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# Development of a Risk Model for Fish Farming Operations

**Helene Nordtvedt**

Reliability, Availability, Maintainability and Safety (RAMS)
Submission date: June 2016
Supervisor: Stein Haugen, IPK
Co-supervisor: Ingunn Marie Holmen, SINTEF Fiskeri og havbruk

Norwegian University of Science and Technology
Department of Production and Quality Engineering

# PREFACE

This thesis is written as a part of the master programme of Mechanical Engineering at the Department of Production and Quality Engineering, with specialisation within Risk, Availability, Maintainability and Safety (RAMS). The focus of this research has been based on the findings from the pre-master research, performed the autumn 2015, where a literature review on risk assessment methods from various industries was conducted to evaluate the potential for implementation for fish farming operations.

The master thesis has been written in collaboration with SINTEF Fisheries and Aquaculture. The research is related to the Exposed Aquaculture Operations Centre, a research centre with the objective of developing knowledge and technologies for exposed aquaculture operations, enabling a sustainable expansion of the fish farming industry.

There are several persons I wish to thank for their involvements through feedback and contributions. First, I wish to thank my main supervisor at NTNU, Professor Stein Haugen for his time, patience and helpful feedback.

I would also like to thank my supervisor at SINTEF, Ingunn Holmen, for her time and valuable insight to the industry.

Lastly, I want to thank the informants taking part in the interviews and workshop, for their time and valuable contributions. It played an important part to my understanding of the case study.

Helene Nordtvedt

Helene Nordtvedt, Trondheim, 09.06.16

# SUMMARY

Fish farming has grown to become one of Norway’s largest export industries. By 2050, Norway has the potential of producing 50 million tons of fish each year, if challenges related to the production and environment are solved. This will be of invaluable importance with the growing population worldwide and challenges related to meeting the demand for food.

Fish farming facilities in Norway are gradually moving out from their origin in sheltered fjords to more exposed areas. This is due to the need for more space, as the facilities grow bigger, and better environment for production, as the current localities are related to challenges with fish diseases and accumulation of waste production in the proximity of the facilities.

Today’s fish farming industry has developed high technological solutions and equipment to simplify the tough working environment. Still, several operations involve heavy manual labour and expose the workers to many hazards during a workday. Fish farming is Norway’s second most dangerous occupation. Thus, the personal safety is an important aspect when working with development of the industry. It will be essential to ensure safe work places at existing and future fish farming facilities.

This research has considers the potential of a new risk model for fish farming operations. The development of the model is based on an approach called “major accident risk indicators”. The incentives for developing a new risk model for application in fish farming is the need for decision support systems and barriers against too hazardous work conditions. Usually, decisions related to whether to carry out an operation or not, are solely based on the experience of the workers, which may be affected by a tight schedule and other organisational factors. The idea is that this model will raise the awareness around the impact of influencing factors of hazardous events, thus motivating the workers to avoid working under too hazardous conditions.

Taking basis in a case operation, a potential approach for implementing the model is suggested. The main concept of the model is to identify unwanted events, and all relevant risk influencing factors. The relevant factors involve technical, human and organisational factors. The chosen factors are further modelled as Bayesian Networks, providing a useful illustration of all interconnections. All of the factors may have several potential states. By going through a checklist with statements working as indicators, the practitioners will be able to determine the factors’ state. Further, the aim is to be able to analyse the impact the factors’ different states will have on the risk of the hazardous event. This analysis is enabled using a conditional probability table.

The discussion is related to the potential application of the method. Necessary steps prior of a test period is considered as well as the model's limitations and the potential range of application. The main concern is related to the complexity and time-demand of implementing the model as well as the uncertainty it could include.

This research is not enough to base any final decision on whether or not the model is feasible in the context of fish farming. It does however provide motivation for further testing. This is recommended as further work, along with research on how to integrate the model as a software. The practitioners' perception of the model should be investigated carefully as a part of evaluating the test period.

# SAMMENDRAG

I et globalt perspektiv spiller norsk havbruk en viktig rolle, og næringen har utviklet seg til å bli en av landets største eksportindustrier. Hvis utfordringer knyttet til produksjon og miljø blir løst, er det estimert at Norge vil ha mulighet til produsere 5 millioner tonn fisk per år innen 2050. Dette vil være av stor betydning i en verden med stor befolkningsvekst og økende etterspørsel av mat.

Norske oppdrettsanlegg flyttes stadig ut til mer eksponerte lokaliteter, noe som fører til utfordringer til tekniske løsninger så vel som utfordringer knyttet til å sikkerheten til de involverte i havbruksoperasjoner.

Denne masteroppgaven fokuserer på muligheten til å utvikle en risikomodell som kan ha potensiale til og integreres som en del av risiko- og sikkerhetsstyringssystem ved havbruksanlegg, til bruk i planleggingsfasen av gitte operasjoner. Utviklingen av modellen er basert på tilnærmingen foreslått av metoden «Major Accident Risk Indicators».

Bakgrunnen for å ville tilpasse en ny risikomodell til havbruk er et ønske om et verktøy for beslutningsstøtte i operasjonell kontekst. I dagens drift er avgjørelsen om hvorvidt en operasjon skal gjennomføres eller ikke ofte basert på skjønn. Dette kan i mange tilfeller føre til stress hos de involverte. Tanken er at ved å introdusere beslutningskriterier og bevisstgjøring av hvordan ulike faktorer påvirker en uønsket situasjon, vil man kunne etablere barrierer mot å arbeide under for farlige forhold.

Modellen utføres gjennom flere steg og er i denne oppgaven, basert på en case-operasjon. Et sett med uønskede hendelser er definert og videre er alle relevante faktorer som kan påvirke hendelsene definert. Dette inkluderer både tekniske, menneskelige og organisatoriske faktorer. De faktorene som blir vurdert som mest relevante er videre arrangert i Bayesianske nettverk. Disse nettverkene viser tydelig hvordan de ulike faktorene påvirker hverandre og den valgte hendelsen. Hver av disse faktorene kan ha en eller flere tilstander. En sjekkliste med påstander er foreslått som et verktøy for å indikere faktorenes tilstand. Tanken er at brukeren videre skal kunne vurdere hvordan faktorenes ulike tilstander påvirker risikoen for hendelsen. Dette vil muliggjøres gjennom en kvantitativ analyse der brukeren må sette opp en såkalt betinget sannsynlighetstabell (CPT).

Diskusjonen i oppgaven er knyttet modellens potensial i havbruk. Nødvendige steg for videre testing av modellen ble tatt opp, i likhet med dens begrensinger og potensiale for videre utvikling. De største bekymringene knyttet til modellen, er at den kan være tidkrevende og kompleks å tilpasse til bruk, i tillegg til at det på dette tidspunktet er vanskelig å si noe om hvor stor usikkerheten av modellen vil være i det enkelte tilfellet.

Resultatene presentert i denne oppgaven gir ikke nok bakgrunn til å kunne gjøre en endelig evaluering om hvorvidt modellen vil kunne fungere i bruk. Derimot motiverer den til å gjøre videre undersøkelser knyttet til gjennomførbarheten. Som videre arbeid er en testperiode i industrien foreslått. En viktig del av en slik testperiode vil være brukernes oppfattelse av modellens virkning, for å kunne fastslå dens fordeler samt avdekke eventuelle uforutsette utfordringer.

