision support system
- Control option 2c: Measures for personnel training and safety related to prevention of falling into sea and drowning
- Control option 2a: Measures on net cage related to prevention of falling into sea and drowning

These options are all relatively easily and inexpensive to implement and contribute to increase safety and efficiency.

9 Discussion

Challenges with salmon lice and stagnation in production growth have led the industry to develop many new solutions in attempt to get control over the situation and secure future production growth. However, many accidents and increasing production costs will force the aquaculture industry to prioritise both safety and efficiency in marine operations higher. Thus, the purpose of this master thesis was to systematically assess marine operations in order to optimise the operations with respect to both efficiency and safety.

In this section the previous studies, selection of methodologies, evaluation of data and the confidence of the results and recommendations are discussed.

9.1 Previous Studies

Previously, only Preliminary Hazard Analysis, or similar, has been utilised in order to identify problem areas with respect to safety. Systematic assessment of marine operations has, however, previously not been done in order to propose measures that can combined increase the safety level and efficiency level. This can be explained by:

- Focus in the industry is directed on the challenges they currently are facing. The industry is dealing with problems reactive instead of being proactive. When the industry was struggling with many escapes, the causes were found to be mostly structural. The implementation of NYTEK and NS9415 sets requirements to the fish farms, which secured the structures against failure and breakdown and hence decreased the number of escapements. Today the challenge with salmon lice is the main challenge. Several new methods are quickly developed in order to treat the salmon. This have increased production cost significantly, many new operations are taking place and new hazards are introduced. Thus, systematic assessments of the operations are not prioritised highest.
- Traditionally, the fish farmers have performed all operations necessary at the fish farm. Therefore, the vessels had to perform all kinds of operations, leading to limited possibilities to optimise the vessel and operation with respect to safety and efficiency.
- The industry is still mostly experience-based with respect to planning and performing operations. Job safety analysis is used, but no objective guidelines for when to operate in accordance to weather conditions is established. Vessels are being more specialised for the specific operation they are to perform. However, whether to perform the operation or not mostly rely on the leader in charge and he has to mostly rely his

decisions on previously experience. The knowledge of proper planning and decision-support tools are missing in the aquaculture industry, while it is highly used in the offshore industry.

9.2 Selection of Methodology

There are no available methodologies that identify problem areas regarding both efficiency and safety, although these often are related. Thus, two different methodologies are used.

The IMO guidelines for Formal Safety Assessment is selected for the evaluation of safety in the operations. The FSA is a standard well-proven risk assessment methodology, with the aim of developing risk-reducing measures in a structured and systematic way. Both technical and operational issues may be incorporated in the FSA in order to quantify the risk level and identify areas of problems that need control. Thus, this methodology is a good choice in order to assess whether the service vessels and floating collars are fitted to each other with respect to safety.

The KOSTER III model, developed by the Norwegian Defence and Research Establishment, was selected for the assessment of efficiency in the operations. The model is a standard continual improvement assessment based on lean philosophy. Within lean philosophy, there are several different methods available depending on what kind of business that is under investigation. Traditionally lean originate from improving processes at fabrics and are not suited for investigation of operations directly. However, the KOSTER III model is adapted to assess operations performed by a company in order to identify problem areas within the specific operation. Thus, this methodology is a good choice in order to assess whether the service vessels and floating collars are fitted to each other with respect to efficiency.

These two methodologies were used to establish risk control measures and improvement control measures that were combined to joint control measures and further assessed in order to establish recommendation for decision-makers.

9.3 Evaluation of Data

Uncertainty in data and expert judgements should be assessed in order to evaluate the significance of the uncertainty and check the confidence of the result of the risk assessment. There might, among others, be uncertainty regarding completeness, models, parameters and consequences.

The identification of hazards are based on observations and interviews of personnel on the three attended operations. Thus, not all relevant hazards may have been identified. The completeness of the analysis might therefore be uncertain and hence lead to underestimation of risk. However, the established generic accident categories, which is based on the hazard identification, correspond well to the available accident statistics.

No causal and frequency analysis were modelled, as there are very limited available causal data. A frequency analysis was however performed based on available statistic, and used as input to the generic accident models established in the consequence analysis. For the models established in the consequence analysis, event trees were used. This is the most common method for developing the accident scenarios and establish the risk picture. Thus, the selection of method is appropriate, but there is uncertainty to whether the model covers all scenarios and hence if it represent real world phenomena. Furthermore, there might be uncertainty regarding the consequences in the model, due to lack of knowledge about possible consequences. However, the models are extensive and conservative and therefore thought to be representative.

In this study, it is strived to obtain the most relevant and updated information. A few previous studies have presented accident and causal statistics. Statistics from these studies are used and supplemented with statistics received from the Norwegian Labour Inspection Authority, the Norwegian Maritime Directorate and the Directorate of Fisheries. Several sources indicate that underreporting of accidents is a challenge and that many accidents are not reported if they are not leading to hospital treatment or fatality. Thus, the basis of the analysis might be too low and affect the risk assessment. On the contrary, it might be that some of the statistics used are too old and therefore not representative for the current risk level today. Statistics are collected from several databases, but double counting is prevented by not combining the databases, but rather using the statistics independent of each other.

In previous studies using the FSA methodology, the frequency of accident data is mostly calculated for per "shipyear". Thus, the frequency of accidents is calculated from total number of accidents for a given period divided on the total fleet-at-risk for the same period. However, there are none available database of fleet of service vessels. Thus, the accumulative number of employees at risk in the aquaculture industry are used instead. This gives frequency per "personnelyear", which is well suited to find the frequency for one year based on available accident data. As accidents not only involves accidents with vessels, but also occupational accidents as slip/trip and hit by object, this might be more representative when calculating the individual risk in the models.

Due to limitation on available data, an expert evaluation scheme was established in the consequence analysis. Unfortunately, within the available time of this master thesis, the respond to the evaluation was low and might not give as good evaluation as wanted. Where information was lacking, the authors of this paper have made conservative assumptions based on best available data. Based on this, uncertainty of parameters is clearly present. A more extensive expert evaluation would have increased the certainty. Furthermore, fault trees can be used as a quality check to portray the multiple events leading to the outcome of interest. This regards the initiating event in the event trees, but also the individual branches in the event tree.

A sensitivity analysis should have been performed to assess the uncertainties in the risk assessment. By examining how the results change when changing the inputs as parameters, assumptions or structure of models, this can give a better understanding of the system. Thus, attention can be directed to those parts of the system that have highest impact of the sensitivity analysis. Furthermore, the effect of the control options is based on expert judgement. Therefore, a sensitivity analysis on the suggested control options and their risk reduction potential should have been implemented in order to assess the uncertainty in the expert judgement. This would have strengthened the confidence of the recommendations made for the decision-makers.

In the Continual Improvement Assessment, the three attended operations form the basis for evaluation of efficiency in marine operations. The choice of areas of problem used in the analysis are thus, based on these three operations and conversations with the personnel. There might therefore be areas in these operations with larger efficiency problems that were not identified, or areas in other operations with larger efficiency problems. However, the attended operations were identified and targeted by both of the collaborating companies indicating that these are operations of most concern. Furthermore, three of the areas of problem identified, are concerning most of the operations performed in the industry and not only the three attended ones. Improving these areas found in this thesis, will therefore contribute to increase the efficiency in other operations as well.

A Cause-Effect Analysis followed by a Five Whys Analysis were selected to assess the causes of the areas of problem identified. These are well-proven methods and ensure that the real cause to the problem is identified. However, the analysis of causes is based on attending the operations once, and it can therefore be other causes not revealed during these operations. It could therefore be beneficial to attend the operations several times, but due to long traveling distances, limitations in time and time used to arrange the operation with the companies, this was not possible in the scope of this project.

Further, the Continual Improvement process could derive advantages from having representatives from the industry along during the analysis. However, the identified results of problems and causes clearly contribute to make operations inefficient, thus it might be other causes not identified.

In addition to identifying and improve the main area of problems, an alternative method was used in order to improve the overall equipment effectiveness. For this purpose, SMED was selected. The SMED method is traditionally used to reduce the changeover time in fabrics, but is an effective method to increase the effectiveness in operations as well. By investigating the current process, activities are separated into internal and external activities before internal activities are converted into external activities and the process is streamlined. Thus, it is important that the operation is properly and correctly documented and understood before starting. The operations are well documented through this study, but the documentation is based on attending the operations only once. It can therefore be parts that are misunderstood, overlooked and/or not revealed during the attended operations. E.g. the part of the delousing operation where the actual treating of the fish with peroxide takes place, was not observed due to several abortions because of bad weather. The documentation of this part of the operation relies therefore on conversations with the personnel and procedures for the operation.

9.4 Robustness/Confidence of Results and Recommendations

Frequency classes and consequence categories established in this study are based on classes and categories given in (Rausand, 2011) and in the IMO (2013) FSA Guideline. The classes and categories proposed in the IMO (2013) FSA Guideline do not cover environmental impact. Thus, the classes and categories are adapted to include consequences for personnel, environment and property in order to suit the problems under investigation. These classes and consequences are by best effort used to rank the hazards identified in the hazard identification.

Furthermore, the same consequence categories are used to rank the different consequences in the accident scenarios modelled in the event trees. The defined consequence categories separate between risk for personnel, environment and property, which was important when ranking the consequences in the collision/contact model. For individual risk, the consequence categories are thus used as an equivalence ratio between fatalities, major injuries and minor injuries. There are several concepts for risk equivalence, and different ratios are used. Therefore, it might be that the equivalence ratio used in this study are weighting fatalities and injuries too high.

Based on the hazard identification in the FSA, several accident categories were established. Only four was selected for further study and represents the overall risk picture for the marine operations. The accident categories: capsize, hole in net due to operation, death of fish and a compile category defined as other occupational accidents, were not included in the further risk analysis. Death of fish is an accident category concerning property, but not critical for human safety. Other occupational accidents might be relevant, but not believed to contribute much to the overall risk picture, neither be very critical to the safety of the personnel.

Hole in net during operations is an increasing problem causing large risk for property and environment. These accidents categories are related when looking into whether the vessels and floating collars are fitted to each other. Thus, in the scope of this study, it chosen to combine collision and contact accidents with a hole in net. This limits the hole in net accident to occur only when there is a collision or contact accident from vessel. In the real world, this is not correct as hole in net is caused by several failures. However as mentioned, within the scope of this study, it gives a representative picture of the hole in net accident.

It might have been correct to model capsize into the overall risk picture. However, the scope of this study is to identify whether the vessel and floating collar are fitted to each other. Thus, it is not selected to include capsize as a part of the overall risk picture, even though a capsize accident can occur during operation on net cage. Further studies should therefore consider to include capsize.

Furthermore, the models used are time-consuming and complex, and some of the simplifications had to be done in order to finish this thesis in time.

The ALARP principle is the most commonly used principle for determining whether the risk related to a system is acceptable or not. Thus, this principle is selected together with appropriate risk acceptance criteria in order to evaluate the overall risk found in the risk analysis. There are several standards for risk acceptance criteria, none yet universally accepted. Thus, the risk acceptance criteria must be properly defined. The IMO (2013) FSA Guideline states that a suitable level of risk acceptance criteria would be considerably below the total accident risks experienced in daily life, but might be set similar to risks that are accepted from other involuntary sources. Considering this, the risk acceptance criteria published in (HSE, 2001) was found appropriate for this study, and is broadly used in other industries and the most commonly used criteria in previous FSA studies.

The FSA methodology states that recommendations for decision-makers shall contain an objective comparison of alternative options, based on the potential risk reduction and cost-effectiveness. Therefore, both risk reduction potential must be calculated and a cost benefit analysis utilised in order to calculate the cost-effectiveness of the alternative options. However, the results from the risk analysis shows that the overall individual and individual third parties risk, according to ALARP principle and risk acceptance criteria, are in area of unacceptable risk. According to the ALARP principle, unacceptable risk is defined as intolerable and risk reduction measures are mandatory. Thus, recommendations to decision-makers are not based on cost-effectiveness, but rather on risk reduction potential. Even though no cost-benefit analysis is required, an implicit assessment of cost-effectiveness is given for each control option where cost estimations have been possible.

The purpose of FSA is to reduce the risk to a level that is tolerable. Therefore, the risk picture should be re-evaluated after implementing recommended control options in this study. If new overall risk is found to be in the ALARP region, measures are desirable but should only be implemented if their cost is not grossly disproportionate to the benefit gained. Hence, and cost-benefit analysis must in this case be utilised in order to decide whether new measures should be recommended or not.

The proposed control options are established based on measures identified in the brainstorming sessions for each of the two selected methodologies. The measures are proposed to solve one or several of the identified areas of problem, regarding both HSE and efficiency. Some measures already exist within the industry or other industries, other measures might be inspired by existing solution, while some measures are new concepts. Common for all, is that they are not already mandatory or broadly implemented in the aquaculture industry.

Furthermore, in a marine operation, there are different decision-makers involved, both directly and indirectly. It has therefore been important to establish options that are practical and possible to implement independent of all decision-makers are agreeing upon it. E.g. if a service company want to increase their safety and efficiency in an operation, the suggested control option must be able to be implemented without involvement from fish farm company.

Overall, the risk level is found to be high. This corresponds well to the fact that the industry is the second most dangerous in Norway, and thus the results of high and even unacceptable risk was not unexpected.

10 Conclusion

The objective of this master thesis was to perform a Formal Safety Assessment and a Continual Improvement Assessment in order to answer the research questions in the problem definition. These questions was to investigate whether the service vessels and floating cage collars are fitted to each other to create optimal working conditions with respect to both operational efficiency and HSE. Furthermore, measures on both vessels and floating collars that could improve both operational efficiency and HSE should be investigated.

Through attending three different marine aquaculture operations, a hazard identification analysis were utilised in order to identify a total of 62 hazards within different areas of the operations. Based on these hazards, four generic accident categories was established to represent the total risk picture for operations between service vessels and floating cage collars. These accident categories formed the basis of the development of accident scenario models leading to the consequence spectrum. By use of available accident statistics, expert evaluation and expert judgement, the overall risk in operations between service vessels and floating cage collars was established. Based on predefined risk acceptance criteria, the overall individual risk and overall individual third parties risk were found to be unacceptable, which agrees with the fact that the industry is the second most dangerous to work in. Thus, according to ALARP principle, risk-reducing measures are mandatory to be implemented. Furthermore, the risk related to environment and property are found to be high. Thus, service vessels and floating cage collars are according to these results, not fitted to each other in order to create optimal working conditions with respect to HSE.

The same three operations formed the basis for the Continual Improvement Assessment. Four main areas of problems were identified and further investigated. Three of the four problem areas are general for many operations, while one were more specific for service and maintenance of the floating collar. A cause-and-effect diagram analysis and five whys analysis were utilised in order to identify the true root causes of the problems. This showed that poor and inadequate design, not properly fitted equipment, lacking or inadequate planning and procedures leading to among others delayed and aborted operations are recurring causes to inefficient operations. Thus, service vessels and floating cage collars are in many areas not properly fitted to each other in order to create optimal working conditions with respect to operational efficiency.

Furthermore, the overall operation efficiency in the operations have been assessed with used of SMED approach. Some of the findings were included in the further assessment of control options. However, in order to increase the overall operation efficiency for the attended operations, findings and suggestions from this part should be assessed by the decision makers.

Based on the results from these two assessments, brainstorming sessions were held in order to establish risk control measures and improvement measures that could improve the problem areas identified, and hence improve the working conditions between vessel and floating collar. These measures were combined into ten practical and well thought out control options for improved safety and efficiency. These ten control options consist of six main areas: Planning, prevent falling into sea and drowning, prevent collision and contact, improve vessel stability and crane operation, improvement for new vessels and operation specific improvement. Seven of these were selected for further evaluation in order to give recommendations for decision-makers. Re-evaluation of the risk picture, show that all of the selected control options contribute to reduce the overall individual risk level. Further, the re-evaluation of the risk picture also shows that all options, except control option 2b (measures on vessel for prevention of falling into sea and drowning) and 4a (general vessel stability measures), contribute to reduce the overall individual third parties risk level. However, in order to reduce the individual and third parties individual risk level sufficiently, the calculations shows that it is necessary to implement a combination of several control options. Furthermore, all control options except control option 2a and b (measures on floating collar and vessel for prevention of falling into sea and drowning) and 4a (general vessel stability measures), contribute to reduce the overall environmental and property risk level.

Based on these considerations, several recommendations are made depending on if it concerns individual, individual third parties, environmental or property risk. Noteworthy remarks from these recommendations can be shortly summarised. Control option 1 is recurring for all of the different recommendations. Control option 1 aims to improve control from management through improved planning according to recognized standards. By establish operation limits and ensuring that the weather window in a favourable weather forecast is sufficient long, will contribute to increase both HSE and operational efficiency in marine operation. Control option 2c (training and safety system) is recommended in order to improve safety for individual and third parties individual risk. It includes special training, automatic alarm system if personnel fall into sea and an intercom system in the helmets of the personnel. This will improve communication during operation, and will contribute to improve the efficiency of the operation.

Control option 3a (improve mooring system on net cage) is recommended in order to improve individual third parties risk and environmental and property risk, but will also improve individual risk. At the same time, it will improve the berthing process to net cage and increase the allowing operational limit for vessel to moor to cages in rougher weather conditions, increasing both safety and efficiency.

As the risk level is found to be unacceptable, recommendations are mainly based on the quantitatively risk reduction potential. The recommended control options will also contributing to improved efficiency, which will help to prevent against the raising productivity costs. However, many of the established control options that are not further recommended might give larger improvement with respect to operational efficiency. In an operational efficiency point of view, other of the options established, might therefore be more appropriate if the main focus is to increase efficiency. Overall, the study shows that by ensuring efficient operations often contribute to safe operations and vice versa. Thus, by making the operation safer, it will also contribute to make the operation more efficient.

11 Further Work

A sensitivity analysis should be performed in order to assess the previously discussed uncertainties in the risk assessment. Thus, attention can be directed to those parts of the system that have highest impact of the sensitivity analysis. This will contribute to strengthen the confidence of the recommendations made for the decision-makers. Furthermore, models and analysis performed should be controlled by actors from the industry in order to increase the quality of models and expert judgements.

The established measures should be quality checked, further developed and implemented. Especially those that are recommended for the decision-makers. Some of the proposed control options, e.g. control option 1, need among other further work in order to establish operation criteria's for the different operations.

Further, the risk analysis should be re-evaluated with the control options selected by the decision-makers, in order to check the new overall risk level against the risk acceptance criteria. According to the ALARP-principle, control options should be implemented until the risk level is as low as reasonable possible. Thus, it might be necessary to introduce new measures and perform a cost benefit analysis in order to check the cost-effectiveness of the measures.

This study mostly looked into whether the service vessel and floating collar was fitted to each other with respect to HSE and operational efficiency, by attending three different operations. Thus, in order to continue to increase the safety and efficiency in the industry, other operations have to be investigated to identify other relevant hazards and inefficient problem areas. With a rapidly developing industry, with development of new technology and new concepts for fish farms, will reinforce this need. This master thesis can function as a guideline in this work.

In this study only an assessment of improving individual activities were perform. However, Continual Improvement Assessment is a continual process, were the improvement process has to be continually followed up. When the measures are implemented, goals must be set, and these goals need to be followed up and the continual improvement process start over again.