## ABBREVIATIONS

ALARA – As Low As Reasonably Achievable

ALARP – As Low As Reasonably Possible

BN – Bayesian Networks

CPT – Conditional Probability Table

MARI – Major Accident Risk Indicator

OCS – Operational Conditions Safety

SJA - Safe Job Analysis

STEP – Sequentially Timed Events Plotting

QRA – Quantitative Risk Analysis

## DEFINITIONS

Dødfiskhåv – Landing net for dead fish

Leppefiskskjuler – Wrasse hider

Merde – Net cage

Orkastnot – Casting net

Hamsterhjul – Antibird net floater

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# 1 INTRODUCTION

## 1.1 Background

The world's population is expected to increase with 2 billion, reaching up to 9.6 billion people by 2050. This leads to a serious challenge when it comes to ensuring food supply, while still preserving natural resources for future generations. Fisheries and aquaculture plays an important role in eliminating hunger, promoting healthy food and reducing poverty. Fish is a natural source to proteins and essential nutrients thus an important part of a healthy diet. Employment in the industry has grown worldwide, providing jobs to a great number of people. Still, it is important to ensure an environmental friendly and sustainable industry as aquaculture is one of the fastest growing food producing sectors (FAO, 2014).

In Norway, fish farming has become a considerable industry on national basis concerning economic value creation, employment and for settlement in rural areas (Norddal, 2010). In an international perspective, Norway is exporting high quality seafood worldwide. In 2013, 1.3 million tons of Atlantic salmon was exported, to a value of 39.8 billion NOK (exposedaquaculture.no, 2015).

The industry has grown substantially since its beginning in the 1970's. What started out as small family businesses has grown to large-scale enterprises. The fish farms were originally placed in sheltered fjords, but as the industry is growing, they are moving further from shore to more exposed areas (exposedaquaculture.no, 2015). The growth has led to huge focus on research and development, leading to a high technological development of the equipment. However, today's operations are still very dependent on manual labour, including daily supervision of the fish and net cage at the floating collars (Utne and Schjølberg, 2014).

Not all aspects of the industry have followed the same development, leaving several challenges to consider. Some of which are risk for environmental damage, injury of personnel, economic losses related to escapes and animal welfare. The environmental concerns is related to the biodiversity, emission of feed and nutrient salts to the sea, spreading diseases, waste products from the fish and so on.

If fish escape from a fish farm, it will have huge consequences for a company, considering the economic loss and the environmental impact such an event may cause. Thus, the companies work hard on preventing these events. To ensure that all barriers perform as they should, the workers may stretch far when it comes to preventing escapes, even if it is on the expense of other factors as personal safety (Fenstad et al., 2009).

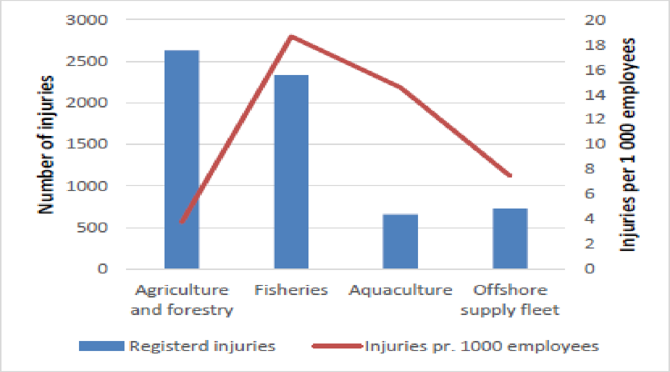


*Figure 1-1 Registered injuries in different occupations. Retrieved from (Holen et al., in prep)*

The aquaculture industry in Norway is met with a strict governmental legislation. The companies have to follow the laws and requirements of four different authorities, the Directorate of Fisheries, the Norwegian Labour Inspection Authority, the Norwegian Food Safety Authority and the County Governor. The authorities supervise the facilities, and give injunctions if they find any violations or deviations (Salomonsen, 2010).

The practice of operation at today’s fish farms exposes the operators to many hazards during a workday. Comparative studies of occupational accident data states that aquaculture has the second highest rate for occupational injuries and fatalities, behind fisheries, but higher than offshore oil and gas supply fleet, presented in figure 1-1 (Holen et al., in prep).

As today’s research raises a lot of focus on moving the production sites further out to more exposed areas, the safety aspect is clearly an important part, as well as maintaining a reliable production (exposedaquaculture.no, 2015).

A more systematic approach to the risk management systems may help to integrate barriers and raising focus on factors that influence the risk in all parts of the operation (Holmen and Thorvaldsen, 2015). A systematic approach to risk assessment is important for understanding all causal connections leading up to hazardous events. It is necessary to identify efficient measures for reducing risk in all operational activities. Quantification of risk levels may be such a measure. Practitioners will have to identify what types of factors that influence the risk of the situations it is desired to avoid, and evaluate how these can be measured (Norddal, 2010).

Not all factors are intuitive when identifying conditions related to the accident sequence, but they can still have significant influence on the probability of the occurrence of an unwanted event. This aspect, gives a rationale for the focus area of this research.

## 1.2 Findings from pre-master Research

The focus of this research is based on the findings from the pre-master research (Nordtvedt, 2015). During the pre-master research, potential methods were reviewed for implementation to fish farming. The motivation of this study was related to the wish of providing improved tool to aid the safety management systems in aquaculture.

The pre-master research included a literature study of risk assessment methods used in other industries and in the research phase. The research included an evaluation of the methods' applicability in fish farming. One of the methods that was considered as having potential for aquaculture was the approach for developing major accident risk indicators (MARI). MARI is primarily developed for the oil and gas industry, but may suit other purposes as well. The approach will be thoroughly described in section 3.5.1.

The thought is that such a model will provide an effective tool for monitoring the risk of an operation based on updated characteristics. Being able to evaluate the risk as the status of the risk influencing factors change has a huge potential as a decision support tool during the planning phase of an operation. Giving the decision maker a better basis for assessing the situation by providing attention to all factors that influence the risk of an operation will potentially simplify their assessment, by allowing a broader perspective.

## 1.3 Significance to the Field

The expected outcome of this research is to provide a further evaluation on the applicability of the model as well an approach that prepare the users for a potential real life test of the model.

If the model turns out to be suitable in the context of sea-based production operations, the idea is that the practitioners will get a reliable tool that will:

- Visualise all influencing factors, providing a broader perspective
- Provide clearer boundaries for safe operations
- Make it easy to follow when factors/parts of the operation are in need of a review
- Involve all parties in the design and development of the safety management
- Decrease stress of the individuals related to the decision-making

The facilities will get an opportunity of integrating a new risk model as a part of the safety management system, which will work as a barrier against working under too hazardous conditions.

## 1.4 Objectives

The objectives of this research is thus to:

(1) Describe relevant research on using indicators to express risk.
(2) Describe important considerations on modelling of influencing factors.
(3) Carry out a case study, describing a common operation at sea-based production sites.
(4) Based on the findings in the case study, suggest an approach to develop a risk model that aims to raise awareness on the impact of risk influencing factors to support decision makers in the planning phase of an operation.
(5) Evaluate feasibility of a further implementation of the model at fish farms, including recommendations to an approach to future testing and range of application.

## 1.5 Scope and Limitations

To narrow down the scope of the research, limitations were set. In addition, factors as lack of data limited the research. All relevant limitations of the research is described in the following list:

- The research only considered the aspect of personal safety at sea-based fish farming facilities. Land-based facilities and other safety challenges were not considered.
- Time-limitation of the research did not allow an in-depth analysis, related to the evaluation of the method. This means that the approach was based on a single operation.
- The evaluation of the operation was carried out on a general level, thus making the evaluation somewhat superficial.
- The lack of available data made it difficult to do any quantitative evaluation of the model, thus only a suggestion to an approach is given.

## 1.6 Structure of the report

The report includes 7 chapters. A short presentation is given in Table 1-1, to give insight to the content.

*Table 1-1 Structure of the report*

| **Chapter** | **Content and purpose** |
|---|---|
| **1** | *Introduction* – Describing the background of the research to motivate the research focus. Describing the research objectives, scope and limitations. |
| **2** | *Method* – Presenting the approach of the research and describing all methods used when retrieving information. |
| **3** | *Theoretical background* – Describing important background knowledge and relevant aspects related to the research. Answering objective (1) and (2). |
| **4** | *Case Study* – Presenting the case operation of which the model is applied. Covering objective (3). |
| **5** | *Development of risk model* – Describing the approach for developing the model and for preparing the model to further testing. Covering objective (4). |
| **6** | *Discussion* – Evaluating the result from chapter 5 as well as considering further preparations necessary for testing the model, its uncertainties and range of application. Covering objective (5). |
| **7** | *Conclusion and recommendations to further work* – Recommending further work related to the research's results. |

# 2 METHOD

## 2.1 Introduction

This chapter aims to provide an explanation of how the research has been conducted and what it contains. This allows the work to be reproduced and gives the reader a holistic understanding of the process and the chosen methods.

Section 2.3 and 2.4 presents the literature study and case study, as they are two main parts of this research. Each section contains an assessment of the strength and weaknesses of the chosen methods.

## 2.2 Approach

Figure 2-1 illustrates the work process through the thesis. The research was an iterative process where regular meetings and discussions with the supervisors, as well as the researcher's assessment, continuously improved the work. The development of the model was a time-consuming part of the research, as it was important to obtain enough information about the case to ensure trustworthy results.

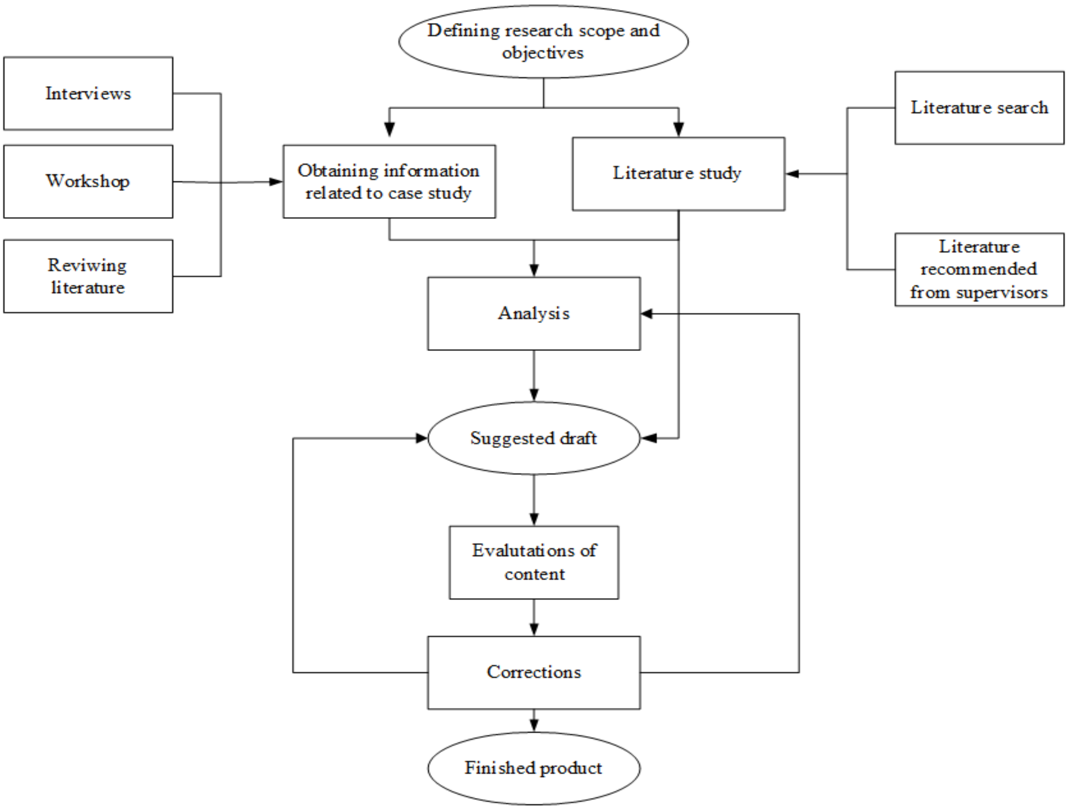


*Figure 2-1 Flowchart of work process*

## 2.3 Literature Study

Karlsson (2009) expresses that review of academic literature in the field of interest is a fundamental part of academic research. It will provide an understanding of the project's possible contribution to the context of research and help to narrow down the scope. By studying relevant literature, subjective knowledge is provided, which is important before reviewing the result of the case study analysis.

The literature study in this research aims to provide important background knowledge of the context as well as to answer two of the research questions. In this section, the approach for searching after literature is presented first, then a evaluation of the relevance of the literature follows.

### 2.3.1 Search Method

The literature study was performed by following the listed approaches (not presented chronologic):

a) Literature retrieved from SINTEF Fisheries and Aquaculture, recommended from one of the project's supervisors
b) Searching for relevant literature using key search words
c) Retrieving relevant literature from the project thesis
d) Finding relevant articles using snowball sampling

Considering point (b), the search for literature consisted of using well-known search engines as Google Scholar, Science Direct and Oria. When searching for literature, a set of key search words were used, both individually and combined. The most relevant key search words are presented in Table 2-1.

*Table 2-1 Key search words*

| | |
|---|---|
| Indicators | Risk<br>Indicators<br>Aquaculture |
| Factors | Organisational<br>Human<br>Factors<br>Modelling |
| Aquaculture | Hazards<br>Risk matrix<br>Risk assessments |
| Crane | Failure modes |

Snowball sampling (d) is explained by Noy (2008) as a process where the researcher accesses articles through the information provided by other researchers. I.e., accessing information through the references of relevant articles. This approach is relevant in this research as it was used, both considering the point (a), (b) and (c) to find a wider range of relevant literature in the topics of interest.

### 2.3.2 Assessment of Literature Study

The relevance for the research topic was evaluated for every chosen article. To be sure that the articles were of good quality, they were chosen with the pre-requisite of being peer-reviewed, but some were also gathered from SINTEF Fisheries and Aquaculture and recommended of one of the supervisors. Since SINTEF Fisheries and Aquaculture is a research institution, they should be objective in their work, which causes subjectivity to not be considered as an issue. The problem of being subjective could also concern the snowball sampling approach. Still, this concern is not of a great importance and should not affect the validity of the results.

## 2.4 Case Study

Using case studies is reviewed as a powerful research method (Karlsson, 2009). Case studies are applied in many situations and they are used to contribute to the practitioners knowledge of individual group, organisational , social, political and related phenomena (Yin, 2009). It can provide holistic and essential characteristics of real-life events to the researchers and readers.

The case study in this research contains two main parts: A description of the chosen operation (chapter 4) and a development of a risk model for the case operation (chapter 5). A qualitative analysis was performed, such that the researcher was able to understand the complex case operation and describe it in a detailed manner. This is further elaborated in section 2.4.1. A description of the development of the model is given in section 2.4.2, and finally an assessment of the process of performing the case study is presented in section 2.4.3.

### 2.4.1 Describing the Case Operation

The chosen case operation was described with thorough details to provide a holistic overview of the situation of which the risk model should be applied. As well as gaining an understanding of the related safety challenges in a common operation in sea-based aquaculture.

To be able to describe the operation, a combination of the following points were considered:

- SINTEF reports describing operations
- Literature search (Presented in chapter 3)
- Confident procedures from two different companies (Procedure–list + Safe Job Analysis)
- Interviews
- Attending workshop

The procedure of the interviews and a description of the workshop follows below.

To validate the description of the case study as well as identifying influencing factors for the chosen hazardous events, a semi-structured qualitative interview was carried out. Semi-structured interviews should be based on a prepared interview guide, but allows the conversation to stray from the guidelines if it feels appropriate (Cohen and Crabtree, 2006).

Each interview was carried out through a phone call. Four informants from the industry were interviewed, which held the following positions:

- HSE manager
- Quality manager
- Service boat operator
- Safety delegate

The number of interview objects is low, but it is still considered as a useful part of the analysis.