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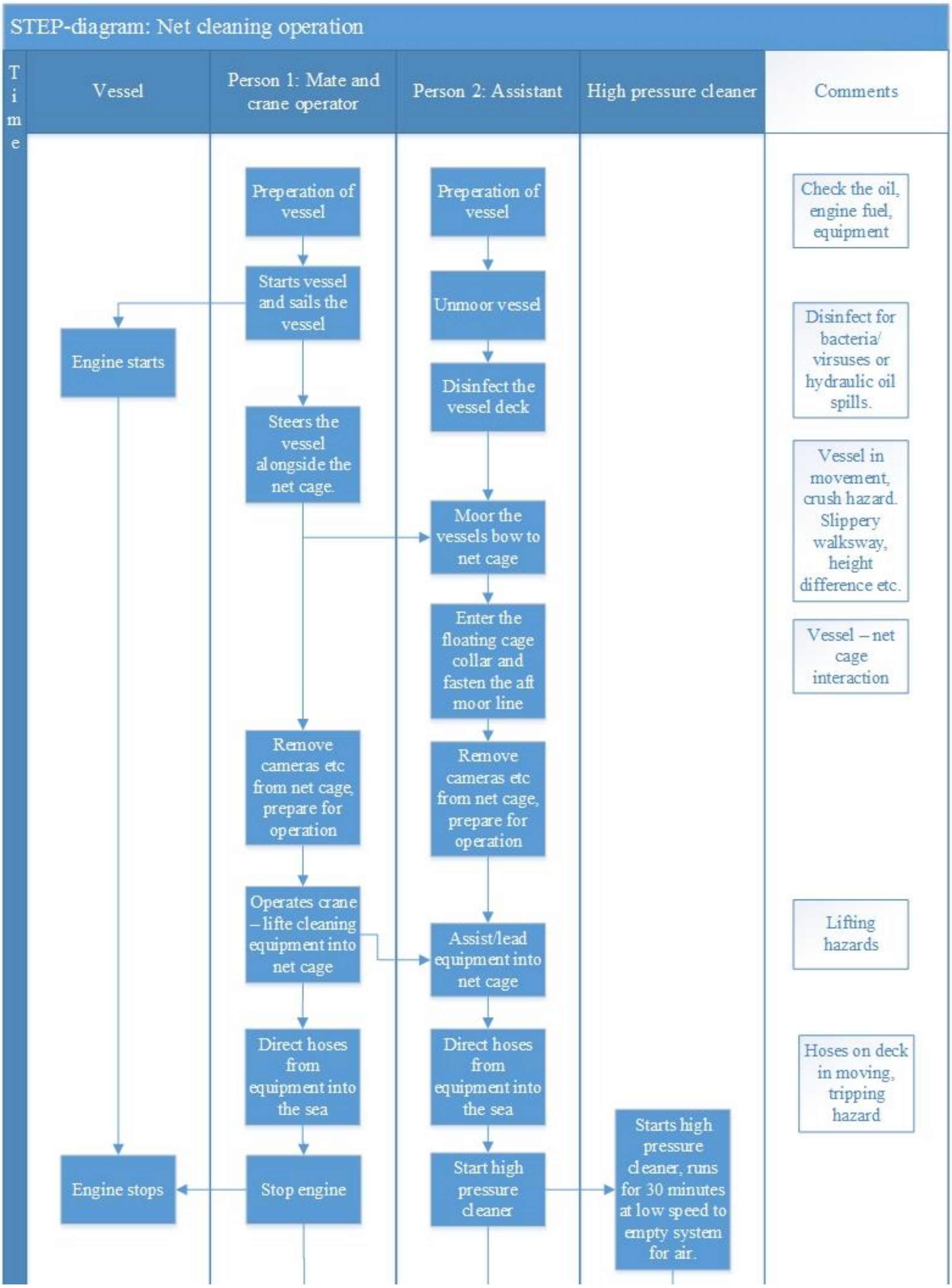
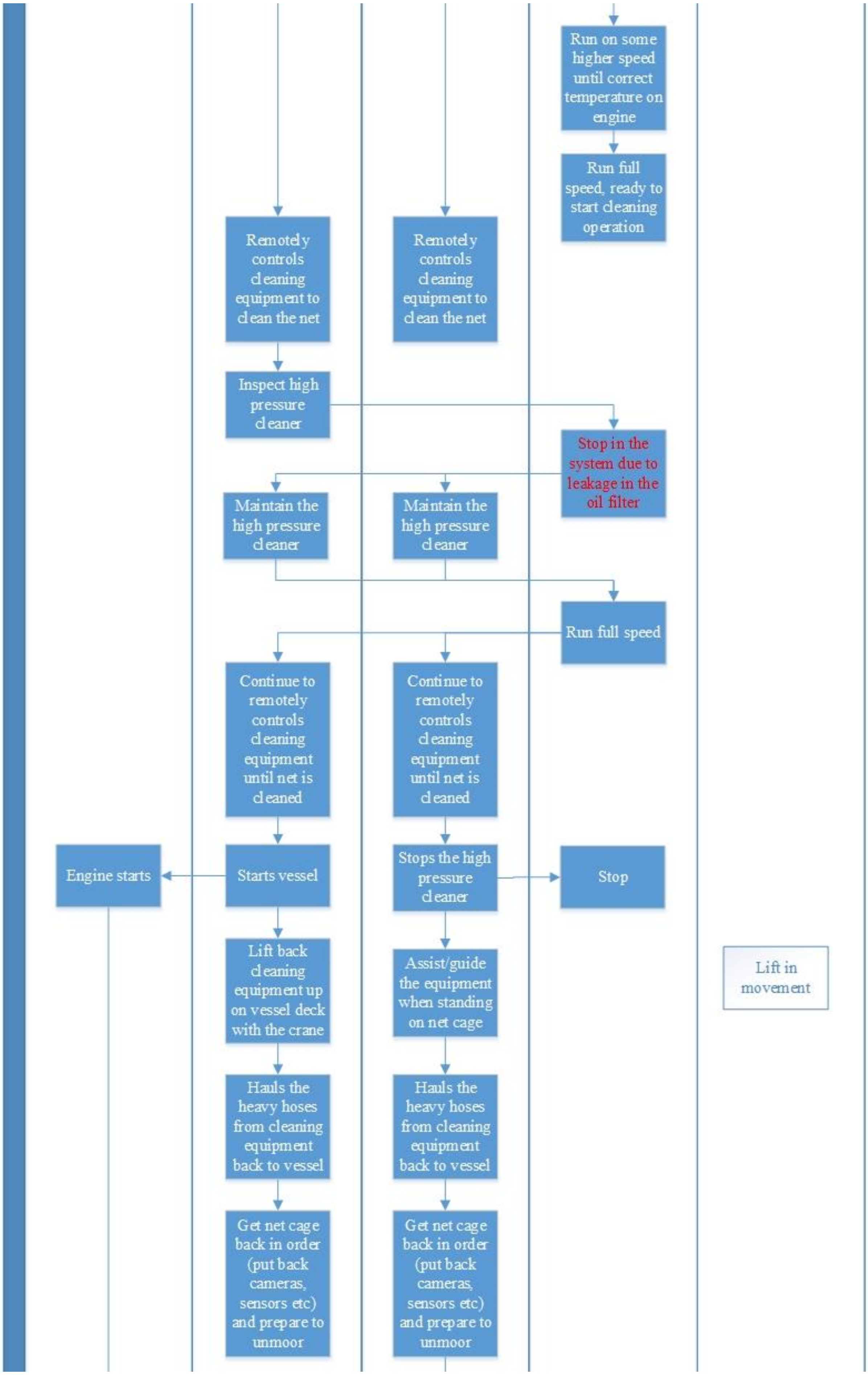
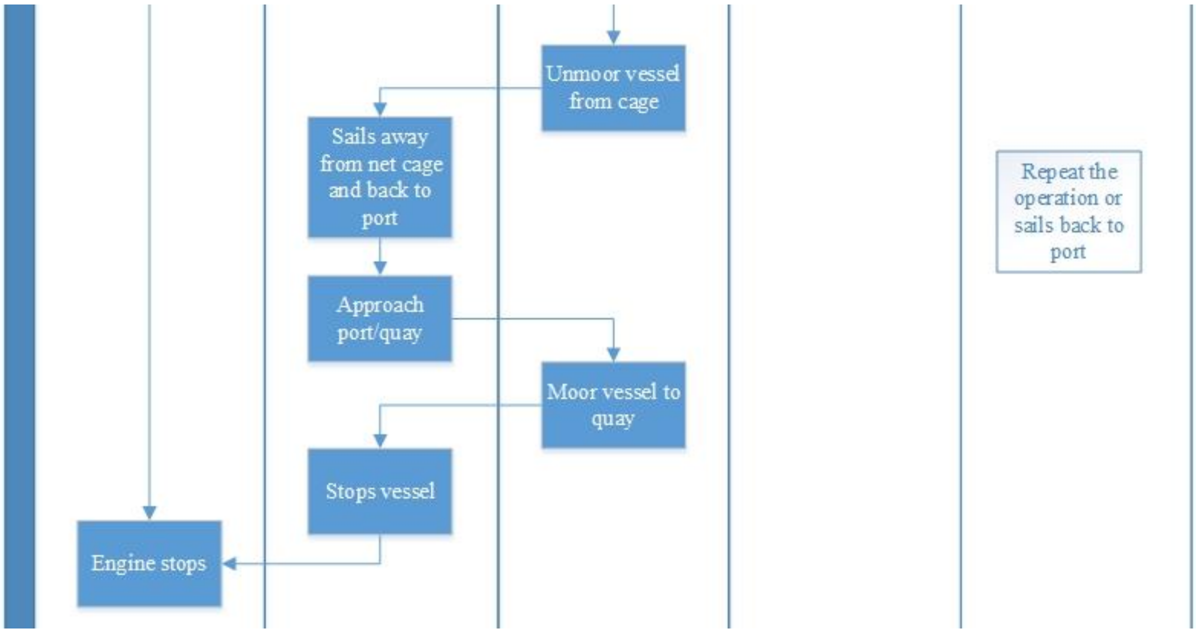
Appendix

A. STEP of the Marine Operations

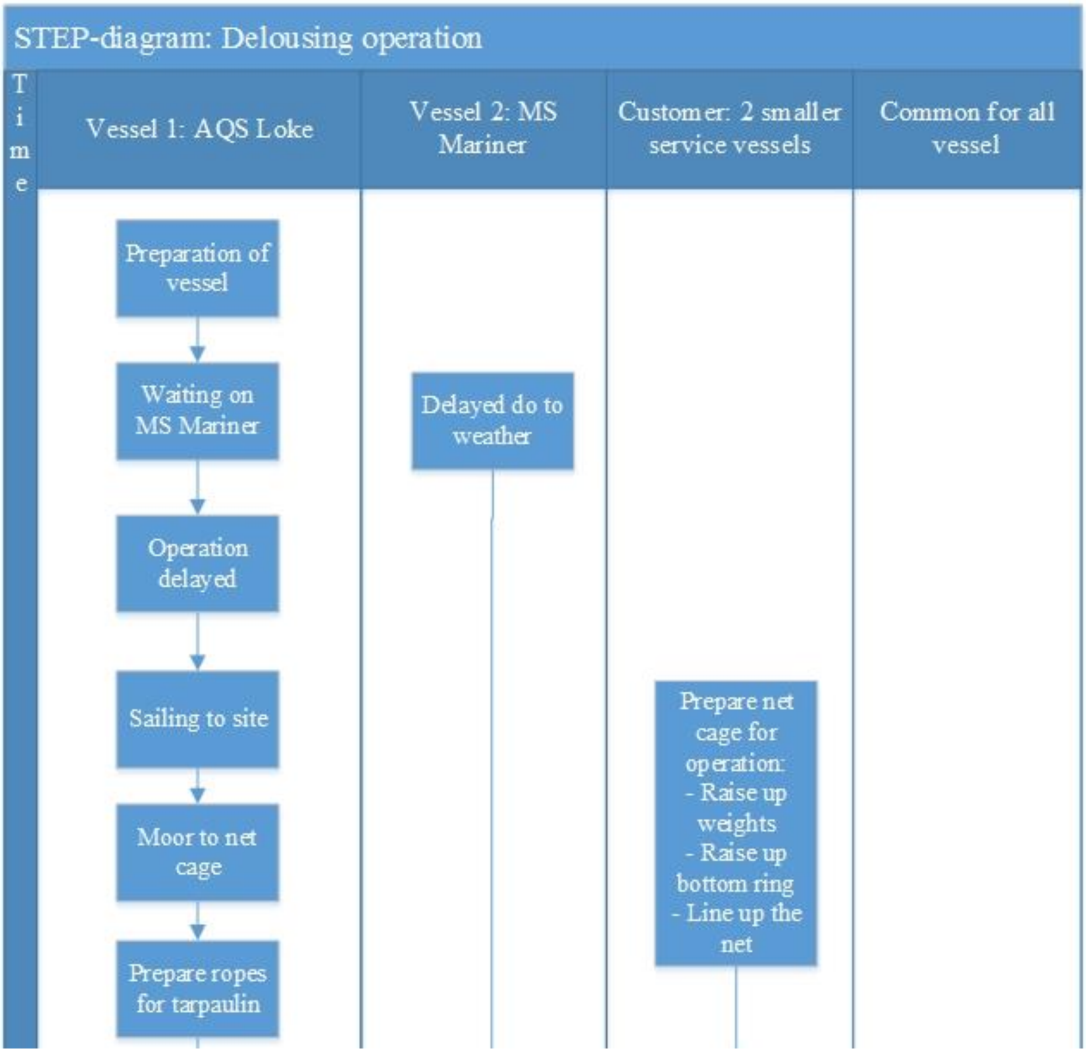
A.1 Net Cleaning

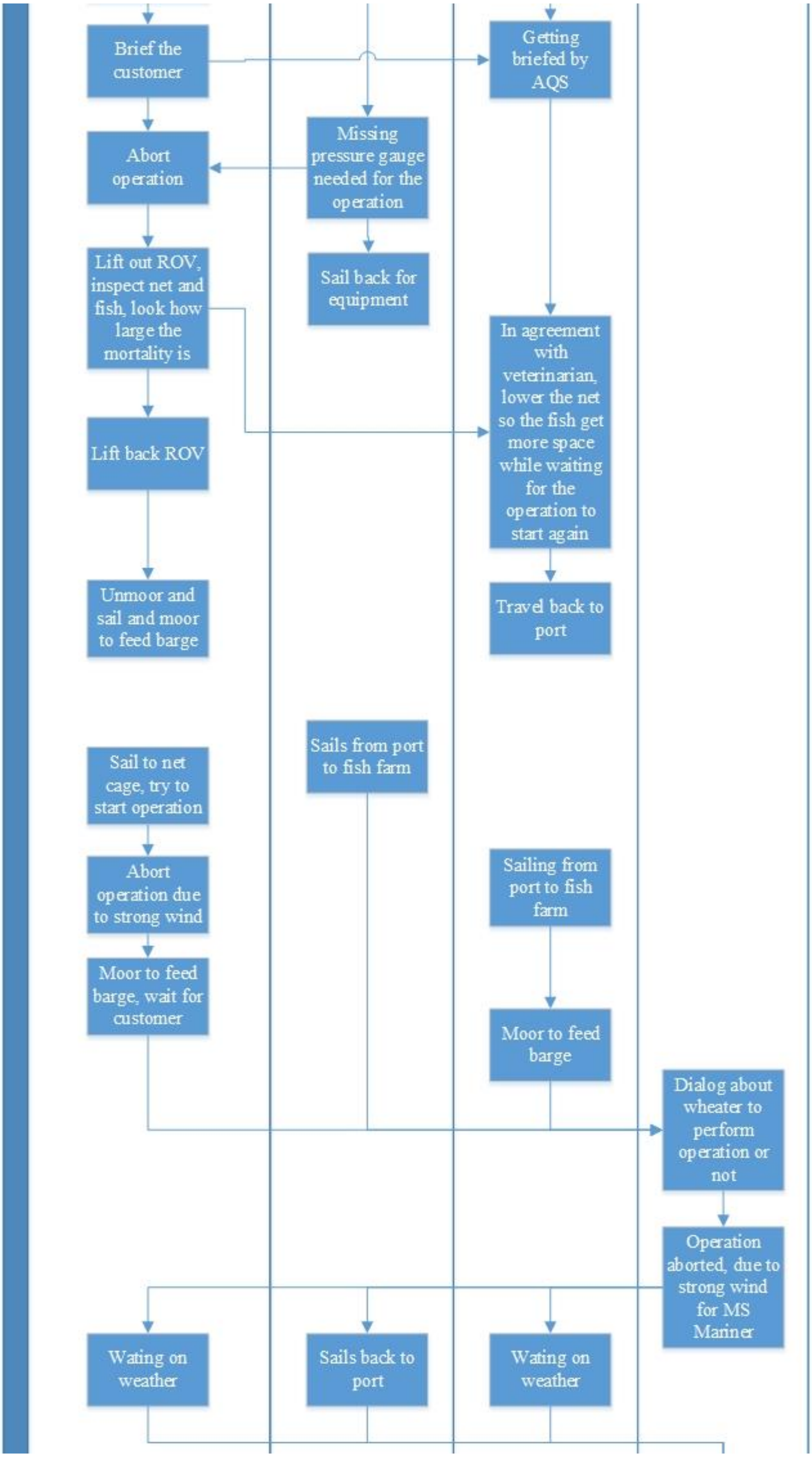


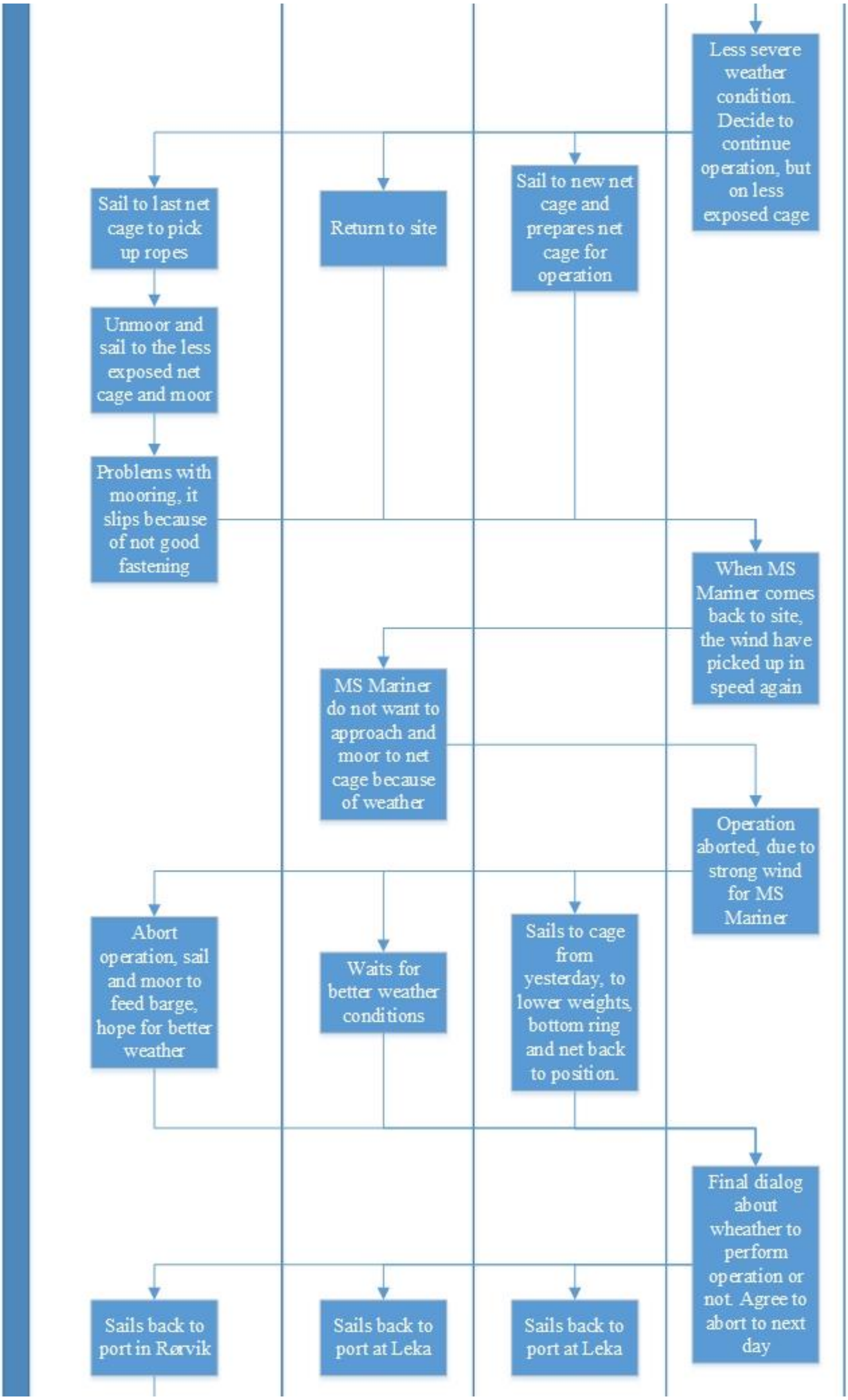

Run on some higher speed until correct temperature on engine
Run full speed, ready to start cleaning operation
Remotely controls cleaning equipment to clean the net
Remotely controls cleaning equipment to clean the net
Inspect high pressure cleaner
Stop in the system due to leakage in the oil filter
Maintain the high pressure cleaner
Maintain the high pressure cleaner
Run full speed
Continue to remotely controls cleaning equipment until net is cleaned
Continue to remotely controls cleaning equipment until net is cleaned
Engine starts
Starts vessel
Stops the high pressure cleaner
Stop
Lift back cleaning equipment up on vessel deck with the crane
Assist/guide the equipment when standing on net cage
Lift in movement
Hauls the heavy hoses from cleaning equipment back to vessel
Hauls the heavy hoses from cleaning equipment back to vessel
Get net cage back in order (put back cameras, sensors etc) and prepare to unmoor
Get net cage back in order (put back cameras, sensors etc) and prepare to unmoor



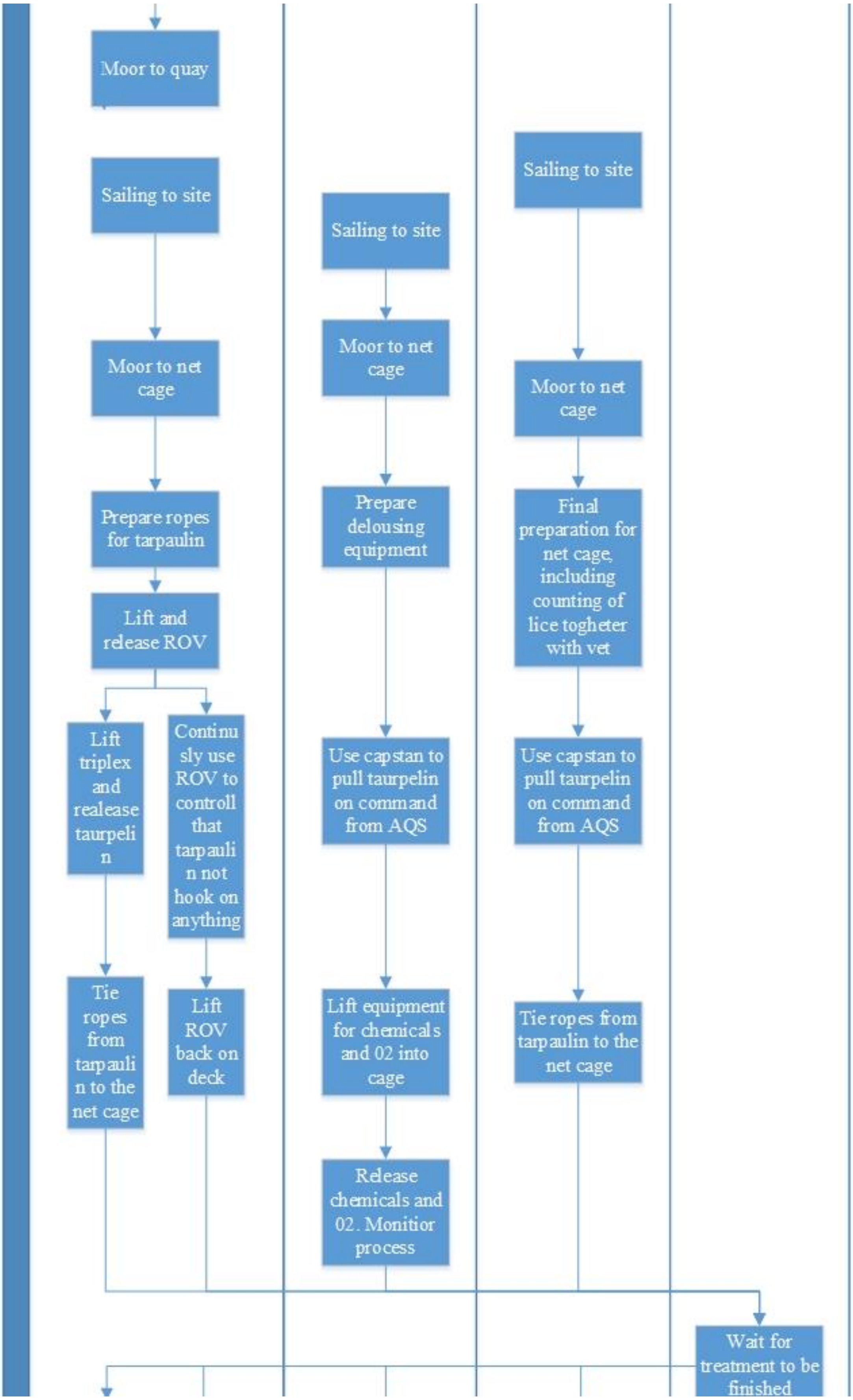
A.2 Delousing

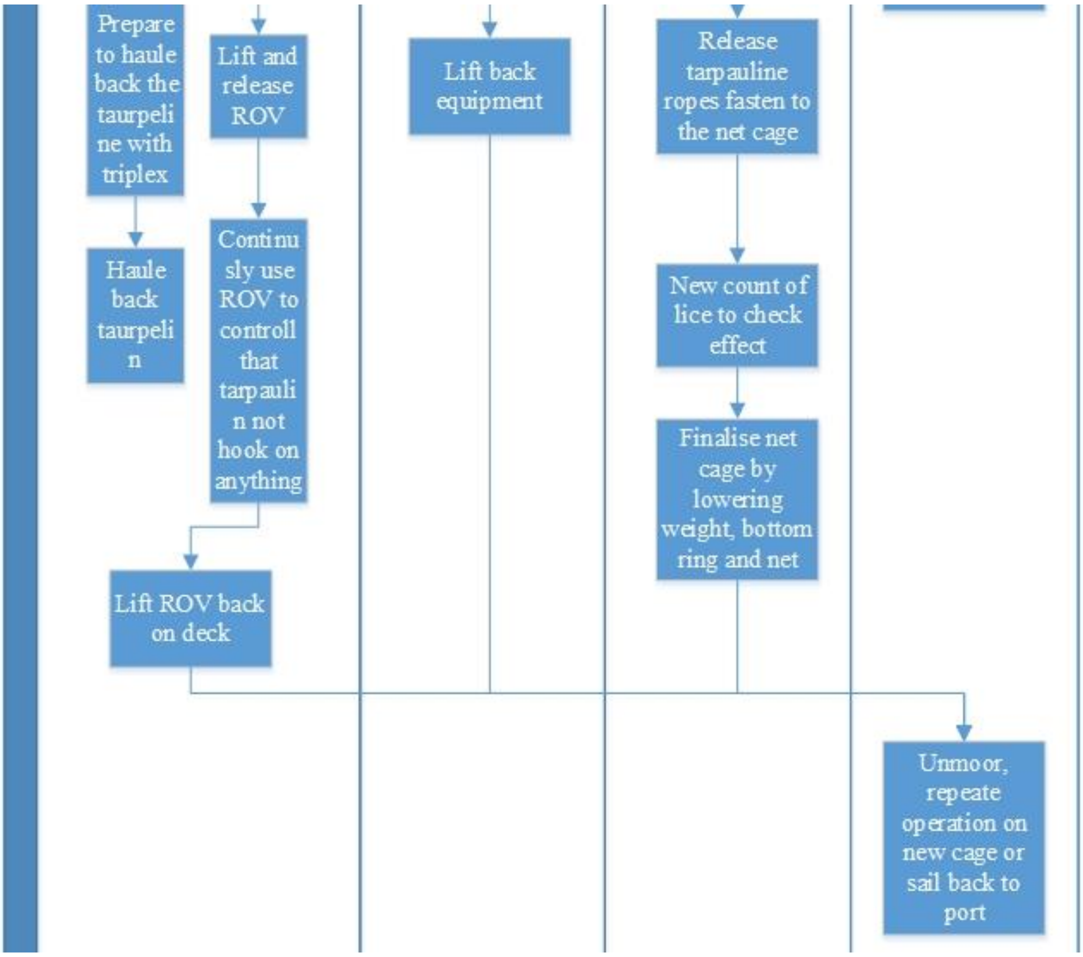



Brief the customer
Getting briefed by AQS
Missing pressure gauge needed for the operation
Abort operation
Lift out ROV, inspect net and fish, look how large the mortality is
Sail back for equipment
In agreement with veterinarian, lower the net so the fish get more space while waiting for the operation to start again
Lift back ROV
Unmoor and sail and moor to feed barge
Travel back to port
Sails from port to fish farm
Sail to net cage, try to start operation
Abort operation due to strong wind
Sailing from port to fish farm
Moor to feed barge, wait for customer
Moor to feed barge
Dialog about wheater to perform operation or not
Operation aborted, due to strong wind for MS Mariner
Wating on weather
Sails back to port
Wating on weather

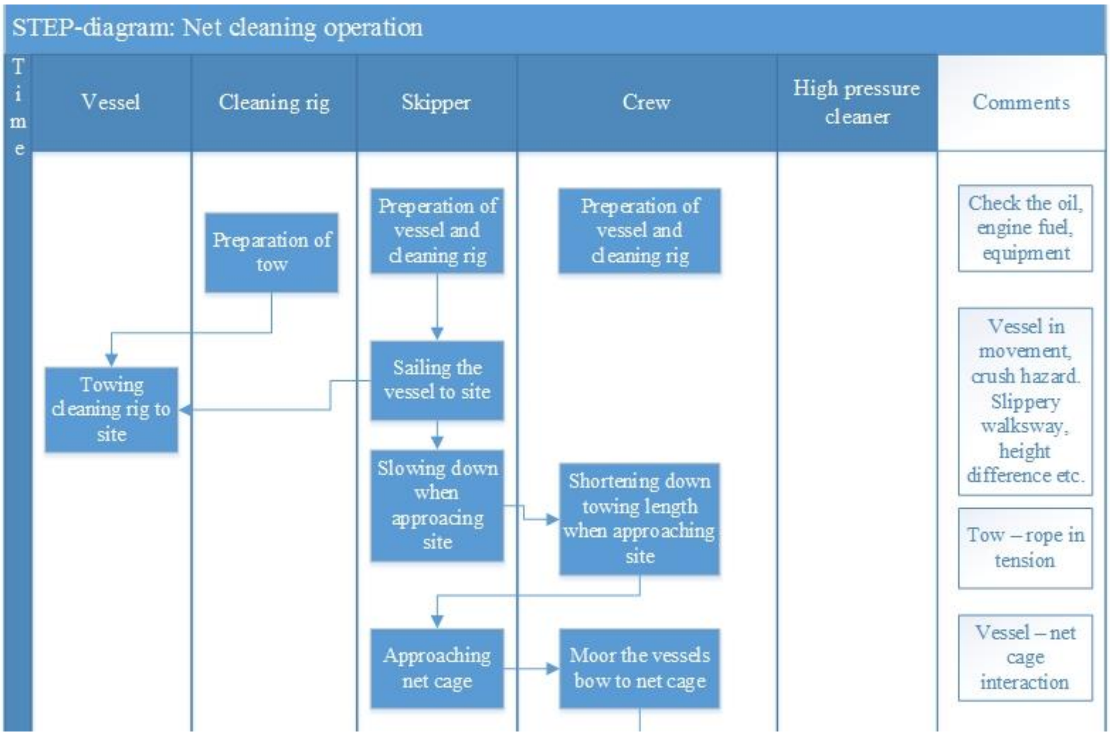


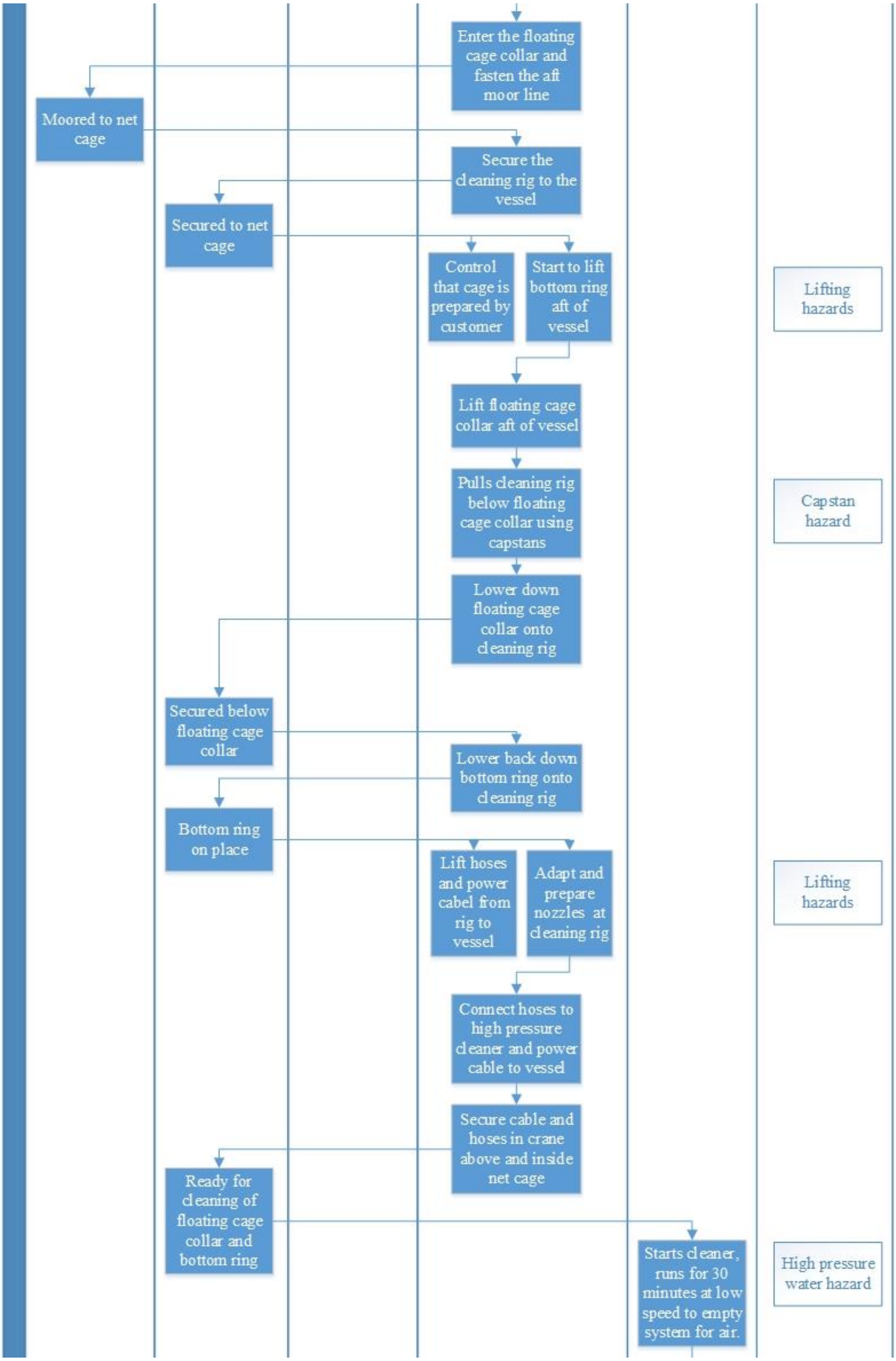
Less severe weather condition. Decide to continue operation, but on less exposed cage
Sail to last net cage to pick up ropes
Return to site
Sail to new net cage and prepares net cage for operation
Unmoor and sail to the less exposed net cage and moor
Problems with mooring, it slips because of not good fastening
When MS Mariner comes back to site, the wind have picked up in speed again
MS Mariner do not want to approach and moor to net cage because of weather
Operation aborted, due to strong wind for MS Mariner
Abort operation, sail and moor to feed barge, hope for better weather
Waits for better weather conditions
Sails to cage from yesterday, to lower weights, bottom ring and net back to position.
Final dialog about wheather to perform operation or not. Agree to abort to next day
Sails back to port in Rørvik
Sails back to port at Leka
Sails back to port at Leka

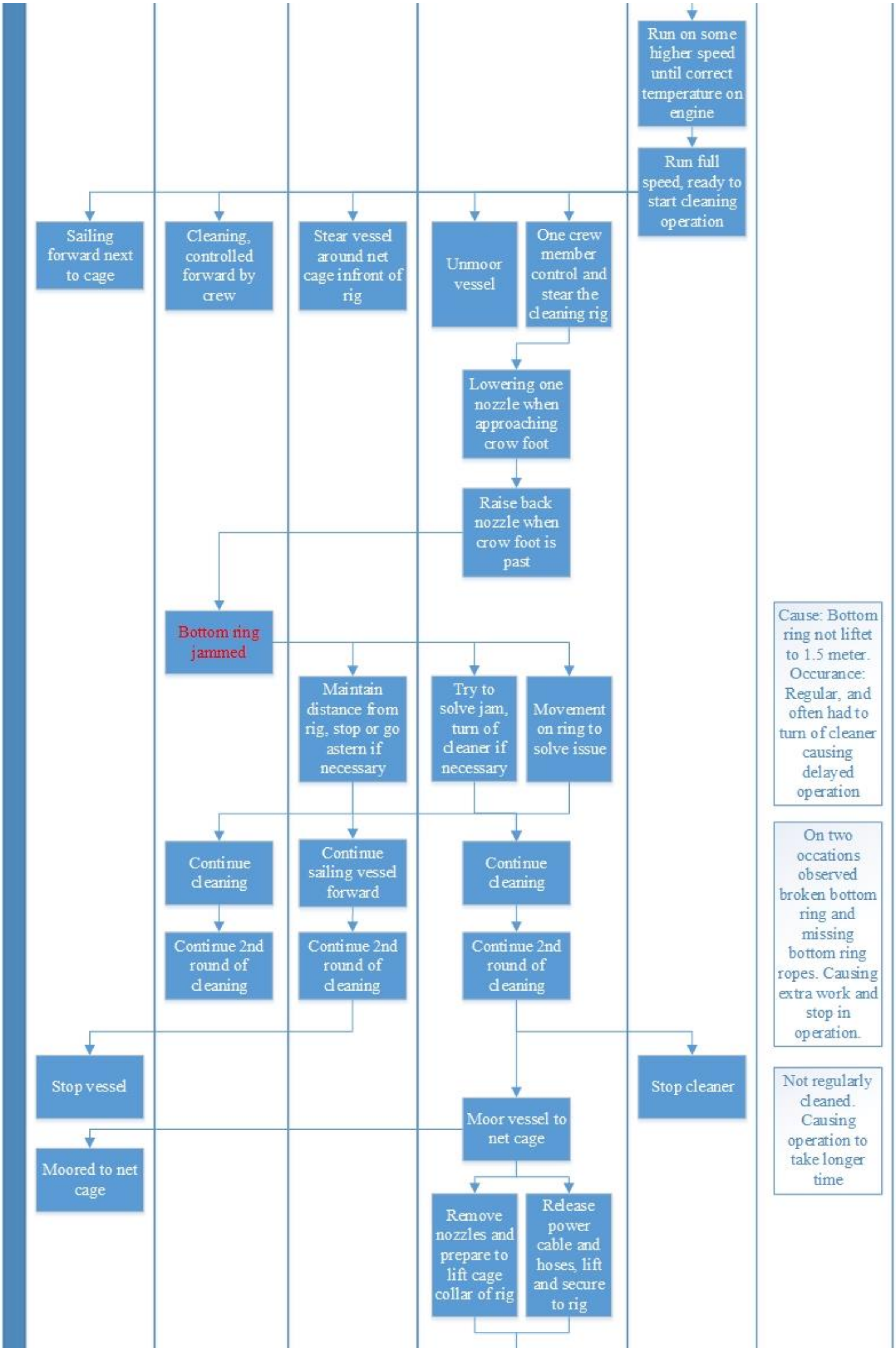

Moor to quay
Sailing to site
Moor to net cage
Prepare ropes for tarpaulin
Lift and release ROV
Lift triplex and realease taurpelin
Continusly use ROV to controll that tarpaulin not hook on anything
Tie ropes from tarpaulin to the net cage
Lift ROV back on deck
Sailing to site
Moor to net cage
Prepare delousing equipment
Use capstan to pull taurpelin on command from AQS
Lift equipment for chemicals and 02 into cage
Release chemicals and 02. Monitior process
Sailing to site
Moor to net cage
Final preparation for net cage, including counting of lice togheter with vet
Use capstan to pull taurpelin on command from AQS
Tie ropes from tarpaulin to the net cage
Wait for treatment to be finished