During the research period, the author got the chance of attending a workshop with safety delegates from a fish farming company. Safety challenges within the company was discussed and the topic of this thesis was presented. This was highly informative for the researcher, as it provided insight to important safety challenges related to daily operations at fish farms.

### 2.4.2 Developing the Risk Model

Development of the risk model was based on a method called MARI, as motivated from the project thesis, mentioned in section 1.2. A thorough description of the method is given in section 3.5.1.

In a simplified manner, the method consist of five main steps:

1) Identify types of accidents (hazardous events) and determine the most critical ones
2) Identify all influencing factors and determine the most critical ones
3) Structure all the relevant factors in a network showing the interconnections (Bayesian Networks, described in section 3.5.2)
4) Identify suitable indicators that will be used to address the status of the relevant factors
5) Preforming a quantitative analysis of the factors, using a Conditional Probability Table (Described in section 3.5.3)

In chapter 5, these steps are implemented to the case operation.

### 2.4.3 Assessment of Chosen Approach on Case Study

Adapting the method to a case study was performed to get a relevant example of the application of the model and to gain a broader understanding before evaluating the model’s further feasibility for fish farming operations.

The MARI approach was chosen because it is an easily understandable tool for visualising important causal factors and interconnections, which can support the decision-makers in the daily operational context. This may provide support to the operators, which will decrease stress of making decisions when operating on the limits of what is considered as safe operation.

On the other hand, there are some limitations regarding the method, as it has the prospect of being both time demanding and complex to implement. This will be important factors to evaluate in comparison to the benefits, and will be discussed in section 6.4.

Weaknesses of the implementation of the case study is the purely qualitative level of investigation. This has to with the scope and time-limitations of the research.

# 3 THEORETICAL BACKGROUND

## 3.1 Introduction

This chapter will provide an understanding of the terms and aspects considered in this project. The topics are carefully chosen based on an evaluation on what was consider as being useful knowledge when developing and evaluating the model.

## 3.2 Relevant Key Terms Related to Risk Management

Risk management is defined by Rausand (2011) as: " A continuous management process with the objective to identify, analyse and assess potential hazards in a system or related to an activity and to identify and introduce risk control measures to eliminate or reduce potential harms to people, the environment or other assets."

The means of risk management comprise of performing an assessment of the risk a system and deciding which risk control measures to implement. Figure 3-1 presents how risk analysis, risk evaluation and risk control are linked together in a loop. Risk management is a continuous process, which, as stated by Rausand (2011) often contains six elements; identify, analyse, plan, track and control.

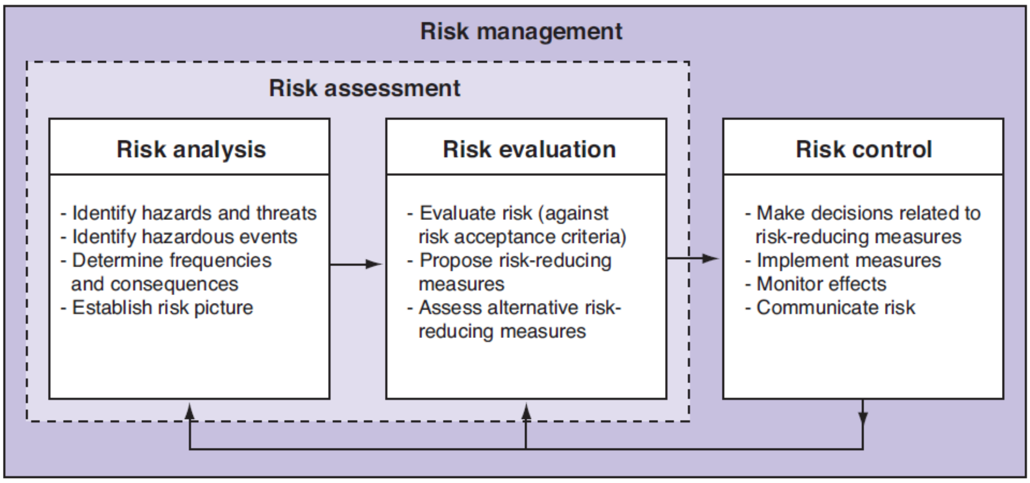


*Figure 3-1 Risk management process. Retrieved from Rausand (2011)*

It is important to understand that risk assessments should never be performed singularly to satisfy requirements from regulatory authorities. The users should rather carry out the assessments for the purpose of providing knowledge to aid the decision-maker. The decision could be related to whether a job should be permitted, or if additional risk reducing measures needs to be implemented (Rausand, 2011).

Risk-informed decision-making is an approach to decision-making where insights to risk of the situation is considered with other factors to establish requirements for the decisions. It aims to focus on that operational issues commensurate with the importance of the aspects of health and safety (Rausand, 2011). This has high relevance to this research as the model, will inform or raise awareness of the workers to support the decision making.

### 3.2.1 Risk Acceptance

The Norwegian standard NS 5814 (2008) defines risk acceptance criteria as: " Criteria used as a basis for decisions about acceptable risk". It can be quantitative or qualitative and based on various criterions, such as legislations, standards, experience, theoretical knowledge or norms (Rausand, 2011). What is acceptable risk in a certain situation will depend on several factors.

Many different approaches are developed for determining what is the acceptable risk in a situation or of a system. One of the most commonly used principles is ALARP. This is a principle for defining the risk acceptance, meaning "as low as reasonably practicable".

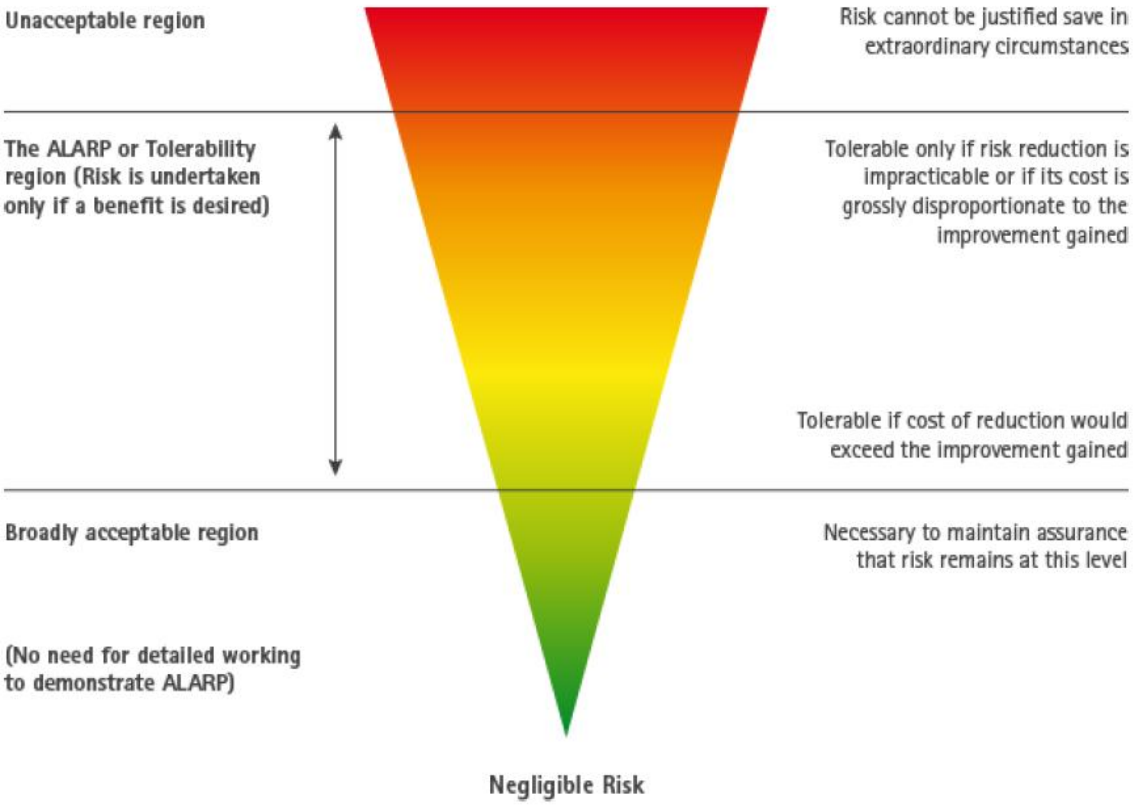


*Figure 3-2 ALARP Principle. Retrieved from Rausand (2011)*

The approach is based on two main concepts. The first is to provide a framework for evaluating risk and risk tolerability. The second is to involve a method for evaluating if the cost of implementing a risk reducing measure is disproportionate to the benefits.

Using ALARP can be explained by reviewing Figure 3-2. The risk is divided into three different levels. The unacceptable region is illustrated at the top of the triangle. In this region, the risk is intolerable and risk reducing measures are essential.  The middle region indicate the level where the benefit of implementing risk measures has to be evaluated up against the cost. The last region, is where the risk is broadly acceptable. Expressing that further risk measures is uneconomical and the resources can be relocated elsewhere.

ALARP is stated as a useful tool for evaluating risk, however it is also recommended that the practitioners interpret the limits of these criteria and us them as guiding benchmarks rather than strict limits (Johansen, 2010).

ALARA is an acronym for “as low as reasonably achievable” and its principle is conceptually similar to ALARP. The difference is that ALARA do not include the region of broadly acceptable risk. The idea of excluding this region is related to the consideration that all risks should be reduced as long as it is reasonable (Johansen, 2010).

The purpose of describing these principles is that it might be valuable to have them in mind when evaluating the potential implementation of a new risk model into fish farming facilities.

## 3.3 Risk and Safety Management in Aquaculture Today

This sections aims to give an understanding of the tools that are used in the aquaculture industry today, to gain knowledge about the environment of which the researcher want to apply a new risk model. Risk management in sea-based fish farming was thoroughly presented in the pre-master project, but as it is of relevance to the content of this report, the most important aspects are briefly mentioned.

Every operation at a fish farm is planned based accessible knowledge about the conditions at the location. The procedures are planned based on the capability of the facility, the costs, and the time limitations for the operation (Moe et al., 2014).

A common method integrated in the safety management systems at fish farms today, is the Safe Job Analysis (SJA). SJA is a simple risk assessment method, used to review job procedures and practices. Usually performed on non routine jobs or new work procedures (Rausand, 2011). At fish farms, SJAs are usually executed before extensive operations involving external service providers, non routine jobs and new practices. This will also be an activity, in relevant operations, where the external service providers meet up with the fish farmers, discussing responsibilities to ensure safe and effective operations.

The most relevant legislation of personal safety management in aquaculture is controlled by the regulation of systematic health, environment and safety work in enterprises, called the internal control requirement (Ministry of Labour and Social Affairs, 2013). The internal control requirements aim to improve the enterprises:

1) Work environment and personal safety
2) Prevention of injuries and environmental disturbance
3) Protection of the environment from pollution

These aspects concern knowledge of the workers, risk assessments, routines for detecting, reporting and monitoring of hazards, violations, and internal control systems.

The introduction of NS9415, requirements for site survey, risk analyses, design, dimensioning, production, installation and operation (Standard Norge, 2009). It is claimed to have led to an increase the technical standard of the equipment of that time and decreasing the number of escapes (Thorvaldsen et al., 2015). In both the internal control requirement and NS9415 it is recommended that all risk assessments should follow the Norwegian Standard of Requirements to risk assessments, NS 5814 (Standard Norge, 2008).

Registration of undesired events is an important aspect of safety management in sea-based fish farming. It is comprised as a part of the requirement to internal control systems. The register will usually contain records of all events or hazards that deviate from normal operation. This concerns near accidents and minor occupational injuries as well as fatal accidents. A challenge in many companies is to make sure that all unwanted events are registered. Surveys show that some workers tend to fix a problem as it occurs, and forget to register it afterwards. Hence, the companies' register may contain underreporting of unknown magnitude (Salomonsen, 2010).

Requirements from customers have led to an increase of certifications in the Norwegian fish farming industry (Holen et al., in prep). A wide range of standards is standards now a common part of the safety management systems at fish farms. The fish farms that want to be certified have to comply with all the requirements stated in these standards. GlobalGAP is an example of such a non-governmental standard, setting requirements to legal compliance, food safety, worker occupational safety, animal welfare, and environmental and ecological care. This standard is becoming more and more common for Norwegian fish farms (GlobalGAP.org, 2016).

## 3.4 Occupational Safety at Fish Farms

It is important to underline that there has been a comprehensive development in the safety management in aquaculture. The companies are considering personal safety as their highest priority and work hard to ensure safe workplaces. However, there may still be situations in daily operational context where the safety guidelines are given less priority in order to reduce economic loss or avoiding unwanted events related to the fish, e.g. escapes (Fenstad et al., 2009).

Norddal (2010) states that sanctions from the authorities seem to be decisive to ensure that safety procedures are followed through in many cases. However, it seem to be some disagreement on this aspect. Fenstad et al. (2009) claim that the industry has shown positive trends the latest years, with more focus on theoretic and safety-focused training. Still, it is claimed that there are tendencies of seeing a gap between the safety practices provided by the administration and the actual procedures at the facilities. Surveys show that by some operators, the safety procedures of daily operations are viewed as redundant and some might even be ignored.

A survey performed by Moe et al. (2014) showed that several fish farmers express that they would like better guidelines to conditions or requirements that need to be fulfilled to carry through an operation.

Large companies have come further than the small actors have, possibly because they have more resources for improving the safety management systems and may have a broader basis for sharing experience of unwanted events (Fenstad et al., 2009).

Holen et al. (in prep) conducted an analysis of occupational accident data. They expressed that today’s production methods expose the operators to several hazards during a workday. This is because many of the current procedures still include tough manual labour. Further stating that the design of the fish farms combined with the current equipment and influence from the environment, increase the likelihood for occupational injuries and fatalities.

A survey done by Sandberg et al. (2012) highlight critical operations in Norwegian fish farming; well boat operations, lice treatment, handling of chemicals and operations involving cranes. Holen et al. (in prep) expressed a list of common sources of hazards, present in some of these operations, shown in Table 3-1.

*Table 3-1 Sources of hazards, adapted from Holen et al. (in prep)*

| | |
|---|---|
| Mechanical types | ○ Moving cranes<br>○ Rotating equipment<br>○ Sharp knives<br>○ Stability problems |
| Environmental | ○ Harsh weather conditions |
| Human | ○ Stress |

Further, Holen et al. (in prep) presented the most common modes of occupational injuries as blow by object, fall, entanglement and electric shock. These findings were based on recordings done by The Norwegian Labour Authority between 2011 and 2013.

Myers' and Durborow 's (2012) survey is slightly older, showing the modes in the years 1980 -1999. Here, the occupational injuries often relate to use of machinery, followed by slips and trips, use of knives and handling of chemicals. They stated hazards for personnel working in sea-based fish farming by five categories. This is simplified and shown in Table 3-2.

*Table 3-2 Hazards at fish farming facilities. Adapted from Myers and Durborow (2012)*

| Category | Hazards |
|---|---|
| Physiological (work design) | Heavy lifts<br>Poor ergonomic modifications (awkward postures, repetitive tasks, prolonged standing) |
| Physical | Slips and falls<br>Transportation (boats, vessels)<br>Machinery<br>Electricity<br>Noise |
| Chemical | Disinfectants<br>Strong medications<br>Flammability |

| | |
|---|---|
| Biological | Sharp teeth<br>Bacteria<br>Parasites |
| Physiological | High demand<br>Tight schedule<br>Low control<br>Exposed to weather |

## 3.5 Methods used in the Development of the Risk Model

Before starting at the case study, it is important with an in-depth understanding of the theoretic background of the methods used to develop the risk model.