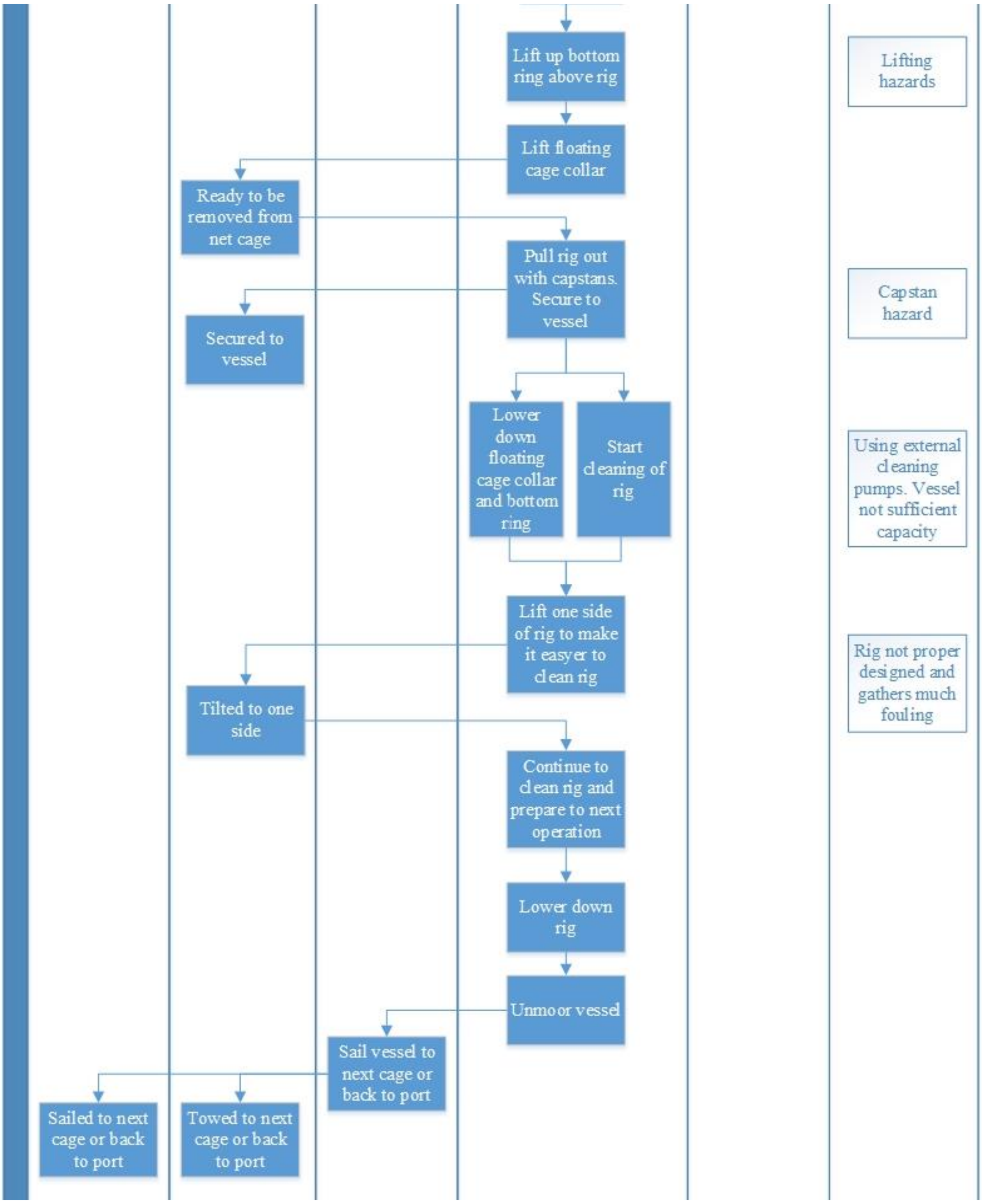
A.3 Service and Maintenance of Floating Collar




Enter the floating cage collar and fasten the aft moor line
Moored to net cage
Secure the cleaning rig to the vessel
Secured to net cage
Control that cage is prepared by customer
Start to lift bottom ring aft of vessel
Lifting hazards
Lift floating cage collar aft of vessel
Pulls cleaning rig below floating cage collar using capstans
Capstan hazard
Lower down floating cage collar onto cleaning rig
Secured below floating cage collar
Lower back down bottom ring onto cleaning rig
Bottom ring on place
Lift hoses and power cabel from rig to vessel
Adapt and prepare nozzles at cleaning rig
Lifting hazards
Connect hoses to high pressure cleaner and power cable to vessel
Secure cable and hoses in crane above and inside net cage
Ready for cleaning of floating cage collar and bottom ring
Starts cleaner, runs for 30 minutes at low speed to empty system for air.
High pressure water hazard



Run on some higher speed until correct temperature on engine
Run full speed, ready to start cleaning operation
Sailing forward next to cage
Cleaning, controlled forward by crew
Stear vessel around net cage infront of rig
Unmoor vessel
One crew member control and stear the cleaning rig
Lowering one nozzle when approaching crow foot
Raise back nozzle when crow foot is past
Bottom ring jammed
Maintain distance from rig, stop or go astern if necessary
Try to solve jam, turn of cleaner if necessary
Movement on ring to solve issue
Cause: Bottom ring not liftet to 1.5 meter. Occurance: Regular, and often had to turn of cleaner causing delayed operation
Continue cleaning
Continue sailing vessel forward
Continue cleaning
On two occations observed broken bottom ring and missing bottom ring ropes. Causing extra work and stop in operation.
Continue 2nd round of cleaning
Continue 2nd round of cleaning
Continue 2nd round of cleaning
Stop vessel
Stop cleaner
Not regularly cleaned. Causing operation to take longer time
Moor vessel to net cage
Moored to net cage
Remove nozzles and prepare to lift cage collar of rig
Release power cable and hoses, lift and secure to rig


Lift up bottom ring above rig
Lift floating cage collar
Ready to be removed from net cage
Pull rig out with capstans. Secure to vessel
Secured to vessel
Lower down floating cage collar and bottom ring
Start cleaning of rig
Lift one side of rig to make it easyer to clean rig
Tilted to one side
Continue to clean rig and prepare to next operation
Lower down rig
Unmoor vessel
Sail vessel to next cage or back to port
Sailed to next cage or back to port
Towed to next cage or back to port
Lifting hazards
Capstan hazard
Using external cleaning pumps. Vessel not sufficient capacity
Rig not proper designed and gathers much fouling

B. Hazard Logs

B.1 Net Cleaning and Service and Maintenance

System: Fish farm		**Name**:	Odd Helge Hatlem & Bettina Kvamme		
Reference:		**Date created**:	10.02.2016		
Hazard/threat	**Where?**		**Amount**	**Safeguard**	**Comments**
Mechanical hazard					
Sharp edges	On net cage				
	Blue mussels etc				
High pressure	During net cleaning				
	Lift-up				
Moving parts	Net cleaner				
	Camera				
	Lift-up				
Vessel	Moored or close to fish farm				
Rotating equipment	Feeding system				
	Net cleaner				
Stability problems	Floating collar				
Degradation of materials	Floating collar				
	Net and ropes				
	Mooring system				
Dangerous materials					
Flammable	Net and ropes				
	floating collars (HEPE)				
Oxidizing	Hydrogenperoxide				
Electrical hazards	Feeding system				
	Light				
	Camera				
Noise hazard	Nearby machinery, vessel etc				
	Wind and bad weather				
Hazard generated by neglecting ergonomic principles					
Unhealthy postures or excessive effort	Work on net cage				
	Work on mooring system				
Stress	Generally on fish farm				
Human error	Generally on fish farm				
Environmental hazards					
Wave	Floating collars				
Current	Net pen				
Storm	Floating collars and net pen				
Predators	Outside net cage				
Organizational hazards					
Safety culture	Work on net cage				

Maintenance	Floating collars
	Net and ropes
	Mooring system
Competence	Workers
Sabotage/terrorism	
Tourism - fishing etc	Near net
Interaction hazards	
Material incompatibilities	Floating collars and net pen
	Floating collars and mooring system
	Net pen and bottom ring
DIV	
UV radiation	Degradation of materials
Thermic hazard	Sea water

B.2 Delousing

System:	Fish farm	**Name**:	Odd Helge Hatlem & Bettina Kvamme
Reference:		**Date created**:	10.02.2016

Hazard/threat	Where?	Amount	Safeguard	Comments
Mechanical hazard				
Acceleration	Vessel			
Kinetic energy	High speed			
Sharp edges	Ship deck			
	Engine room			
	Bridge			
Potential energy	Rope, etc. in tension			
	Equipment on deck			
	Lifted object			
High pressure	High pressure cleaner and hoses			
	Hydraulic hoses			
Moving parts	Engine room			
	Crane			
	Other deck equipment			
Rotating equipment	Capstan			
	Winch			
	Propeller and thrusters			
Stability problems	Vessel			
	Crane			
Degradation of materials	Mooring lines			
	Deck equipment			
	Equipment hoses			
	Electrical equipment			

Net pen and mooring system	Propeller and thrusters	
Dangerous materials		
Explosive/flammable ; fuel, oil, etc.	Engine room	
	Ship deck	
Oxidizing; hydrogenperoxide	Ship deck	
Electrical hazards		
Electromagnetic hazard	Bridge	Disturbed compass
Electrostatic hazard	Bridge	Navigation system, etc.
	Control system	
	Engine room	
Overload	Engine room	
Noise hazard		
External; wind and weather	Bridge	
	Ship deck	
Internal machines	Engine room	
	Ship deck	
	Bridge	
Hazard generated by neglecting ergonomic principles		
Unhealthy postures or excessive effort	Ship deck	manual lift and pull/push
Inadequate local lightning	Ship deck	
Stress	Ship deck	
	Bridge	
Human error	Bridge	
	Ship deck	
Inadequate design or location of visual display units	Bridge	
	Ship deck	
Environmental hazards		
Flooding	Engine room	
Wave	Vessel	
Current	Vessel	
Wind	Vessel	
Storm	Vessel	
Fog	Vessel	Navigation
Organizational hazards		

Safety culture	Shipper and crew		
Maintenance (less than adequate)	Vessel systems and equipment		
Competence (less than adequate)	Shipper and crew		
Interaction hazards			
Material incompatibilities	Vessel generally		Not design for this kind of operation

C. Preliminary Hazard Analysis

C.1 Documentation of Visit 1 – Net Cleaning

Study object: Work on deck/net cage and entering/disembarking vessel/net cage — Date:

References: 1 — Name:

Work place: — Work operation: Net cleaning

No.	Hazard/ threat	Hazardous event	Cause	Consequence	Freq	Cons	RPN	Risk-reducing measures
1	Wet/ slippery surface due to water, oil, ice etc.	Slip/trip and falls on vessel deck/ net cage	Vessel deck not secured against wet surfaces, e.g. no disinfection of deck, antiskid	Minor damage to body. Possible lost time injury	3	2	5	Secure all ships with antiskid. Proper routines for cleaning
2	Untidy deck	Slip/trip and falls on vessel deck	Hoses or other equipment laying around on vessel deck, not secured in a winch etc.	Minor damage to body. Possible lost time injury	3	2	5	Ensure proper procedures for tidy the deck, install a winch for hoses
3	Wind+waves	Worker slips/trips/fall when moving on ship deck or net cage	Strong wind/high waves. Worker not showing caution.	Possible injury and drowning	2	3	5	Protect against wind and waves. Always use safety equipment when moving on deck (life jacket)
4	Thermic hazard, wind, waves,	Slips/trips when entering/ disembarking vessel to net	Lack of attention, disturbed in his work, gap	Human injury, possible drowning/hypothermia	2	4	6	Routines for entering vessel/cage. Routines for proper berthing to

	motion in vessel	cage and falls into the	between vessel and net cage, movement in vessel/net cage, slippery walkway					net cage. Routines for emergency action.
5	Potential energy/ deck equipment	Unwanted movement of deck equipment/deck load	Poor or missing sea fastening, break in sea fastening. Bad weather conditions	Crew squeezed/ trapped between moving object and other objects.	2	3	5	Proper routines for sea fastening. Training and competence. Secure zones and safety equipment.
6	Thermic hazard	Fall into cold water inside net cage from plastic walkway on cage	Bend to inspect moorings, help guiding cleaning equipment into net cage etc. Slippery/wet/ice on walkway	Fall into net cage, risk of staying long in the sea, drowning/hypothermia	1	4	5	Protect against wind and waves and antiskid on net cage walkway. Always use safety equipment (life jacket). Routines for emergency action.
7	Difference of height between vessel and net cage	Fall from level above when entering/ boarding net cage/vessel from vessel/net cage. Fall down on net cage or into sea.	Not proper ladder on vessel	Minor damage to body, possible strain or bone fracture. Possible drowning	2	4	6	Make sure to improve all ladders on vessel
8	Gap between vessel and quay	Slip/trip when entering net cage/vessel. Fall down on vessel/net cage or into the sea	Vessel not proper moored. Worker not showing caution	Minor damage to body, possible strain or bone fracture.	2	3	5	Routines for proper mooring. Always use safety equipment (life jacket)

				Possible drowning				

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent				
3	Occasional		1,2		
2	Possible			3,5,8	4,7
1	Unlikely				6

Study object: Lift operation	Date:
References: 2	Name:
Work place:	Work operation: Net cleaning

No.	Hazard/ threat	Hazardous event	Cause	Consequence	Freq	Cons	RPN	Risk-reducing measures
1	Lifted object	Lifted object swing and hit worker on deck/net cage	Movement in object or vessel due to bad weather conditions (waves, wind). Inexperienced crane operator or other human	Hit by object on body. Possible fatality due to injury or drowning	2	4	6	Not stand under or close to lifted objects (safe zones). Use of securing lines preventing object from swinging. Not lift in indefensible weather conditions. Always use life jacket

			error (HE). Moving in unsafe zone.					
2	Lifted object	Lifted object swing and hit other object that hit worker on deck	Inexperienced crane operator or other HE. Bad weather conditions. Unsecured deck load.	Hit by object on body. Possible fatality	1	4	5	Not stand under or close to lifted objects (safe zones). Use of securing lines preventing object from swinging. Not lift in indefensible weather conditions. Ensure proper securing of objects on deck
3	Lifted object	Lifted object falls down and hit worker on deck/net cage due to fastening slips/loosen or strops/ropes snaps.	HE, lack of competence. Standing below lifted object. To heavy object. Degradation of material	Hit by object, crushed. Possible fatality or drowning	2	4	6	Never stand under lifted object. Training and competence in securing objects to hook. Use easy systems for fastening to hook. Always use life jacket
4	Lifted object + inadequate design or location of visual display units	Crane operator get hit by swinging object	Bad placement of control lever	Hit by object on body.	2	2	4	Remote control lever
5	Unhealthy postures or excessive effort	Worker push and pulls object directly to guide it to wanted position	Bad weather causing object to swing, inexperienced crane operator,	Back injury. Possible squeeze of fingers/arm	4	3	7	Prepare for use of lines to secure object. Can use winch system to prevent manual work

6	Human error	Crane operator lose control of lifted object and hit worker on deck/net cage	Stress, lack of competence, lack of experience, bad weather	Hit by object on body. Possible fatality due to injury	1	4	5	Ensure proper training and competence. Secure zones
7	Noise hazard	Worker get hit by lifted object because they can't hear each other	Noise from wind and waves, noise from engine. Lack of competence	Hit by object on body. Possible fatality due to injury	3	4	7	Use communication system. Have good dialog and agreement on proper commands
8	Stability problems	Vessel loose stability when lifting to heavy object	Lack of competence	Vessel capsize. Possible human fatalities	2	4	6	Ensure proper competence and training. Procedures and information for heavy lifts. Competence of limits for ship and crane.
9	Stability problems	Worker slips/trips/falls due to movement in vessel when performing lifting operation	Lack of competence, sudden lift or move of lifted object	Minor damage to body, possible strain or bone fracture	1	3	4	Safety equipment
10	Moving parts	Worker on net cage get squeezed between vessel and net cage because vessel is moving due to lift operation	Lack of competence, movement in unsecure zone, poor communication	Squeeze. Possible fatality due to injury or drowning	2	4	6	Safe zone. Procedures. Always use safety equipment

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent			5	
3	Occasional				7
2	Possible		4		1,3,8,10
1	Unlikely			9	2,6

Study object: Cleaning operation	Date:
References: 3	Name:
Work place:	Work operation: Net cleaning

No.	Hazard/ threat	Hazardous event	Cause	Consequence	Freq	Cons	RPN	Risk-reducing measures
1	High pressure water and moving parts	High pressure water and wear from cleaning discs weaken the net	Regular cleaning triggers wear and degradation on the net material. Possible holes from sharp blue mussels on the net.	Minor damage to net, fraying and structural changes in net fibres. Worst case a hole and escape of salmon	3	3	6	Ensure proper routines on maintenance of net and control after cleaning operation
2	Lifting object	Washing equipment tangled in ropes or net	Powerful cranes try to pull out the equipment from the net.	Damage to net cage, hole in net and possible escape of salmon	3	3	6	Ensure proper routines and competence of crew

			HE, lack of competence					
3	Moving parts and sharp edges	Sharp edges on washing equipment cuts the net	Sharp edges from fractures, cracks, loose screws etc.	Cuts hole in net, possible escape of salmon	2	3	5	Ensure proper routine for checking the equipment for loose screws, nozzles, crack or any other sharp edges
4	System overload	Cleaning equipment sinks to bottom of net and can get tangled in net	High pressure cleaner breakdown	Minor damage to net	3	1	4	Ensure proper maintenance of system and competence of crew using the system
5	Unhealthy postures or excessive effort	Lifting heavy hoses or other equipment by hand back into vessel after cleaning operation	No proper equipment installed. Wrong lifting technique.	Back problems, minor body injury	4	2	6	Winch for hoses

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent		5		
3	Occasional	4		1,2	
2	Possible			3	
1	Unlikely				

C.2 Documentation of Visit 2 – Delousing

Study object: Vessel berthing to net cage	Date:
References: 4	Name:
Work place: Steinflesa	Work operation: Delousing

No.	Hazard/ threat	Hazardous event	Cause	Consequence	Freq	Cons	RPN	Risk-reducing measures
1	Crowfoot and other ropes	Propel in contact or stuck in rope when approaching net cage/fish farm	Slack crowfoot, slack crowfoot due to strong current, floating ropes	Damage to propel and crowfoot, potential stuck in rope and partly loss of propulsion.	4	2	6	Protected/built-in propeller. Improve control routines to secure that crowfoot and floating ropes are identified and improved. Lookout for ropes and crowfoots
2	Thruster/propel	Contact with net when approaching net cage	Slack in net, not proper weights etc., deformation of net due to strong current	Hole in net. Escapement of fish	2	4	6	Protected/built-in propeller. Proper calculation for weights and inspection. Lookout for deformed net, when strong current
3	Human error	Loss of control of vessel when approaching net cage	Lack of attention, disturbed in his work, lack of competence, bad weather conditions	Collision with floating cage collar. Minor property damage to cage collar. Possible injury to worker(s) on net cage	2	3	5	Proper routines at bridge. Proper routines for check of competence and to ensure safety perspective. Aids in bad weather and decision support.