The motivation for implementing MARI was introduced in section 1.2, based on the findings in the pre-master research. A more detailed description is given in section 3.5.1. As a part of following the procedure suggested in MARI, relevant risk influencing factors are modelled as Bayesian Networks (BN), which is further described in section 3.5.2, followed by a description of Conditional Probability Tables (CPT) in section 3.5.3. CPT is a prerequisite before performing a quantitative analysis of the BNs.

### 3.5.1 MARI

MARI suggests approaches on how to identify and develop indicators for monitoring the major accident risk of an activity. It shows a structured approach for addressing factors that influence the risk level in a significant matter and therefore need to be monitored or that there are measures that need to be taken.

The main steps were presented in a simplified manner in section 2.4.2. A more thorough description is presented here, as explained by Haugen et al. (2015):

1) Determine the purpose of the indicators and whom the users of the system will be.
2) Identify major accident types, which contribute significantly to risk. It will be natural to base this on a Quantitative Risk Assessment (QRA). Indicators will only be established for the most significant contributors.

   In this research, critical hazardous events were identified and used as basis.
3) For the chosen events, relevant factors that influence the types of events/accidents are identified. Additional factors may be added from a risk assessment.
4) The identification of influencing factors are based on:
   - Preconditions and external factors: e.g. environmental conditions, design of system, regulations, company policies.
   - Planning: e.g. operational practice, maintenance procedures, competence plans.
   - Activity levels: activities comprised in the different operations.
   - Operations and control functions: Performance of the current barriers

   The identified factors comprise both technical, human and organisational risk influencing factors.
5) Factors are structured in a network where they are linked together with one or more arrows. In this research, Bayesian Networks is chosen as a modelling method.
6) Identify suitable indicators, that will be used to monitor the status of the factors that are identified. Indicators are measurable parameters that can say something about the status of the factor.

   In this research, checklists with statements, will work as indicators to determine the factors' state.

A list of methods and approaches that can be used to gain a satisfying overview of the influencing factors are suggested by Seljelid et al. (2012) as follows:

- Using QRAs or other risk assessment methods to identify the most critical events of the activity
- Review current safety barriers in the system/activity
- Governing documents of relevant procedures from the company
- Review the functional and logical relationship between factors
- Review accident investigation reports

MARI should primarily concern the entire process of an operation, comprising several layers of influencing factors. In the model developed in this research, there are three levels of influencing factors, which are further described in the next section.

An example of a modelling of relevant factors, as suggested in MARI is shown in Figure 3-3.

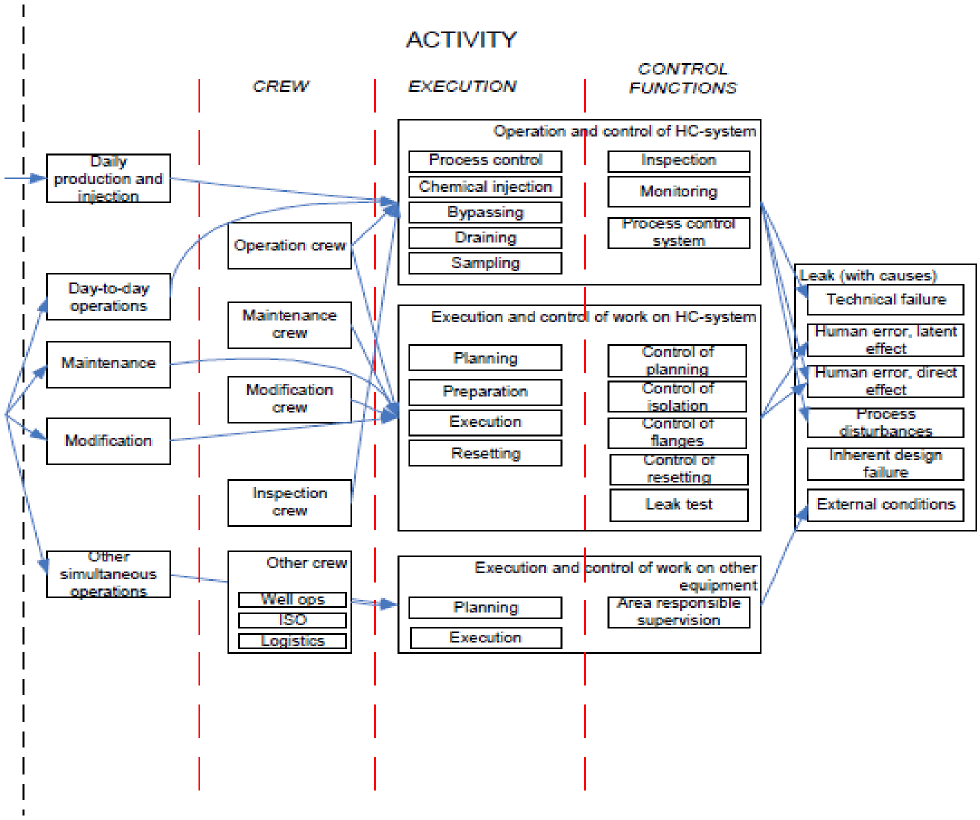


*Figure 3-3 MARI model. Retrieved from Seljelid et al. (2012)*

By applying MARI, the practitioners can get a powerful tool for visualising the interaction and influence of factors (Haugen et al., 2015). It can be used for raising the employees' attention on how the performance of the work they do affect the risk of the operation. The model may also be used actively as a contributor in day-to-day planning, which is the main suggested application considering an implementation to fish farming facilities.

When starting the development of MARI, it is important to have sufficient background knowledge about the system. Providing the basis information, a combination of an inductive and deductive approach may be advantageous. An inductive approach is based on accident investigation reports and statistics of accident types. While a deductive approach is based on the results from risk assessments.

After addressing all the factors, there needs to be a screening to identify the most critical factors. A multidisciplinary team should perform the screening, to ensure good and trustworthy results. The selected set of relevant factors will further be used to compose a model that will be a useful tool for presenting the interactions between the factors and their importance in each level of the operation. The construction of the model is based on the knowledge from methods like Bayesian Networks, showing a hierarchal diagram of the factors. An advantage with this model is the way it works as a visualisation tool, qualitatively showing the influence of direct and indirect factors that may not be very intuitive for the workers involved. (Haugen et al., 2011).

The method's strengths are expressed as its ability to provide a general and qualitative overview, which is useful in many contexts. In addition, the indicators can provide a quantitative basis practitioners can make decisions from. It is underlined also that this may be an approach to provide improved awareness of risk throughout the organisation, by showing how workers' involvement at the organisational level fits to the bigger picture. It takes a wide range of factors into account, and still try to avoid being overly complex. It can be used both on a daily basis, as an active planning tool, or a long-term planning tool by assessing changes in risk levels (Seljelid et al., 2012).

### 3.5.2 Bayesian Networks

Bayesian Network is a graphical method used for causal and frequency analysis. It illustrates the relationship between influencing factors on a hazardous event or accident. Bayesian Networks are popular in risk and reliability analysis (Rausand, 2011).

The Bayesian Network is an acyclic graph, often evaluated together with a set of probability tables. Acyclic means that cycles are not allowed. The influencing factors are referred to as nodes and arrows express the relationship between the different nodes. Each node represent a random variable with discrete distribution. The value of a random variable is referred to as a state of the factor represented by the node. The factors may have two or more states. When one node influence another node, it is called the parent node and the node of influence is called the child node. If it is only these two nodes, the parent node is also called the root node. An important rule is that a node can never be its own ancestor or its own descendant.

It is often distinguished between technical, human and organisational influencing factors.

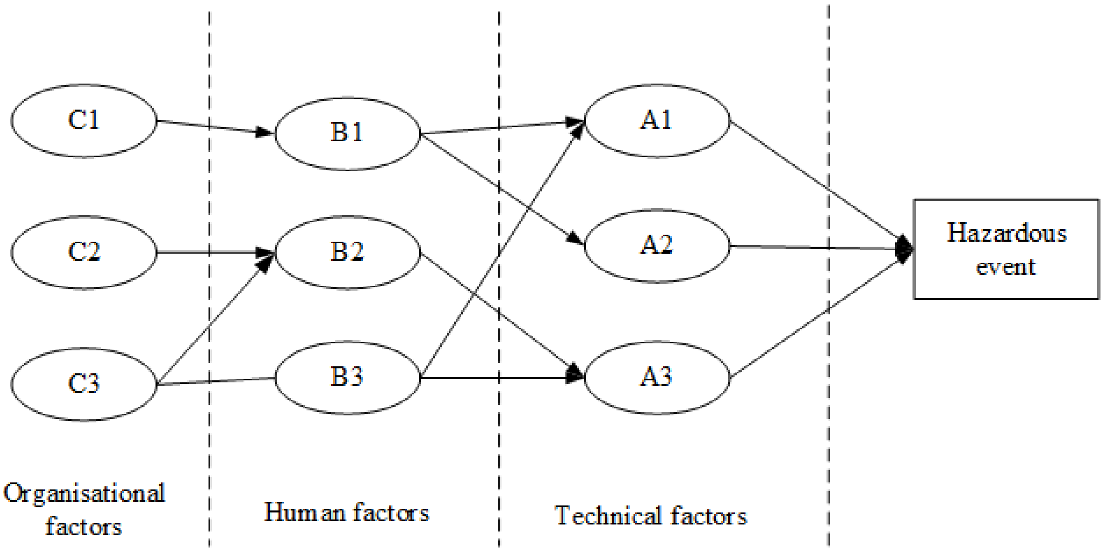


*Figure 3-4 Bayesian Network, Adapted from Rausand (2011)*

Figure 3-4 shows an example of such a case. The figure shows that how the three categories of factors may influence each other and potential hazardous event.

### 3.5.3 Conditional Probability Tables

Before calculating the probabilities of the states of the factors in the Network, it is assumed that each factor is conditionally independent of each other, when the parents' states are known.

Conditional dependence can be explained by an example, taken from Rausand (2011):

Consider the three events K, L, and M. If we know that event M has occurred, event K and event is said to be conditionally dependent, given M if

$$\Pr(K \cap L \mid M) = \Pr(K \mid M) * \Pr(L \mid M)$$

When applying the Bayesian Network to a practical case, the user want to be able to calculate the probability of the critical event and to identify which factors that are the most important contributors to this probability (Rausand, 2011).

Before calculating the probability of the hazardous events, a conditional probability table (CPT) has to be constructed and associated with every node in the network. The conditional probabilities represents the likelihoods based on prior information or experience from past events. The table gives the distribution of variables for each combination of parent states. To make an example, say that the work practice is divided into three different states. Then we want to be able to present how these three different states affect the probability of the event in next level.

The complexity of the CPT will increase with the number of nodes and the number of parents of the given node. The natural way to start constructing the CPT is with the root nodes, and assign probabilities to these. Then the process is continued until the end node is assigned a value. The CPT entries could be based on expert judgement, external sources, and estimations from data or using a combination of these.

The entries will show the probabilities of a node given the state of the influencing factors. Such that if A is a specific event or node and B is the event's only influencing factors, then we can use Bayes formula to describe the probability:

$$\Pr(\mathrm{A}\ |\mathrm{B}) = \frac{\Pr(B \mid A) * \Pr(A)}{\Pr(B)}$$

In this case study however, there is not enough data to give an accurate quantitative analysis. It will rather give an example of how it can be carried through.

As mentioned, the complexity of the CPTs increase with the number of states. It is easily noticeable that the example of this case study forms a quite complex CPT. However, it will be natural that this is constructed using a software.

The users do need to evaluate the probability of the nodes. Reviewing past events and experience would be suitable way to do this. By reviewing a locality's records of all unwanted events, the analyst may gain an overview of number of events related to the different factors.

This might be a wise approach. To report all occurrences that deviate from normal activity is something the fish farming companies strive for. To evaluate the probabilities using past occurrences will certainly involve some uncertainties, but it is difficult to say exact level.

## 3.6 Identifying and Modelling Risk Influencing Factors

This section will present relevant findings in the literature related to modelling of risk influencing factors. The available research on how human and organisational factors may influence the operations is relevant to consider prior of developing the model.

### 3.6.1 Identifying Influencing Factors

A holistic and systematic understanding of safety is an important aspect of a safety management system at any enterprise. Involved parties should have an understanding of the fact that several operational factors may be underlying in the causal chain of an unwanted event and are therefore important to consider (Fenstad et al., 2009).

Thorvaldsen et al. (2015)  identify causes of escape accidents at Norwegian fish farms with a focus on organisational factors. As the equipment develops and the frequency of structural failures on fish farms decrease, human errors and operational factors have been highlighted as a challenge when preventing escapes. However, the term human error may be too accusatory of the individual and one should rather focus on the bigger picture and underlying organisational aspects. The article express that accidents may be prevented by improved technology and a focus on organisation of work, communication, skills and experience, workers' sense of responsibility, learning and safety perception. The degree workers feel that economic profit is prioritised before workers safety is important to consider as well (Fenstad et. al, 2009, as cited by Thorvaldsen et al., 2015).

Wachter and Yorio (2013) consider different approaches on how to improve the safety management of organisations. Many accident reports will accuse human error as solely being the reason of an unsafe event's occurrence, which is stated as a misguiding and inaccurate claim. Wachter and Yorio (2013) point at several tools for reducing the chance of human error. Such as "pre-and-post–task briefings", "performing peer-checklists" among others and awareness approaches like "take-a-minute". An important aspect is stated as the worker's engagement to safety. Their survey showed a significant correlation in the safety management systems on the workers’ engagement and safety performance outcomes. Thus, backing up interest for having a tool that raise awareness to critical factors and states.

Holen (2015) considers how operators on fish farms and involved service providers perceive risk and how their communication practices work. Investigation on fatal accidents in fish farming shows that lack in competence related to hazards during the operation is a clear contributing factor (AIBN, 2014, 2015, as cited by Holen, 2015). A challenge in some situations may be the external actors, as operators from the service providers, perceive risk differently than the workers from the fish farms. This problem is usually solved by performing SJA prior of the operation. The involved parties will use these meetings to clarify all hazards.

Human fatigue is a factor that is difficult to measure, but will certainly affect the performance of the workers. A study of offshore fleet workers done by Hansen et al. (2010) concluded that long working hours with few breaks on moving platforms affect both physical and cognitive performance. This is perceived as relatable to the fish farming industry by Thorvaldsen et al. (2015), expressing that it is likely that long working hours and little sleep will affect the fish farmers safety performance in intensive working-periods or during long lasting and demanding operations.

### 3.6.2 Modelling Risk Influencing Factors

Rasmussen’s (1997) research focused on risk management in a dynamic society. As shown by Figure 3-5, he presents the socio-technical system involved in safety management. The system illustrates how complex modelling socio-technical systems is, and how the different actors in a dynamic system affect each other.