4	Human error	Vessel moor line loses when vessel is berthing to net cage. Not proper fasten	Lack of attention, disturbed in his work, lack of competence/inexperienced	Vessel drift partly away and work is disturbed/delayed. Possible collision/contact and injury to worker(s)	2	2	4	Proper routines for check of competence
5	Obstacles	Collision with another moving or moored vessel	Tight passage or unexpected act of the other object. Bad weather conditions	Property damage and possible human injuries to crew	2	3	5	Secure good communication. Aids in bad weather and decision support.
6	Obstacle/interaction hazard	Lay on crowfoot and pushing it down when berthing to net cage	To large/long vessel. Not enough space between crowfoots	Damage, wear and tear to crowfoot. Possible floating net collar pulled down and submerged. Risk of fish escapement.	4	3	7	Different mooring system. Use of DP. Other berthing approach. Routines
7	Obstacles and human error	Collision with feed hose(s)	Tight passage, lack of attention, bad weather conditions	Damage to propel and/or feed hose	3	1	4	Protected/built-in propeller. Sub-merged feed hoses
8	Sharp edges	Worker cut himself/herself when moving on deck or net cage	Sharp edges not secured	Human injury	3	2	5	Ensure that all sharp edges are secured. Protective working clothes.

9	Rotating equipment	Failure when using capstan to tighten mooring lines	Stress or wrong use of capstan, bad placement of control lever	Squeeze/crush of fingers/hand between rope and capstan	2	2	4	Proper routines for use of capstan, proper training. Ensure user-friendliness, use from several and different positions. Emergency stop. Safety equipment
10	Interaction hazard	Moor line tears on fastening or line slides up on the cage pillar	Bad design for fastening. Lack of proper fastening possibilities/bad design	Mooring line tears off and vessel may drift apart from the net cage. Danger of collision/contact. Possible human injury	3	2	5	Ensure proper design of fastening. Use protective material on mooring close to fastening
11	Thermic hazard	Slips/trops and Fall in cold water when moor the vessel	Lack of attention, disturbed in his work, gap between vessel and net cage, movement in vessel/net cage	Human injury, possible drowning	1	4	5	Routines for entering vessel/cage. Routines for proper berthing to net cage. Routines for emergency action.
12	Kinetic energy/ high speed	To high speed when approaching net cage	Lack of attention, disturbed in his work, lack of competence, bad weather	Collision with net cage, possible damage to crew, workers on net cage and damage to net cage. Worst case;	2	3	5	Proper routines for check of competence and training. Alarm/warning systems

				escapement of fish				
13	Noise hazard	Communication error when approaching and berthing to net cage	Wind noise, noise from engine, not using communication equipment	Collision with net cage, possible damage to crew. Work is disturbed/delayed. Take longer time. Crew injury, not able to warn against threat	4	2	6	Isolate engine to reduce noise. Use of communication equipment
14	System overload	Loss of propulsion/navigation	Technical failure	Collision with net cage, possible damage to crew, workers on net cage and damage to net cage. Worst case; escapement of fish	2	3	5	Ensure routines for maintenance. Warning systems
15	Severe weather conditions	Loss of control of vessel when approaching net cage	Lack of competence/inexperienced, technical failure in system,	Collision with net cage, possible damage to crew, workers on net cage and damage to net cage. Worst case; escapement of fish	2	3	5	Ensure routines for maintenance. Warning systems. Decision support. Ensure competence and proper training

16	Wind	Vessel laying against floating cage collar and transferring large point load to the floating cage collar deforming the cage	Floating collar not designed for such point loads. Vessel to heavy and having too much windbreak (vindfang)	Affect ongoing operation. Work may be disturbed/delayed. Take longer time. Put workers in danger. Wearing of mooring system due to high tension. Worst case; Damage to floating collar, possible collapse of floating collar escapement of fish	3	4	7	Decision support. Alternatively mooring system, reducing load from ship.
17	Waves	Vessel hitting floating collar when moored to net cage	Vessel is a stiff object, while floating collar is a flexible object. Different impact and motion in waves, causing vessel to hit and slam on top of the floating collar (especially smaller vessel)	Damage to floating collar. Hard work conditions. Impossible or dangerous to enter vessel/net cage. Possible human injury	3	3	6	Decision support. Alternatively mooring system, reducing load and contact from ship.
18	Failure in moor lines	Vessel moor lines fails and vessel drift away when berthed to net cage	Strong wind/high waves catches the vessel and cause high loads	Vessel drift towards other net cages, vessels or rocks, causing damage	2	3	5	Routines for quality check of mooring lines. Ensure that proper materials are

			on vessel causing failure to mooring lines	to itself and/or other objects. Possible human injury				used for mooring lines

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent		1,13	6	
3	Occasional	7	8,10	17	16
2	Possible		4,9	3,5,12,14,15,18	2
1	Unlikely				11

Study object: Delousing operation	Date:
References: 5	Name:
Work place: Steinflesa	Work operation: Delousing

No.	Hazard/ threat	Hazardous event	Cause	Consequence	Freq	Cons	RPN	Risk-reducing measures
1	Lift of bottom weight using capstan	Crushed/pinched when using capstan to lift weight	Stress or wrong use of capstan. Rope in tension, inexperienced user, unstable movement in vessel, bad	Squeeze/crush of fingers/hand between rope and capstan	2	2	4	Proper routines for use of capstan, proper training. Ensure user-friendliness, use from several and different positions. Emergency

			placement of control lever					stop. Safety equipment
2	Lift of bottom weight using crane	Rope/strop tied to the rope from weight loosen or snaps	HE, too high tension in rope/bad decision of selection of rope	Rope hit and injury worker. Lost time, possible loss of weight.	2	2	4	Ensure competence, safety equipment,
3	Lift of bottom ring	Lifting rope snaps and hit worker	Too rapid hoist of bottom ring. Too high tension in rope/bad decision of selection of rope.	Hit by object. Injury to worker	2	2	4	Ensure competence, safety equipment,
4	Lift of bottom ring	Contact between the net and the bottom ring and or the rope/chain down to bottom ring	Slack in the net due to hoist of the bottom ring. Current deforming the net.	Hole in net. Escapement of fish. Possible large escapement if not discovered	2	4	6	Use divers/ROV after operation to survey the net
5	Lift/ lowering of bottom ring	Moving vessel hit/squeeze worker on net cage	Bad communication, bad weather condition, worker/captain not paying attention.	Worker squeezed or trapped. Possible injury to worker	3	3	6	Communication equipment, good routines, good competence, other methods for lifting bottom ring
6	Floating net	Net coming in contact with propeller/thruster	Movement of vessel during operation. Lack of competence.	Hole in net. Escapement of fish.	2	3	5	Good routines for hauling up net regular during operation.

7	Rotating equipment /Tarpaulin	Crushed/pinched when using capstan to lift weight	Stress or wrong use of capstan. Rope in tension, inexperienced user, unstable movement in vessel, bad placement of control lever	Squeeze/crush of fingers/hand between rope and capstan	2	2	4	Proper routines for use of capstan, proper training. Ensure user-friendliness, use from several and different positions. Emergency stop. Safety equipment
8	Rotating equipment /Tarpaulin	Ropes used to pull tarpauling on place snaps	Inexperienced user of capstan, too rapid hoist of bottom ring. Too high tension in rope/bad decision of selection of rope.	Hit by object. Injury to worker	2	2	4	Competence and training/education. Proper safety system for securing ropes in high tension
9	Chemicals	Too strong blending/too long treatment	Error in calculating amount of water inside tarpaulin.	Death of fish	2	4	6	Competence. Better ways of estimating amount of water. Quick release system of tarpaulin
10		O2 fails during treatment	Technical failure	Death of fish	2	4	6	Proper routines for maintenance. Backup systems
11	Lower the bottom ring	Rope or net not loosen before lowering starts	HE; stress, inexperienced worker	Hole in net	2	3	5	Ensure good routines
12	Lowering the bottom weight	Worker tangles in rope and get pulled down by the rope	HE, lack of competence and experience, much rope on deck/untidy	Fall injury, possible drowning from being pulled under water	2	4	6	Ensure good routines. System for collection of ropes. Ensure good competence

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent				
3	Occasional			5	
2	Possible		1,2,3,7,8	6,11	4,9,10,12
1	Unlikely				

C.3 Documentation of Visit 3 – Service and Maintenance of Floating Collar

Study object: Cleaning of floating collar	Date: 16.04.16
References: 6	Name:
Work place: Kvitneset	Work operation: Service and maintenance

No.	Hazard/ threat	Hazardous event	Cause	Consequence	Freq	Cons	RPN	Risk-reducing measures
1	Sharp edges	Blue mussels is blown with high speed in the air by the high pressure cleaner and hits worker in the eyes/face	High pressure cleaner makes water and biofouling flowing through air in high speed, making visibility bad	Cuts and bruises, possible damage to eyes	3	2	5	Protective goggles
2	High pressure water	Body part coming against the nozzles during operation	Crew works very close to the high pressure on cleaning barge during	Damage to body parts, bruises/cuts/bon	2	2	4	Protective design on cleaning barge, proper working procedures for

			operation, to assist the barge around the floating collar and controlling operation	e fracture/loss of skin				operation. Protective working clothes.
3	Height difference	Worker falls down at cleaning barge when standing on the floating collar that rests on cleaning barge	Slippery surface with no handrails/securing trips/slips due to bad weather, distracted/human error	Minor damage to body	3	1	4	Secure surfaces with antiskid, proper procedures to prevent fatigue/tired workers and prevent work on lifted floating collar. Use safety lines.
4		Worker falls into sea when standing on floating collar that is lifted up by crane	Slippery surface with no handrails/securing , trips/slips due to bad weather, distracted/human error, lifting strop snaps	Minor damage to body, possible drowning	3	4	7	Handrail/securing on cleaning barge, proper work procedures. Use safety lines.
5	Potential energy: Lifting strop in tension	The lifting strop snaps due to high tension, and hits worker, or worker standing on cleaning barge falls into sea	The floating collar is lifted at one point to be able to lift it over the cleaning barge.	Damage to body, possible drowning/death	3	4	7	Design on floating collar that makes lifting with even load easy, proper work procedures ensuring no worker on lifted barge, standing in safe zones during lift
8		Floating collar collapses	Large load on floating collar because lifted at one point	Breakdown of floating collar	2	3	5	Design on floating collar that makes lifting with even load easy
9	Gap between net cage	Slip/trip when entering cleaning	No ladder or design for	Damage to body or possible drowning	3	4	7	Ladder or design for proper

	and cleaning barge	barge/net cage. Fall down on net cage/barge or into the sea	entering feed barge					entering/disembarking cleaning barge
10	Moving object	Squeeze/crush of body parts/fingers etc between rotating wheels on cleaning barge and floating collar	During bad weather it is hard to place the floating collar on the wheels, and the worker must assist using their hands	Squeeze/crush body part, damage to body	2	2	4	Better design for wheels
11	Unhealthy postures or excessive effort	Strain or damage to body while shovelling the waste accumulating on the cleaning barge after cleaning one net cage	Hard work to shovel the waste from removed biofouling into the sea	Strain/damage to body parts, back problems, neck problems etc.	3	2	5	Different design of cleaning barge so that the waste is easier removed

		Severity (SI)			
		1	2	3	4
FI	Frequency	Minor	Significant	Major	Catatastrophic
4	Frequent				
3	Occasional	3	1,11		4,5,9
2	Possible		2,10	8	
1	Unlikely				

D. Expert Evaluation

Average results from expert evaluation is filled into the original scheme.

This session will be answered of several external experts within the industry and will be used in the further work of our master thesis regarding safety and efficiency in marine operations in the aquaculture industry. The name of experts participated will be depersonalized implying that none of the answers can be traced back to any of the participators. Be therefore as honest as possible and try to give your best opinion in each scenario.

Please give a number between 0-1, where 0 will not ever happen and 1 will always happen (i.e. 0.5 will happen in 50 % of the incidents). Please use as many decimal as you wish (i.e. 0.01 = will happen in 1 of 100 incidents)

Scenario 1: Falling

Scenario 1 a:

Assume that:

- A falling event has occurred either on vessel or on floating collar
- On vessel, can also include entering and disembarking the vessel

What is the probability that	Given \ On	Vessel	Floating collar
Worker falls into the sea	Good weather	0.1	0.2
	Bad weather	0.15	0.45

Scenario 1 b:

Assume that:

- A falling event has occurred resulting in the worker either falling into sea or not
- Critical injured: broken body parts or more severe

Given <u>fallen</u> into sea:

What is the probability that	Given \ On	Vessel	Floating collar
Worker get critical injured	Good weather	0.15	0.2
	Bad weather	0.35	0.4

Given not fallen into sea:

What is the probability that	Given \ On	Vessel	Floating collar
Worker get critical injured	Good weather	0.075	0.075
	Bad weather	0.15	0.15

Scenario 1 c:

Assume that:

- A falling event has occurred resulting in critical injury and falling into sea

Given good weather:

What is the probability that	Given \ If	No life west	Life west
Worker is unable to get out of water or being rescued	Working alone	0.7	0.35
	Not working alone	0.45	0.1

Given bad weather:

What is the probability that	Given \ If	No life west	Life west
Worker is unable to get out of water or being rescued	Working alone	0.85	0.55
	Not working alone	0.6	0.175

Scenario 1 d:

Assume that:

- A falling event has occurred and worker has fallen into the sea
- The worker is not critical injured

Given good weather:

What is the probability that	Given \ If	No life west	Life west
Worker is unable to get out of water or being rescued	Working alone	0.4	0.15
	Not working alone	0.3	0.075

Given bad weather:

What is the probability that	Given \ If	No life west	Life west
Worker is unable to get out of water or being rescued	Working alone	0.5	0.35
	Not working alone	0.325	0.15

Scenario 2: Hit by object

Scenario 2 a:

Assume that:

- An event where a worker has been hit by an object has occurred (hit by lift object, rope in tension etc.)

What is the probability that	Given \ On	Vessel	Floating collar
Worker falls into sea	Good weather	0.5	0.775
	Bad weather	0.4	0.675

Scenario 2 b:

Assume that:

- An event where a worker has been hit by a object has occurred

Given good weather:

What is the probability that	Given \ On	Vessel	Floating collar
Worker get critical damaged / injured	Using protective equipment	0.55	0.7
	No protective equipment	0.4	0.55

Given bad weather:

What is the probability that	Given \ On	Vessel	Floating collar
Worker get critical damaged / injured	Using protective equipment	0.65	0.75
	No protective equipment	0.45	0.55

Scenario 2 c:

Assume that:

- An event where a worker has been hit by a object has occurred
- Not fallen into sea
- Worker is critical injured

What is the probability that	Vessel	Floating collar
Worker do not survive the impact	0.3	0.3

Scenario 3: Squeeze - trapped

Scenario 3 a:

Assume that:

- An event where a worker has been squeezed or trapped has occurred (e.g. squeeze of fingers during handling of ropes with capstan, trapped between equipment etc.)

What is the probability that	Given \ On	Vessel	Floating collar
Worker falls into sea	Good weather	0.15	0.5
	Bad weather	0.25	0.65

Scenario 3 b:

Assume that:

- An event where a worker has been squeezed or trapped has occurred.
- Critical damage/injury defined as broken body parts or more severe

Given good weather:

What is the probability that	Given \ On	Vessel	Floating collar
Worker get critical damaged / injured	Using protective clothes	0.3	0.2
	Not using protective clothes	0.45	0.35

Given <u>bad</u> weather:

What is the probability that	Given \ On	Vessel	Floating collar
Worker get critical damaged / injured	Using protective clothes	0.45	0.4
	Not using protective clothes	0.6	0.55

Scenario 3 c:

Assume that:

- An event where a worker has been squeezed or trapped has occurred
- <u>Not</u> fallen into sea
- Worker is critical injured

What is the probability that	Vessel	Floating collar
Not surviving impact/ injury	0.15	0.225

Scenario 4: Collision and contact

Scenario 4 a:

Assume that:

- A collision event has occurred

Given <u>good</u> weather:

What is the probability that	Collision with net cage (Vessel hitting is less than 15 m)	Collision with net cage (Vessel hitting is larger than 15 m)	Collision with other vessel, feed barge etc.
The vessel get critical damage	0.175	0.1	0.3
The object collided with get critical damage	0.65	0.85	0.4

Given bad weather:

What is the probability that	Collision with net cage (Vessel hitting is less than 15 m)	Collision with net cage (Vessel hitting is larger than 15 m)	Collision with other vessel, feed barge etc.
The vessel get critical damage	0.225	0.15	0.45
The object collided with get critical damage	0.75	0.9	0.55

Scenario 4 b:

Assume that:

- A collision event has occurred and the vessel is critical damaged

What is the probability that	Given	On vessel
It leak fuel, oil etc.	-----------	0.1
It will take fire and/or explosion	Leak	0.1
Crew will not survive	Fire/explosion	0.15

Scenario 4 c:

Assume that:

- A collision/contact event has occurred where vessel has collided into net cage

What is the probability that	On net cage
It is crew on net cage	0.25
Crew on net cage is not surviving impact if hit	0.25

Scenario 5: Hole in net

Scenario 5 a:

Assume that:

- A event causing hole in net has occurred
- Small hole meaning that none or only a few number of fish will escape

What is the probability that	Given \ If	During operation (The ongoing operation is causing the hole)	Other cause (Bad weather, predators, abrasion etc.)
It is a large sized hole	Good weather	0.1	0.1
	Bad weather	0.3	0.4

Scenario 5 b:

Assume that:

- An event causing hole in net has occurred
- Short time meaning that only a few number of fishes will escape before hole is identified and maintained

What is the probability that	Given \ If	During operation	Other cause
It take long time before identified	Small hole	0.35	0.35
	Large hole	0.075	0.2

Scenario 5 c:

Assume that:

- A event causing hole in net has occurred

What is the probability that \ If	During operation	Other cause
Cannot be fixed without diver/ ROV	0.6	0.95
Need of external diver/ ROV	0.8	0.9

Participator:

____

Company:

____

E. ETA

E.1 Slip/Trip

Slip/trip frequency model			Damage extent model		Safety system	Survivavility model		Outcome				
Slip/trip	Fall distribution	Bad weather	Fall into sea	Critical injury	No life west on	Working alone	Unable to get out of water	Id code	End event description	Cons. factor	Frequency	Risk contribution
	Floating collar											
1.8E-03	0.5	0.7	0.45	0.4	0.1	0.2	0.85	FF1.1.1	Drowning, not rescued and not able to get out of water	4	1.9E-06	7.7E-06
							0.15	FF1.1.2	Able to get out of water, but critical injured	3	3.4E-07	1.0E-06
						0.8	0.6	FF1.2.1	Drowning, not rescued in time and not able to get out of water	4	5.4E-06	2.2E-05
							0.4	FF1.2.2	Rescued, but critical injured	3	3.6E-06	1.1E-05
					0.9	0.2	0.55	FF1.3.1	Drowning, not rescued and not able to get out of water	4	1.1E-05	4.5E-05
							0.45	FF1.3.2	Able to get out of water, but critical injured	3	9.2E-06	2.8E-05
						0.8	0.175	FF1.4.1	Drowning, not rescued in time and not able to get out of water	4	1.4E-05	5.7E-05
							0.825	FF1.4.2	Rescued, but critical injured	3	6.7E-05	2.0E-04
				0.6	0.1	0.2	0.5	FF1.5.1	Drowning, not rescued and not able to get out of water	4	1.7E-06	6.8E-06
							0.5	FF1.5.2	Able to get out of water, less severe injury	2	1.7E-06	3.4E-06
						0.8	0.325	FF1.6.1	Drowning, not rescued in time and not able to get out of water	4	4.4E-06	1.8E-05
							0.675	FF1.6.2	Able to get out of water, less severe injury	2	9.2E-06	1.8E-05
					0.9	0.2	0.35	FF1.7.1	Drowning, not rescued and not able to get out of water	4	1.1E-05	4.3E-05
							0.65	FF1.7.2	Able to get out of water, less severe injury	2	2.0E-05	4.0E-05
						0.8	0.15	FF1.8.1	Drowning, not rescued in time and not able to get out of water	4	1.8E-05	7.3E-05
							0.85	FF1.8.2	Able to get out of water, less severe injury	2	1.0E-04	2.1E-04
			0.55	0.15	N/A	0.2	N/A	FF1.9	Not falling into sea, but critical injured	3	1.0E-05	3.1E-05
		0.3	0.3	0.2	0.1	0.2	0.7	FF2.1.1	Drowning, not rescued and not able to get out of water	4	2.3E-07	9.1E-07
							0.3	FF2.1.2	Able to get out of water, but critical injured	3	9.7E-08	2.9E-07
						0.8	0.45	FF2.2.1	Drowning, not rescued in time and not able to get out of water	4	5.8E-07	2.3E-06
							0.55	FF2.2.2	Rescued, but critical injured	3	7.1E-07	2.1E-06
					0.9	0.2	0.35	FF2.3.1	Drowning, not rescued and not able to get out of water	4	1.0E-06	4.1E-06
							0.65	FF2.3.2	Able to get out of water, but critical injured	3	1.9E-06	5.7E-06
						0.8	0.1	FF2.4.1	Drowning, not rescued in time and not able to get out of water	4	1.2E-06	4.7E-06
							0.9	FF2.4.2	Rescued, but critical injured	3	1.0E-05	3.1E-05
				0.8	0.1	0.2	0.4	FF2.5.1	Drowning, not rescued and not able to get out of water	4	5.2E-07	2.1E-06
							0.6	FF2.5.2	Able to get out of water, less severe injury	1	7.8E-07	7.8E-07
						0.8	0.3	FF2.6.1	Drowning, not rescued in time and not able to get out of water	4	1.6E-06	6.2E-06
							0.7	FF2.6.2	Able to get out of water, less severe injury	1	3.6E-06	3.6E-06
					0.9	0.2	0.15	FF2.7.1	Drowning, not rescued and not able to get out of water	4	1.7E-06	7.0E-06
							0.85	FF2.7.2	Able to get out of water, less severe injury	1	9.9E-06	9.9E-06
						0.8	0.075	FF2.8.1	Drowning, not rescued in time and not able to get out of water	4	3.5E-06	1.4E-05
							0.925	FF2.8.2	Able to get out of water, less severe injury	1	4.3E-05	4.3E-05
			0.7	0.075	N/A	0.2	N/A	FF2.9	Not falling into sea, but critical injured	2	2.8E-06	5.7E-06

True
False

Slip/trip frequency model			Damage extent model		Safety system	Survivavility model		Outcome				
Slip/trip	Fall distribution	Bad weather	Fall into sea	Critical injury	No life west on	Working alone	Unable to get out of water	Id code	End event description	Cons. factor	Frequency	Risk contribution
	Vessel 0.5	0.7	0.15	0.35	0.1	0.2	0.85	FV1.1.1	Drowning, not rescued and not able to get out of water	4	5.6E-07	2.2E-06
							0.15	FV1.1.2	Able to get out of water, but critical injured	3	9.9E-08	3.0E-07
						0.8	0.6	FV1.2.1	Drowning, not rescued in time and not able to get out of water	4	1.6E-06	6.4E-06
							0.4	FV1.2.2	Rescued, but critical injured	3	1.1E-06	3.2E-06
					0.9	0.2	0.55	FV1.3.1	Drowning, not rescued and not able to get out of water	4	3.3E-06	1.3E-05
							0.45	FV1.3.2	Able to get out of water, but critical injured	3	2.7E-06	8.0E-06
						0.8	0.175	FF1.4.1	Drowning, not rescued in time and not able to get out of water	4	4.2E-06	1.7E-05
							0.825	FV1.4.2	Rescued, but critical injured	3	2.0E-05	5.9E-05
				0.65	0.1	0.2	0.5	FV1.5.1	Drowning, not rescued and not able to get out of water	4	6.1E-07	2.5E-06
							0.5	FV1.5.2	Able to get out of water, less severe injury	2	6.1E-07	1.2E-06
						0.8	0.325	FV1.6.1	Drowning, not rescued in time and not able to get out of water	4	1.6E-06	6.4E-06
							0.675	FV1.6.2	Able to get out of water, less severe injury	2	3.3E-06	6.6E-06
					0.9	0.2	0.35	FV1.7.1	Drowning, not rescued and not able to get out of water	4	3.9E-06	1.5E-05
							0.65	FV1.7.2	Able to get out of water, less severe injury	2	7.2E-06	1.4E-05
						0.8	0.15	FV1.8.1	Drowning, not rescued in time and not able to get out of water	4	6.6E-06	2.7E-05
							0.85	FV1.8.2	Able to get out of water, less severe injury	2	3.8E-05	7.5E-05
			0.85	0.15	N/A	0.2	N/A	FV1.9	Not falling into sea, but critical injured	3	1.6E-05	4.8E-05
		0.3	0.1	0.15	0.1	0.2	0.7	FV2.1.1	Drowning, not rescued and not able to get out of water	4	5.7E-08	2.3E-07
							0.3	FV2.1.2	Able to get out of water, but critical injured	3	2.4E-08	7.3E-08
						0.8	0.45	FV2.2.1	Drowning, not rescued in time and not able to get out of water	4	1.5E-07	5.8E-07
							0.55	FV2.2.2	Rescued, but critical injured	3	1.8E-07	5.3E-07
					0.9	0.2	0.35	FV2.3.1	Drowning, not rescued and not able to get out of water	4	2.6E-07	1.0E-06
							0.65	FV2.3.2	Able to get out of water, but critical injured	3	4.7E-07	1.4E-06
						0.8	0.1	FF2.4.1	Drowning, not rescued in time and not able to get out of water	4	2.9E-07	1.2E-06
							0.9	FV2.4.2	Rescued, but critical injured	3	2.6E-06	7.9E-06
				0.85	0.1	0.2	0.4	FV2.5.1	Drowning, not rescued and not able to get out of water	4	1.8E-07	7.3E-07
							0.6	FV2.5.2	Able to get out of water, less severe injury	1	2.8E-07	2.8E-07
						0.8	0.3	FV2.6.1	Drowning, not rescued in time and not able to get out of water	4	5.5E-07	2.2E-06
							0.7	FV2.6.2	Able to get out of water, less severe injury	1	1.3E-06	1.3E-06
					0.9	0.2	0.15	FV2.7.1	Drowning, not rescued and not able to get out of water	4	6.2E-07	2.5E-06
							0.85	FV2.7.2	Able to get out of water, less severe injury	1	3.5E-06	3.5E-06
						0.8	0.075	FV2.8.1	Drowning, not rescued in time and not able to get out of water	4	1.2E-06	5.0E-06
							0.925	FV2.8.2	Able to get out of water, less severe injury	1	1.5E-05	1.5E-05
			0.9	0.075	N/A	0.2	N/A	FV2.9	Not falling into sea, but critical injured	2	3.6E-06	7.3E-06
										Sum risk	**5.19E-04**	**1.32E-03**
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7					

E.2 Hit by Object

Hit by object frequency model			Protective equipment				Survivability model		Outcome				
Hit by object	Hit by object - distribution	Bad weather	No helmet or other protective clothes	Critical injury	Falls into sea	Working alone	Not surviving, not able to get out of water		ID Code	End event description	Cons. factor	Frequency	Risk contribution
1.9E-03	Floating collar 0.50	0.7	0.2	0.75	0.825	0.4	0.85	1	HF1.1.1	Drowning - not able to get out of water or dies directly from impact.	4	2.8E-05	1.1E-04
							0.15	2	HF1.1.2	Seriously injury, head and body damage.	3	4.9E-06	1.5E-05
True						0.6	0.6	3	HF1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	3.0E-05	1.2E-04
							0.4	4	HF1.2.2	Seriously injury, head and sligtly less body damage.	3	2.0E-05	5.9E-05
False					0.175	N/A	0.3	5	HF1.3.1	Dies directly from impact	4	5.2E-06	2.1E-05
							0.7	6	HF1.3.2	Seriously injury, head and sligtly less body damage.	3	1.2E-05	3.7E-05
				0.25	0.825	0.4	0.5	7	HF1.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	5.5E-06	2.2E-05
							0.5	8	HF1.4.2	Significant injury, cold and wet from falling into sea	2	5.5E-06	1.1E-05
						0.6	0.325	9	HF1.5.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	5.3E-06	2.1E-05
							0.675	10	HF1.5.2	Minor injury, cold and wet from falling into sea	1	1.1E-05	1.1E-05
			0.8	0.55	0.825	0.4	0.55	11	HF1.6.1	Drowning - not able to get out of water	4	5.3E-05	2.1E-04
							0.45	12	HF1.6.2	Seriously injury, body damage. Prolonged hospital treatment	3	4.3E-05	1.3E-04
						0.6	0.175	13	HF1.7.1	Drowning - not able to get out of water or rescued.	4	2.5E-05	1.0E-04
							0.825	14	HF1.7.2	Seriously injury, body damage, wet and cold. Prolonged hospital treatment	3	1.2E-04	3.6E-04
					0.175	N/A	0.3	15	HF1.8.1	Dies directly from impact or of the injury from impact	4	1.5E-05	6.1E-05
							0.7	16	HF1.8.2	Seriously injury, body damage. Prolonged hospital treatment	3	3.6E-05	1.1E-04
				0.45	0.825	0.4	0.35	17	HF1.9.1	Drowning and not able to get out of water. Do not die directly from impact	4	2.8E-05	1.1E-04
							0.65	18	HF1.9.2	Minor injury, cold and wet from falling into sea	1	5.1E-05	5.1E-05
						0.6	0.15	19	HF1.10.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	1.8E-05	7.1E-05
							0.85	20	HF1.10.2	Minor injury, cold and wet from falling into sea	1	1.0E-04	1.0E-04
		0.3	0.2	0.7	0.725	0.4	0.7	21	HF2.1.1	Drowning - not able to get out of water or dies directly from impact.	4	8.1E-06	3.2E-05
							0.3	22	HF2.1.2	Seriously injury, head and body damage.	3	3.5E-06	1.0E-05
						0.6	0.45	23	HF2.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	7.8E-06	3.1E-05
							0.55	24	HF2.2.2	Seriously injury, head and sligtly less body damage.	3	9.5E-06	2.9E-05
					0.275	N/A	0.3	25	HF2.3.1	Dies directly from impact	4	3.3E-06	1.3E-05
							0.7	26	HF2.3.2	Seriously injury, head and sligtly less body damage.	3	7.7E-06	2.3E-05
				0.3	0.725	0.4	0.4	27	HF2.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	2.0E-06	7.9E-06
							0.6	28	HF2.4.2	Significant injury, cold and wet from falling into sea	2	3.0E-06	6.0E-06
						0.6	0.3	29	HF2.5.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	2.2E-06	8.9E-06
							0.7	30	HF2.5.2	Minor injury, cold and wet from falling into sea	1	5.2E-06	5.2E-06
			0.8	0.55	0.725	0.4	0.35	31	HF2.6.1	Drowning - not able to get out of water	4	1.3E-05	5.1E-05
							0.65	32	HF2.6.2	Seriously injury, body damage. Prolonged hospital treatment	3	2.4E-05	7.1E-05
						0.6	0.1	33	HF2.7.1	Drowning - not able to get out of water or rescued.	4	5.5E-06	2.2E-05
							0.9	34	HF2.7.2	Seriously injury, body damage, wet and cold. Prolonged hospital treatment	3	4.9E-05	1.5E-04
					0.275	N/A	0.3	35	HF2.8.1	Dies directly from impact or of the injury from impact	4	1.0E-05	4.1E-05
							0.7	36	HF2.8.2	Seriously injury, body damage. Prolonged hospital treatment	3	2.4E-05	7.2E-05
				0.45	0.725	0.4	0.15	37	HF2.9.1	Drowning and not able to get out of water. Do not die directly from impact	4	4.5E-06	1.8E-05
							0.85	38	HF2.9.2	Minor injury, cold and wet from falling into sea	1	2.5E-05	2.5E-05
						0.6	0.075	39	HF2.10.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	3.3E-06	1.3E-05
							0.925	40	HF2.10.2	Minor injury, cold and wet from falling into sea	1	4.1E-05	4.1E-05

Hit by object frequency model			Protective equipment				Survivability model		Outcome				
Hit by object	Hit by object - distribution	Bad weather	No helmet or other protective clothes	Critical injury	Falls into sea	Working alone	Not surviving, not able to get out of water		ID Code	End event description	Cons. factor	Frequency	Risk contribution
	Vessel 0.50	0.7	0.2	0.65	0.45	0.4	0.85	41	HV1.1.1	Drowning - not able to get out of water or dies directly from impact.	4	1.3E-05	5.3E-05
							0.15	42	HV1.1.2	Seriously injury, head and body damage.	3	2.3E-06	7.0E-06
						0.6	0.6	43	HV1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	1.4E-05	5.6E-05
							0.4	44	HV1.2.2	Seriously injury, head and sligtly less body damage.	3	9.3E-06	2.8E-05
					0.55	N/A	0.3	45	HV1.3.1	Dies directly from impact	4	1.4E-05	5.7E-05
							0.7	46	HV1.3.2	Seriously injury, head and sligtly less body damage.	3	3.3E-05	1.0E-04
				0.35	0.45	0.4	0.5	47	HV1.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	4.2E-06	1.7E-05
							0.5	48	HV1.4.2	Significant injury, cold and wet from falling into sea	2	4.2E-06	8.4E-06
						0.6	0.325	49	HV1.5.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	4.1E-06	1.6E-05
							0.675	50	HV1.5.2	Minor injury, cold and wet from falling into sea	1	8.5E-06	8.5E-06
			0.8	0.45	0.45	0.4	0.55	51	HV1.6.1	Drowning - not able to get out of water	4	2.4E-05	9.5E-05
							0.45	52	HV1.6.2	Seriously injury, body damage. Prolonged hospital treatment	3	1.9E-05	5.8E-05
						0.6	0.175	53	HV1.7.1	Drowning - not able to get out of water or rescued.	4	1.1E-05	4.5E-05
							0.825	54	HV1.7.2	Seriously injury, body damage, wet and cold. Prolonged hospital treatment	3	5.3E-05	1.6E-04
					0.55	N/A	0.3	55	HV1.8.1	Dies directly from impact or of the injury from impact	4	4.0E-05	1.6E-04
							0.7	56	HV1.8.2	Seriously injury, body damage. Prolonged hospital treatment	3	9.2E-05	2.8E-04
				0.55	0.45	0.4	0.35	57	HV1.9.1	Drowning and not able to get out of water. Do not die directly from impact	4	1.8E-05	7.4E-05
							0.65	58	HV1.9.2	Minor injury, cold and wet from falling into sea	1	3.4E-05	3.4E-05
						0.6	0.15	59	HV1.10.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	1.2E-05	4.7E-05
							0.85	60	HV1.10.2	Minor injury, cold and wet from falling into sea	1	6.7E-05	6.7E-05
		0.3	0.2	0.55	0.35	0.4	0.7	61	HV2.1.1	Drowning - not able to get out of water or dies directly from impact.	4	3.1E-06	1.2E-05
							0.3	62	HV2.1.2	Seriously injury, head and body damage.	3	1.3E-06	4.0E-06
						0.6	0.45	63	HV2.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	3.0E-06	1.2E-05
							0.55	64	HV2.2.2	Seriously injury, head and sligtly less body damage.	3	3.6E-06	1.1E-05
					0.65	N/A	0.3	65	HV2.3.1	Dies directly from impact	4	6.1E-06	2.4E-05
							0.7	66	HV2.3.2	Seriously injury, head and sligtly less body damage.	3	1.4E-05	4.3E-05
				0.45	0.35	0.4	0.4	67	HV2.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	1.4E-06	5.7E-06
							0.6	68	HV2.4.2	Significant injury, cold and wet from falling into sea	2	2.2E-06	4.3E-06
						0.6	0.3	69	HV2.5.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	1.6E-06	6.5E-06
							0.7	70	HV2.5.2	Minor injury, cold and wet from falling into sea	1	3.8E-06	3.8E-06
			0.8	0.4	0.35	0.4	0.35	71	HV2.6.1	Drowning - not able to get out of water	4	4.5E-06	1.8E-05
							0.65	72	HV2.6.2	Seriously injury, body damage. Prolonged hospital treatment	3	8.3E-06	2.5E-05
						0.6	0.1	73	HV2.7.1	Drowning - not able to get out of water or rescued.	4	1.9E-06	7.7E-06
							0.9	74	HV2.7.2	Seriously injury, body damage, wet and cold. Prolonged hospital treatment	3	1.7E-05	5.2E-05
					0.65	N/A	0.3	75	HV2.8.1	Dies directly from impact or of the injury from impact	4	1.8E-05	7.1E-05
							0.7	76	HV2.8.2	Seriously injury, body damage. Prolonged hospital treatment	3	4.1E-05	1.2E-04
				0.6	0.35	0.4	0.15	77	HV2.9.1	Drowning and not able to get out of water. Do not die directly from impact	4	2.9E-06	1.1E-05
							0.85	78	HV2.9.2	Minor injury, cold and wet from falling into sea	1	1.6E-05	1.6E-05
						0.6	0.075	79	HV2.10.1	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	2.2E-06	8.6E-06
							0.925	80	HV2.10.2	Minor injury, cold and wet from falling into sea	1	2.7E-05	2.7E-05
											Sum risk	**1.53E-03**	**4.26E-03**

Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | Level 6 | Level 7

E.3 Squeeze/Trapped

Squeeze/ trapped frequency model			Protective equipment	Damage extent model		Survivability model		Outcome				
Squeeze/ trapped	Squeeze/ trapped - distribution	Bad weather	No protective clothes	Critical injury	Falls into sea	Working alone	Not surviving	ID Code	End event description	Cons. factor	Frequency	Risk contribution
1.5E-03	Floating collar 0.5	0.7	0.7	0.55	0.65	0.2	0.85	SF1.1.1	Drowning - not able to get out of water or dies directly from impact.	4	2.2E-05	8.9E-05
							0.15	SF1.1.2	Seriously injury to body. Prolonged hospital treatment	3	3.9E-06	1.2E-05
						0.8	0.6	SF1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	6.3E-05	2.5E-04
							0.4	SF1.2.2	Seriously injury to body. Prolonged hospital treatment	3	4.2E-05	1.3E-04
					0.35	N/A	0.225	SF1.3.1	Dies directly from impact	4	1.6E-05	6.4E-05
							0.775	SF1.3.2	Seriously injury, body damage. Prolonged hospital treatment	3	5.5E-05	1.6E-04
				0.45	0.65	0.2	0.5	SF1.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	1.1E-05	4.3E-05
							0.5	SF1.4.2	Minor injury, cold and wet from falling into sea	1	1.1E-05	1.1E-05
						0.8	0.325	SF1.5	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	2.8E-05	1.1E-04
			0.3	0.4	0.65	0.2	0.55	SF1.6.1	Drowning - not able to get out of water or dies directly from impact.	4	4.5E-06	1.8E-05
							0.45	SF1.6.2	Seriously injury, body damage.	2	3.7E-06	7.4E-06
						0.8	0.175	SF1.7.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	5.7E-06	2.3E-05
							0.825	SF1.7.2	Significant injury, cold and wet from falling into sea	2	2.7E-05	5.4E-05
					0.35	N/A	0.225	SF1.8.1	Dies directly from impact or of the injury from impact	4	5.0E-06	2.0E-05
							0.775	SF1.8.2	Significant injury from impact	2	1.7E-05	3.4E-05
				0.6	0.65	0.2	0.35	SF1.9.1	Drowning - not able to get out of water	4	4.3E-06	1.7E-05
							0.65	SF1.9.2	Minor injury, cold and wet from falling into sea	1	8.0E-06	8.0E-06
						0.8	0.15	SF1.10	Drowning - not able to get out of water or rescued.	4	7.4E-06	2.9E-05
		0.3	0.7	0.35	0.5	0.2	0.7	SF2.1.1	Drowning - not able to get out of water or dies directly from impact.	4	3.9E-06	1.5E-05
							0.3	SF2.1.2	Seriously injury to body. Prolonged hospital treatment	3	1.7E-06	5.0E-06
						0.8	0.45	SF2.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	9.9E-06	4.0E-05
							0.55	SF2.2.2	Seriously injury to body. Prolonged hospital treatment	3	1.2E-05	3.6E-05
					0.5	N/A	0.225	SF2.3.1	Dies directly from impact	4	6.2E-06	2.5E-05
							0.775	SF2.3.2	Seriously injury, body damage. Prolonged hospital treatment	3	2.1E-05	6.4E-05
				0.65	0.5	0.2	0.4	SF2.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	4.1E-06	1.6E-05
							0.6	SF2.4.2	Minor injury, cold and wet from falling into sea	1	6.1E-06	6.1E-06
						0.8	0.3	SF2.5	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	1.2E-05	4.9E-05
			0.3	0.2	0.5	0.2	0.35	SF2.6.1	Drowning - not able to get out of water or dies directly from impact.	4	4.7E-07	1.9E-06
							0.65	SF2.6.2	Seriously injury, body damage.	2	8.8E-07	1.8E-06
						0.8	0.1	SF2.7.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	5.4E-07	2.2E-06
							0.9	SF2.7.2	Significant injury, cold and wet from falling into sea	2	4.9E-06	9.7E-06
					0.5	N/A	0.225	SF2.8.1	Dies directly from impact or of the injury from impact	4	1.5E-06	6.1E-06
							0.775	SF2.8.2	Significant injury from impact	2	5.2E-06	1.0E-05
				0.8	0.5	0.2	0.15	SF2.9.1	Drowning - not able to get out of water	4	8.1E-07	3.2E-06
							0.85	SF2.9.2	Minor injury, cold and wet from falling into sea	1	4.6E-06	4.6E-06
						0.8	0.075	SF2.10	Drowning - not able to get out of water or rescued.	4	1.6E-06	6.5E-06

Squeeze/ trapped frequency model			Protective equipment	Damage extent model		Survivability model		Outcome				
Squeeze/ trapped	Squeeze/ trapped - distribution	Bad weather	No protective clothes	Critical injury	Falls into sea	Working alone	Not surviving	ID Code	End event description	Cons. factor	Frequency	Risk contribution
	Vessel											
	0.5	0.7	0.1	0.6	0.25	0.2	0.85	SV1.1.1	Drowning - not able to get out of water or dies directly from impact.	4	1.3E-06	5.4E-06
							0.15	SV1.1.2	Seriously injury to body. Prolonged hospital treatment	3	2.4E-07	7.1E-07
						0.8	0.6	SV1.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	3.8E-06	1.5E-05
							0.4	SV1.2.2	Seriously injury to body. Prolonged hospital treatment	3	2.5E-06	7.6E-06
					0.75	N/A	0.15	SV1.3.1	Dies directly from impact	4	3.5E-06	1.4E-05
							0.85	SV1.3.2	Seriously injury, body damage. Prolonged hospital treatment	3	2.0E-05	6.0E-05
				0.4	0.25	0.2	0.5	SV1.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	5.3E-07	2.1E-06
							0.5	SV1.4.2	Minor injury, cold and wet from falling into sea	1	5.3E-07	5.3E-07
						0.8	0.325	SV1.5	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	1.4E-06	5.5E-06
			0.9	0.45	0.25	0.2	0.55	SV1.6.1	Drowning - not able to get out of water or dies directly from impact.	4	5.8E-06	2.3E-05
							0.45	SV1.6.2	Seriously injury, body damage.	2	4.8E-06	9.6E-06
						0.8	0.175	SV1.7.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	7.4E-06	3.0E-05
							0.825	SV1.7.2	Significant injury, cold and wet from falling into sea	2	3.5E-05	7.0E-05
					0.75	N/A	0.15	SV1.8.1	Dies directly from impact or of the injury from impact	4	2.4E-05	9.6E-05
							0.85	SV1.8.2	Significant injury from impact	2	1.4E-04	2.7E-04
				0.55	0.25	0.2	0.35	SV1.9.1	Drowning - not able to get out of water	4	4.5E-06	1.8E-05
							0.65	SV1.9.2	Minor injury, cold and wet from falling into sea	1	8.4E-06	8.4E-06
						0.8	0.15	SV1.10	Drowning - not able to get out of water or rescued.	4	7.8E-06	3.1E-05
		0.3	0.1	0.45	0.15	0.2	0.7	SV2.1.1	Drowning - not able to get out of water or dies directly from impact.	4	2.1E-07	8.5E-07
							0.3	SV2.1.2	Seriously injury to body. Prolonged hospital treatment	3	9.1E-08	2.7E-07
						0.8	0.45	SV2.2.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	5.5E-07	2.2E-06
							0.55	SV2.2.2	Seriously injury to body. Prolonged hospital treatment	3	6.7E-07	2.0E-06
					0.85	N/A	0.15	SV2.3.1	Dies directly from impact	4	1.3E-06	5.2E-06
							0.85	SV2.3.2	Seriously injury, body damage. Prolonged hospital treatment	3	7.3E-06	2.2E-05
				0.55	0.15	0.2	0.4	SV2.4.1	Drowning and not able to get out of water. Do not die directly from impact	4	1.5E-07	5.9E-07
							0.6	SV2.4.2	Minor injury, cold and wet from falling into sea	1	2.2E-07	2.2E-07
						0.8	0.3	SV2.5	Drowning and not able to get out of water or rescued in time. Do not die directly from impact	4	4.5E-07	1.8E-06
			0.9	0.3	0.15	0.2	0.35	SV2.6.1	Drowning - not able to get out of water or dies directly from impact.	4	6.4E-07	2.6E-06
							0.65	SV2.6.2	Seriously injury, body damage.	2	1.2E-06	2.4E-06
						0.8	0.1	SV2.7.1	Drowning - not able to get out of water or rescued or dies directly from impact.	4	7.3E-07	2.9E-06
							0.9	SV2.7.2	Significant injury, cold and wet from falling into sea	2	6.6E-06	1.3E-05
					0.85	N/A	0.15	SV2.8.1	Dies directly from impact or of the injury from impact	4	7.7E-06	3.1E-05
							0.85	SV2.8.2	Significant injury from impact	2	4.4E-05	8.8E-05
				0.7	0.15	0.2	0.15	SV2.9.1	Drowning - not able to get out of water	4	6.4E-07	2.6E-06
							0.85	SV2.9.2	Minor injury, cold and wet from falling into sea	1	3.6E-06	3.6E-06
						0.8	0.075	SV2.10	Drowning - not able to get out of water or rescued.	4	1.3E-06	5.1E-06
										Sum risk	7.77E-04	2.24E-03
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7					

E.4 Collision/Contact

Collision frequency model		Damage extent model			Survivability model		Third party model			Outcome: Vessel crew		Cons. factor						
Collision/ contact	Bad weather	Critical damage to vessel	Leak of fuel, oil, etc.	Fire/ explosion	Not surviving	Not working alone	Critical damage to net cage	Probability of fatalities other than crew on vessel	# fatalities	ID Code	End event description	People	Environment	Property	Frequency	Individual Risk	Env. Risk	Property Risk
3.1E-03	0.7	0.1875	0.1	0.1	0.15	0.8	0.825	0.0625	1	C1.1	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4	3	4	4.9E-07	2.0E-06	1.5E-06	2.0E-06
								0.9375	0									
							0.175	N/A	0									
						0.2	0.825	0.0625	1	C1.2	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4	3	4	1.2E-07	4.9E-07	3.7E-07	4.9E-07
								0.9375	0									
							0.175	N/A	0									
					0.85	N/A	0.825	0.0625	1	C1.3	Vessel critical damaged, leak and explosion. Vessel sinks due to damage. Workers evacuated, medical treatmen	2	3	4	3.5E-06	6.9E-06	1.0E-05	1.4E-05
								0.9375	0									
							0.175	N/A	0									
				0.9	N/A	N/A	0.825	0.0625	1	C1.4	Vessel critical damaged, leak of fuel, oil etc. Detected and explosion prevented. Minor injuries	1	2	2	3.7E-05	3.7E-05	7.3E-05	7.3E-05
								0.9375	0									
							0.175	N/A	0									
			0.9	N/A	N/A	N/A	0.825	0.0625	1	C1.5	Vessel critical damaged, but no leak or fatalities. Minor injuries	1	0	2	3.7E-04	3.7E-04	0.0E+00	7.3E-04
								0.9375	0									
							0.175	N/A	0									
		0.8125	N/A	N/A	N/A	N/A	0.825	0.0625	1	C1.6	Vessel minor damaged	0	0	1	1.8E-03	0.0E+00	0.0E+00	1.8E-03
								0.9375	0									
							0.175	N/A	0									
	0.3	0.1375	0.1	0.1	0.15	0.8	0.75	0.0625	1	C2.1	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4	3	4	1.5E-07	6.1E-07	4.6E-07	6.1E-07
								0.9375	0									
							0.25	N/A	0									
						0.2	0.75	0.0625	1	C2.2	Vessel critical damaged, leak and explosion. Vessel sinks due to damage and none surviving	4	3	4	3.8E-08	1.5E-07	1.2E-07	1.5E-07
								0.9375	0									
							0.25	N/A	0									
					0.85	N/A	0.75	0.0625	1	C2.3	Vessel critical damaged, leak and explosion. Vessel sinks due to damage. Workers evacuated, medical treatmen	2	3	4	1.1E-06	2.2E-06	3.3E-06	4.3E-06
								0.9375	0									
							0.25	N/A	0									
				0.9	N/A	N/A	0.75	0.0625	1	C2.4	Vessel critical damaged, leak of fuel, oil etc. Detected and explosion prevented. Minor injuries	1	2	2	1.2E-05	1.2E-05	2.3E-05	2.3E-05
								0.9375	0									
							0.25	N/A	0									
			0.9	N/A	N/A	N/A	0.75	0.0625	1	C2.5	Vessel critical damaged, but no leak or fatalities. Minor injuries	1	0	2	1.2E-04	1.2E-04	0.0E+00	2.3E-04
								0.9375	0									
							0.25	N/A	0									
		0.8625	N/A	N/A	N/A	N/A	0.75	0.0625	1	C2.6	Vessel minor damaged	0	0	1	8.0E-04	0.0E+00	0.0E+00	8.0E-04
								0.9375	0									
							0.25	N/A	0									

Collision frequency model		Damage extent model			Survivability model		Third party model			Outcome: Third parties	Cons. factor						
Collision/ contact	Bad weather	Critical damage to vessel	Leak of fuel, oil, etc.	Fire/ explosion	Not surviving	Not working alone	Critical damage to net cage	Probability of fatalities other than crew on vessel	ID Code	End event description	People	Environment	Property	Frequency	Individual Risk	Env. Risk	Property Risk
3.1E-03	0.7	0.1875	0.1	0.1	0.15	0.8	0.825	0.0625	C1.1.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	2.1E-07	8.4E-07	8.4E-07	6.3E-07
								0.9375	C1.1.2	Net cage critical damaged. Significant escpament of fish	0	4	3	3.1E-06	0.0E+00	1.3E-05	9.4E-06
							0.175	N/A	C1.1.3	Net cage minor damaged. Minor escapement	0	3	1	7.1E-07	0.0E+00	2.1E-06	7.1E-07
						0.2	0.825	0.0625	C1.2.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	2.1E-07	8.4E-07	8.4E-07	6.3E-07
								0.9375	C1.2.2	Net cage critical damaged. Significant escpament of fish	0	4	3	3.1E-06	0.0E+00	1.3E-05	9.4E-06
							0.175	N/A	C1.2.3	Net cage minor damaged. Minor escapement	0	3	1	7.1E-07	0.0E+00	2.1E-06	7.1E-07
					0.85	N/A	0.825	0.0625	C1.3.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	2.1E-07	8.4E-07	8.4E-07	6.3E-07
								0.9375	C1.3.2	Net cage critical damaged. Significant escpament of fish	0	4	3	3.1E-06	0.0E+00	1.3E-05	9.4E-06
							0.175	N/A	C1.3.3	Net cage minor damaged. Minor escapement	0	3	1	7.1E-07	0.0E+00	2.1E-06	7.1E-07
				0.9	N/A	N/A	0.825	0.0625	C1.4.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	1.9E-06	7.6E-06	7.6E-06	5.7E-06
								0.9375	C1.4.2	Net cage critical damaged. Significant escpament of fish	0	4	3	2.8E-05	0.0E+00	1.1E-04	8.5E-05
							0.175	N/A	C1.4.3	Net cage minor damaged. Minor escapement	0	3	1	6.4E-06	0.0E+00	1.9E-05	6.4E-06
			0.9	N/A	N/A	N/A	0.825	0.0625	C1.5.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	1.9E-05	7.6E-05	7.6E-05	5.7E-05
								0.9375	C1.5.2	Net cage critical damaged. Significant escpament of fish	0	4	3	2.8E-04	0.0E+00	1.1E-03	8.5E-04
							0.175	N/A	C1.5.3	Net cage minor damaged. Minor escapement	0	3	1	6.4E-05	0.0E+00	1.9E-04	6.4E-05
		0.8125	N/A	N/A	N/A	N/A	0.825	0.0625	C1.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	9.1E-05	3.6E-04	3.6E-04	2.7E-04
								0.9375	C1.6.2	Net cage critical damaged. Significant escpament of fish	0	4	3	1.4E-03	0.0E+00	5.5E-03	4.1E-03
							0.175	N/A	C1.6.3	Net cage minor damaged. Minor escapement	0	3	1	3.1E-04	0.0E+00	9.3E-04	3.1E-04
	0.3	0.1375	0.1	0.1	0.15	0.8	0.75	0.0625	C2.1.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	6.0E-08	2.4E-07	2.4E-07	1.8E-07
								0.9375	C2.1.2	Net cage critical damaged. Significant escpament of fish	0	4	3	9.0E-07	0.0E+00	3.6E-06	2.7E-06
							0.25	N/A	C2.1.3	Net cage minor damaged. Minor escapement	0	3	1	3.2E-07	0.0E+00	9.6E-07	3.2E-07
						0.2	0.75	0.0625	C2.2.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	6.0E-08	2.4E-07	2.4E-07	1.8E-07
								0.9375	C2.2.2	Net cage critical damaged. Significant escpament of fish	0	4	3	9.0E-07	0.0E+00	3.6E-06	2.7E-06
							0.25	N/A	C2.2.3	Net cage minor damaged. Minor escapement	0	3	1	3.2E-07	0.0E+00	9.6E-07	3.2E-07
					0.85	N/A	0.75	0.0625	C2.3.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	6.0E-08	2.4E-07	2.4E-07	1.8E-07
								0.9375	C2.3.2	Net cage critical damaged. Significant escpament of fish	0	4	3	9.0E-07	0.0E+00	3.6E-06	2.7E-06
							0.25	N/A	C2.3.3	Net cage minor damaged. Minor escapement	0	3	1	3.2E-07	0.0E+00	9.6E-07	3.2E-07
				0.9	N/A	N/A	0.75	0.0625	C2.4.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	5.4E-07	2.2E-06	2.2E-06	1.6E-06
								0.9375	C2.4.2	Net cage critical damaged. Significant escpament of fish	0	4	3	8.1E-06	0.0E+00	3.2E-05	2.4E-05
							0.25	N/A	C2.4.3	Net cage minor damaged. Minor escapement	0	3	1	2.9E-06	0.0E+00	8.6E-06	2.9E-06
			0.9	N/A	N/A	N/A	0.75	0.0625	C2.5.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	5.4E-06	2.2E-05	2.2E-05	1.6E-05
								0.9375	C2.5.2	Net cage critical damaged. Significant escpament of fish	0	4	3	8.1E-05	0.0E+00	3.2E-04	2.4E-04
							0.25	N/A	C2.5.3	Net cage minor damaged. Minor escapement	0	3	1	2.9E-05	0.0E+00	8.6E-05	2.9E-05
		0.8625	N/A	N/A	N/A	N/A	0.75	0.0625	C2.6.1	Net cage critical damaged. Worker hit and dies of impact. Significant escpament of fis	4	4	3	3.8E-05	1.5E-04	1.5E-04	1.1E-04
								0.9375	C2.6.2	Net cage critical damaged. Significant escpament of fish	0	4	3	5.6E-04	0.0E+00	2.3E-03	1.7E-03
							0.25	N/A	C2.6.3	Net cage minor damaged. Minor escapement	0	3	1	2.0E-04	0.0E+00	6.0E-04	2.0E-04

F. Five Whys Analysis

F.1 Berth to Net Cage

Problem: Berth to net cage					
Cause	**Why?**	**Why?**	**Why?**	**Why?**	**Why?**
<u>**6M: Machine**</u>					
Poor/ inadequate design	Cage not fitted for vessel	Poor possibilities to berth	Inadequate or no places to connect mooring line	Vessels<15 m: Steel/plastic fittings used by other ropes and/or is too small for mooring lines Vessels>15 m: No good solutions available, since main berthing should not be on cage	No solutions available specified only for vessel
	Vessel not fitted for cage	Difficult to enter net cage	For some vessels, no ladder/ stairs available. If stairs, no railings	Either damaged or not included in design	
Reduced propulsion power	Declutch SB engine	To reduce risk of propeller/ net contact	Main propeller not protected	Not installed propel protector	
	Engine failure	Poor maintenance of engine	Poor procedures or lacking of follow-up on procedures	Not enough focus from management	Not prioritized, heavy workload etc.
Incorrect tool selection	Use of capstan	May be cumbersome and hazardous if not used correctly	Skill, knowledge and stress	None or not good enough training	Missing or lack of following procedures
<u>**6M: Milieu**</u>					
Bad weather conditions	Strong current, waves and wind	Hard to get next to cage	None or not enough thruster	None or only one thruster for some vessels. Not	More costly to have two or to have

			power to berth to cage	enough thruster capacity	larger capacity
	Unnecessary transit to/from net cage	Operation is postponed after arriving to location of operation	Insufficient planning in regard to weather	No adequate procedures to follow	Not enough focus from management , lacking competence
Untidy workplace (hard to move around on deck)	Hoses, equipment etc. laying around on deck	No proper equipment or layout for a clean deck.	Not following or none routines or procedures for tidy workplace	Not enough focus from management	Not prioritized, heavy workload etc.
<u>6M: Man</u>					
Lack of skills	No proper training	Insufficient or none procedures, or procedures not followed	Not enough focus from management	Not prioritized, heavy workload etc.	
<u>6M: Method</u>					
Poor communication	Hard to be heard	Noise or other disturbances, distance between workers	Vessel, equipment, stress/ workload, method used for operation	Lack of soundproofing, lack of communication system, lack of or insufficient work procedure	

F.2 Unnecessary Work and Transit

Problem: Unnecessary work/transit					
Cause	**Why?**	**Why?**	**Why?**	**Why?**	**Why?**
6M: Machine					
Incorrect tool selection	Forgotten to bring correct tools	Lack of or poor communicati on	Not followed or lack of procedures	Not enough focus from management	Not prioritized, heavy workload etc.
Defective equipment	Equipment not proper prepared for operation	No proper maintenance and preparation	Inadequate procedures	Not enough focus from management	Not prioritized, heavy workload etc.
Poor design	Equipment not fitted for operation	Extra work to fit equipment during operation	Equipment is not properly designed for task	Proper design do not exist	Custom build, costly
	Equipment not fitted for operation	Not performing operation optimal, cause delays and stop in in system/ operation	Wrong equipment, equipment no suited for task, design is not optimal	Proper design do not exist	Custom build, costly
6M: Milieu					
Bad weather conditions	Unnecessary transit to/from net cage	Operation is postponed after arriving to location of operation	Insufficient planning in regard to weather	No adequate procedures to follow	Not enough focus from managemen t, lacking competence
Untidy workplace (extra work to move around on deck or clean deck)	Hoses, equipment etc. laying around on deck, slippery fluids	No proper equipment or layout for a clean deck. No routines or procedures for tidy workplace	Not enough focus from management	Not prioritized, heavy workload etc.	
6M: Man					
Lack of knowledge/ skills	Need to pick up missing equipment for operation	Poor planning and preparation, ignorance	Not following or none procedure to follow, lack of training	Culture, management	

	Not performed correct first time, or using equipment wrong or inefficient	No proper training, lack of training, lack of work procedures	Insufficient or none procedures, or procedures not followed	Not enough focus from management	Not prioritized, heavy workload etc.
Stress	Forget to bring necessary equipment	Too heavy workload/ pressure	Poor planning and preparation, too few workers, to many tasks	Management	
<u>6M: Maintenance</u>					
Poor maintenance	Operation takes longer time or must be aborted	Stop in system, failure of equipment	Not properly maintained or checked after maintenance	No proper training or procedures	Not enough focus from managemen t
<u>6M: Method</u>					
Poor communicati on	Operation relay on much communicati on to be performed	Operation need teamwork with other external vessels/ workers	Poor planning before and during operation	Not prioritized, none or not followed procedures	Manageme nt
Poor planning/ preparation	Extra work if operation not properly prepared by customer	Net cage not fitted for cleaning etc.	Bottom ring not hoisted, missing ropes etc.	Poor communicatio n with customer	Manageme nt
	Missing equipment, wrong equipment, cannot perform operation due to weather conditions etc.	Lack of knowledge. None, inadequate or not following procedure	Not proper trained. Culture, management.	Poor communicatio n, prioritizing, management	
	Operation and equipment not proper prepared and need to be done at sea	More time consuming at sea due to motion in vessel, bad weather etc.	Poor planning before and during operation	Not prioritized, none or not followed procedures	Manageme nt

Inadequate method	Ineffective method for operation. I.e. lift the bottom ring at one point at a time	Poor or missing procedure. Missing equipment. Inadequate design of equipment and/or floating collar/vessel.	Management. Planning/ preparation. Not adapted, not installed or not thought of.	Culture, management. Implementation, cost, conservative.	
Inadequate procedures	Inefficient way of taking decisions	Do not know when to perform the operation or not	Do not have adequate procedures in regard to decision making when bad weather	Lack of competence/ knowledge, time consuming	Preparation, procedures, training, management
<u>6M: Material</u>					
Lack of equipment	Missing or forgotten to bring correct tools	Bad communication	Poor or incorrect procedures/planning	Not enough focus from management	Not prioritized, heavy workload etc.
Wrong equipment	Lack of knowledge	No proper training	Not enough focus from management	Not prioritized, heavy workload etc.	

F.3 Lift of Bottom Ring and Floating Collar

Problem: Lift of bottom ring and floating collar					
Cause	**Why?**	**Why?**	**Why?**	**Why?**	**Why?**
6M: Machine					
Poor design	Floating collar is not designed for efficient way of lifting it (require to be lifted from two points)	Increasing demand of lifting floating collar sufficient high out water.	To be able to perform necessary operations	Bigger equipment	Development regarding safe and efficient operations
	Vessel not suited/ designed for operation	Vessel has limiting crane capacity. Vessel heeling, limiting lifting capacity	Crane too small for operation. Crane placed in wrong location Not installed anit-heeling.	Inadequate/ poor design	
	Bottom ring is not designed for efficient way of lifting it (system not fitted with winch system)	Need to move vessel around the cage and performing operation several times	Heavy, need to be lifted in steps and in steps around the cage by use of crane or capstan	Tension in bottom ring. Not sufficient strong and too large to be lifted in one step	Poor/ inadequate design
Incorrect tool selection	Forgotten to bring correct tools	Bad communication	Incorrect procedures	Not enough focus from management	Not prioritized, heavy workload etc.
6M: Mileu					
Bad weather conditions	Lift cannot be performed in too poor weather	Waves, wind and current making the operation dangerous to perform	Safety for human, environment and property	Limited weather window with today's procedures and methods for performing operations	
6M: Man					

Lack of skills	Non or improper training	Insufficient or none procedures, or procedures not followed	Management	Not prioritized, heavy workload etc.
Operator error	Lack of knowledge. Stress.	No proper training. Heavy workload.	Management	
<u>6M: Method</u>				
Poor communication	Hard to be heard	Noise or other disturbances, distance between workers	Vessel, equipment, stress/ workload, method used for operation	Lack of soundproofing, lack of communication system, lack of or insufficient work procedure
Poor method	Ineffective method for operation. I.e. lift the bottom ring at one point at a time	Poor or missing procedure. Missing equipment. Inadequate design of equipment and/or floating collar/vessel.	Management. Planning/ preparation. Not adapted, not installed or not thought of.	Culture, management. Implementation, cost, conservative.

F.4 Cleaning Barge

Problem: Cleaning barge					
Cause	**Why?**	**Why?**	**Why?**	**Why?**	**Why?**
6M: Machine					
Poor design	Difficult to lift floating collar onto cleaning barge	Floating collar is heavy and cleaning barge high and difficult to place on correct location below floating collar (especially in poor weather)	Wheels not properly adjusted to fit the floating collar. No guiding pins to lead barge/ floating collar to correct location	Inadequate design of cleaning barge	
	Difficult to lift floating collar	Heavy. Required arrangement of lifting floating collar.	Limitation crane capacity	Reduced further because vessel is heeling.	Improper design of vessel and/or floating collar
	Cleaning barge not fitted for cleaning of lots of blue mussels/biofouling	Must shovel away blue mussels after cleaning one net cage and sometimes during cleaning	Blue mussels accumulating on cleaning rig, making it very heavy and deep in the water, hard to work on	Not proper designed for its purpose. Today's solution not working. Hoses becomes obstacles	Missing a hole in the middle or design for the biofouling to easily come off. Hoses and cables should be integrated into structure
	Cleaning nozzles not fitted to clean the floating collar properly	Nozzles must be adjusted between cleaning of every net cage	One of the nozzles must be manually (by hydraulic control) removed every time the barge met a bridle ("hanefot")	Inadequate and inefficient design	

	Hard to get from floating collar onto barge	Missing proper stairs	Inadequate design	
	Have to use manual water pump to wash deck and equipment	Low pressure on internal water pump on vessel. Few connection possibilities.	Not installed pump with sufficient capacity.	Poor or inadequate design
Defective equipment	Cleaning nozzles defective, or other equipment	Equipment not adjusted for operation	Poor design or bad maintenance	Inadequate design
6M: Milieu				
Bad weather conditions	Cleaning operation hard to perform	Hard to place barge below floating collar. Hard to steer around the net cage in front of cleaning barge	Inadequate design. HPC cleaner is placed on vessel and not on cleaning barge	Inadequate design
Inadequate layout of work	Cleaning barge dependent on vessel to be able to clean	HPC not placed on cleaning barge	Design of cleaning barge do not allow the HPC to be placed there	Poor design of cleaning barge
6M: Man				
Lack of skill	No proper training	Insufficient or none procedures, or procedures not followed	Management	Not prioritized, heavy workload etc.
Operator error	Lack of knowledge. Stress.	No proper training. Heavy workload.	Management	
6M: Maintenance				
Poor maintainability	Equipment on cleaning barge defect	None, missing or improper procedures for maintenance. Procedure not followed	Management	Not prioritized, heavy workload etc.
6M: Method				

Setup time	HPC has to run for 30 min without using it. No work during this	Must have correct temperature before starting	Danger of damaging equipment/ engine	Poor/ inadequate work procedure/ method
	Ineffective setup time of process	Have to connect and disconnect power cable and hoses in between every operation/net cage	Inadequate design	
Poor method	Inefficient process with maintenance work after cleaning	Setup of equipment on every collar after finished cleaning	Performed cleaning on every collar and then go back to tightening screws etc.	Procedures not optimal

G. SMED

G.1 Net Cleaning

Operation: Net cleaning										
Current operation			**Type**			**Improvement**		**Goal**		
#	**Task**	**Detail**	**In**	**Ex**	**W**	**Plan**	**Ty**	**EI**	**ME**	**R**
1	Preparation	Check oil, fuel	X			Improve procedure/ routines	P			X
2	Put off from quay	Cast off the moorings	X							
3	Transit to site			X						
4	Evaluate weather conditions	Safe to moor? Wait for better weather conditions	X			Include in preparation. Weather window	P			X
5	Moor to net cage			X		Improve mooring system for vessel	E + D			X
6	Prepare net cage for operation		X							
7	Lift ROV	Connect hook, lift from vessel and into cage. Unhook.	X			Remote hook	E			X
8	Lift RONC	Connect hook, lift from vessel and into cage. Unhook.	X			Remote hook	E			X
9	Tie RONC to cage		X			Natural buoyancy	U	X		
10	Release hoses into cage		X			Storage winch	E			X
11	Start HPC		X							
12	Wait for correct temperature on HPC		X			Start earlier. Have water supply on board. Have ROV and RONC submerged in water	M		X	
13	Release RONC		X			Natural buoyancy	U	X		
14	Perform cleaning operation			X		Future: Automatic driven				
15	Continuously monitor system			X						
16	Drive ROV and RONC to surface			X		Use natural buoyancy				X

17	Tie RONC to net cage			X		Natural buoyancy		X		
18	Turn of HPC			X						
19	Lift ROV	Connect hook, lift from cage and onto vessel. Unhook.	X			Remote hook				X
20	Lift RONC	Connect hook, lift from cage and onto vessel. Unhook.	X			Remote hook				X
21	Hoist hoses manually		X			Storage winch				X
22	Put back equipment		X			Second person can do this during lift and hoist.				X
23	Put back bird net		X			Second person can do this during lift and hoist.				X
24	Decide whether to wash new cage or sail back to port	Time to wash more, weather conditions etc.	X							
25	Unmoor		X							
26	Transit			X						
27	If new cage	Perform #5-26								
28	If back to port	Moor to quay	X							
29	Prepare vessel for next day		X			Ensure good routines in preparation of vessel	P			X

G.2 Delousing with tarpaulin

Operation: Delousing with tarpaulin										
Vessels: Customer x2 (C1 and C2), Tarpaulin vessel (TV) and Chemical vessel (CV)										
Current operation			**Type**			**Improvement**		**Goal**		
#	**Task**	**Detail**	**In**	**Ex**	**W**	**Plan**	**Ty**	**EI**	**ME**	**R**
1	Preparation (all)		X			Include meeting with all involved vessels (skype)	P			X
2	Put off from quay	Cast off the moorings	X							
3	Transit to site			X						
4	Evaluate weather conditions	Safe to moor? Wait for better weather conditions	X			Include in preparation. Weather window. Improve preparation procedure (weather restricted operation)	WW			X
5	Moor to net cage (C1,C2,TV)			X		Mooring system	D			X
6	Prepare lift of bottom ring in steps	Must be lifted to 6-7 meter to fit tarpaulin	X					X		
7	Pull rope/ chain from bottom ring	Must be lifted in steps of max 5-8 meters with capstan or crane	X			Bottom ring lift	P + E			X
8	Unmoor, move and moor vessel for next lift		X			Method for lifting bottom ring. Reduce necessary movement of vessel	P + E			X
9	Repeat lift of rope/chain	May need two rounds	X				P + E			X
10	Take up slack in net	Due to hoist of bottom ring	X							
11	Lift up equipment from cage	Net tip, weights, dead fish equipment, etc.	X							
12	CV moor to net cage			X		Mooring system	D			X

13	CV lift out O2 equipment	Using crane and pull in place	X							
14	TV prepare ropes for pulling tarpaulin.	7 ropes pulled below crowfoots to position 0’ 45’, 90’ and 135’	X							
15	TV mount a weight to the tarpaulin	Make the tarpauling sink and easy the process pulling the tarpaulin	X			Include in preparation		X		
16	Lift and release the ROV (TV)	For monitoring the operation	X			Releases system	D			X
17	TV start to release tarpaulin	Preferable against the stream		X						
18	CV, C1 and C2 start to pull tarpaulin with capstan	First 0’, then 45’, followed by 90’ and 130’		X		Improve communication system.				X
19	Use ROV to monitor process (TV)			X						
20	The tarpaulin is tied to the net cage when pulled on place			X		Standardize best practice to tie rope	P			X
21	Control O2 level (CV)			X						
22	Pump out medicine (CV)			X						
23	Continuously control O2 level (CV)			X						
24	Wait for treatment to be finished	Depending on treatment		X						
25	Release ropes tied to net cage			X		Standardize best practice to tie rope	P			X
26	Pull back tarpaulin using triplex (TV)			X						

27	Use ROV to monitor process (TV)			X						
28	Lift back ROV (TV)		X				D			X
29	CV unmoor and put off net cage			X		Mooring system	D			X
30	Repeat operation on new cage if planned. If not continue with # 31-	Repeat #5-11 Repeat #12-29 C1 and C2 continues with # 31-32				Make # 5-11 external: C1 and C2 perform task while treatment of cage 1 occur. Make # 31-32 external: C1 and C2 perform task while # 12-29 occur			X	X
31	C1, C2 (and TV) put cage back in order	Release net and lower the bottom ring.	X							
32	C1, C2 (and TV) unmoor and put off net cage.		X							

G.3 Service and Maintenance of Floating Collar

Operation: Service and maintenance										
Current operation			**Type**			**Improvement**		**Goal**		
#	**Task**	**Detail**	**In**	**Ex**	**W**	**Plan**	**Ty**	**EI**	**ME**	**R**
1	Preparation	Check oil, fuel	X			Improve procedure/ routines	P			X
2	Put off from quay	Cast off the moorings	X							
3	Transit to site			X						
4	Moor to net cage			X		Improve mooring system for vessel	E + D			X
5	Prepare net cage for operation	Walk around net cage to check if everything is okay; no ropes, bottom ring at 1.5 m, release the bird “cage”	X							
6	Lift the bottom ring up on 2-3 places aft of vessel		X			Bottom ring lift Make #6-11 external: New design of barge with HPC	P + D		X	X
7	Lift up floating net collar		X			Design of floating collar and equipment for lifting floating collar. Make #7-11+14 external: New design of barge with HPC	D		X	X
8	Pull cleaning rig below the floating net collar using two capstans		X			Improve design of cleaning barge.	D		X	X
9	Lower the bottom ring back down		X			Bottom ring lift	P + D		X	X
10	Lower the floating collar back down		X			X			X	X

11	Pick up hoses and el-cable from cleaning rig and lift on board vessel		X			New design of barge with HPC		X		
12	Connect power cable to vessel and hoses to HPC		X					X		
13	Drive cleaning rig and control and fit all cleaning nozzles. Ensure that everything is okay		X			“Cleaner” and easier design of barge			X	X
14	Start and wait for correct temperature on HPC			X		Eliminate waiting time		X		
15	Perform cleaning operation by manually driving the cleaning rig			X						
16	Drive the vessel in front of cleaning rig			X		Design of barge with HPC		X		
17	Continuously monitor system			X						
18	Clean for a second round			X						
19	Stop cleaner when finished round 2			X						
20	Disconnect power and hoses and lift back to cleaning rig		X			Design of barge with HPC		X		
21	Lift back up bottom ring 2-3 places		X			Bottom ring lift				X
22	Lift up floating collar		X			Design of floating collar and equipment for lifting floating collar.				X
23	Pull out the cleaning rig with capstans and moor to vessel		X							
24	Lower the floating net collar		X							

25	Lower down the bottom ring to 1.5 m		X			Bottom ring lift				X
26	Connect to manual pumps for cleaning of rig		X			Design of barge. Design of vessel		X		X
27	Lift up one side of rig, to make it easier to clean		X			Design of barge		X		
28	Cleaning of rig		X			Design of barge				X
29	Lower down the rig and disconnect the pumps		X			Design of barge		X		
30	Unmoor and put off net cage.			X						
	Transit	Sail back to port		X						
	Moor	Moor to quay	X							
31	Service of net cage (use barge to lift up floating collar to be able to perform service)	Start with #1-13 Not #6, #12-13 only electric cable to be connected. Prepare other necessary equipment for operation (tools, spare parts, HPC etc.)	X			Eliminate #1-13: Perform service, before cleaning next cage. Prepare while cleaning operation occur		X		
32	Maintain and perform service on floating collar	Tighten and change of bolts and parts if necessary. Wash with manual HPC (small) where necessary.		X						
33	Drive floating collar forward while performing task #33 until finished	One round around the cage		X						
34	End operation and prepare for next operation	Perform task #21-25 and #30	X			Perform only after service	P	X		
35	Unmoor and put off net cage.		X			Perform only after service	P	X		

	Transit	Sail back to port		X		Perform only after service	P	X		
	Moor	Moor to quay	X			Perform only after service	P	X		