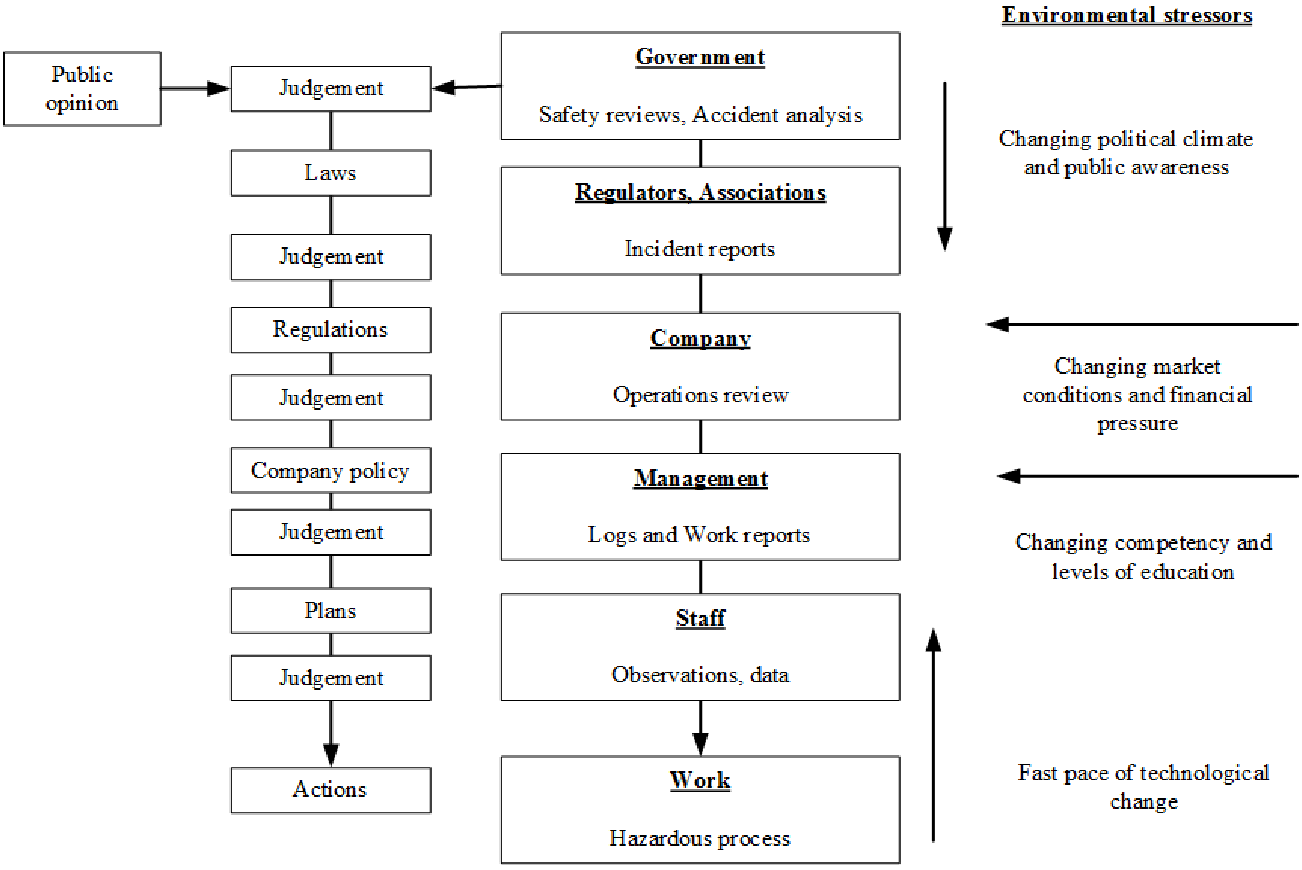


*Figure 3-5 Socio-technical system involved in risk management. Adapted from Rasmussen (1997)*

Kongsvik et al. (2010) discuss to which extent indicators can represent organisational factors in relation to safety and how the method called Operational Safety Condition (OSC) may be a resource to the safety management system. The discussion is related to weaknesses of correlations between indicators or factors and the safety performance of the systems of consideration. It is stated that these correlations are often weak due to layers of intervening factors and conditions making it difficult to point at single effects or causes that relates to safety. Many resources will be needed to express the causal connections of socio-technical systems. This relates to the Figure 3-5, adapted from Rasmussen (1997). As accidents often will have complex origins, apprehending this complexity trough indicators is a demanding task. Organisational factors will influence each other in addition to other factors like technical factors, making it harder to identify causal chains.

Kongsvik et al. (2010) state that OSC is a suitable tool for capturing the complexity of organisational factors.  Hazards that are difficult to identify may be potential unknown connections between organisational factors. Qualitative approaches may provide valuable information about this, and is important to evaluate. OSC is a method developed for the purpose of monitoring operational safety barriers (Sklet et al., 2010). The method divides the organisational safety barriers into 7 different categories; work practice, competence, procedures and documentation, communication, workload and physical working environment.

Measuring or evaluating human and organisational factors are not an easy task, as these are dynamic factors. The implementation of OSC require dedication and careful performance of each of the steps comprising the method. This is due to be sure of having trustworthy results. By going through relevant data in combination with experienced personnel, observations related to the performance level of the barriers are made, before evaluating and assigning the relevant barriers a grading.  The grading will indicate how the barrier may deviate from a desired reference value, being best practice.

The authors of the OSC report discuss the quality of their method based on a generic list of requirements for measuring instruments in science (Hale, 2009, as cited by Sklet et al., 2010). This list include the following aspects:

1) Validity
2) Reliability
3) Sensitivity
4) Representativeness
5) Openness to bias
6) Cost-effectiveness

The strongest argument against implementing the method is that it is time-consuming and hence costly. Still, it is recommended as a qualitative tool that is systematic and independent. It can provide basis to suggestions, decisions and implementation of risk reducing measures to improve the existing operational safety barriers with a focus on the most critical factors.

### 3.7 Monitoring Risk Levels

In the oil and gas industry, there has been a growing interest for developing indicators to monitor the risk of fatal accidents for high risk activities and installations over the last few years (Seljelid et al., 2012). In the development of the risk model in this thesis, it is of interest to use indicators to monitor the status of the influencing factors. However, this will not be on a continuous level, but rather with updated characteristics for an upcoming operation. Hence, reviewing research related to this topic is of interest. Indicators were also mentioned in relation to a relevant approach for modelling organisational factors in section 3.6.2, used to monitor the performance of safety barriers.

Norddal (2010) carried through a project with the purpose of developing a risk model for aquaculture production sites. They looked at the whole value chain of the fish farming industry, trying to develop a set of indicators. The approach they used for developing the indicators is based on describing a set of factors as detailed as possible. The indicators should all be independent of each other and should be possible to assign a score by asking a set of questions describing its properties. A table for providing score to the indicators is suggested. Norddal (2010) recommends that an analysis of events related to personal injuries are carried through. This should further be used to select an accident classification.

Using a multi-disciplinary team, Norddal (2010) has set a list of requirements to risk indicators:

1) They should be able to describe the indicator with high precision.
2) Each indicator is independent from the others.
3) It should be possible to quantify the indicator, by answering questions describing its characteristics.

The approach Norddal (2010) uses is mainly developed for the purpose of preventing escapes of fish. Regarding personal safety indicators, the results are rather limited and Norddal (2010) have no model to show any connections between the factors they wish to indicate the state of. Norddal (2010) explains that the data is not edited to be suitable as a base for developing satisfying risk indicators, claiming that providing a suitable risk indicators for personal safety will require an extensive amount of details.

Tidemann et al. (2011) did research on implementation of a system that is based on so-called Case Based Reasoning (CBR). The main foundation of the system is to retrieve information from a situation and store it, which may help gain experience. This is further used for problem solving when a new situation occur. Its intention is to decrease the gap between human expertise and low-sensor data, functioning as a decision-support system. They underline that the development of such a system will require tight cooperation between users, human experts, knowledge engineers and system developers. The way of combining low sensor data and experience from past cases has successfully been implemented in the oil and gas industry, used to monitor drilling oil wells.  It also expressed that the system has the potential of predicting potential future trends.

## 3.8 Summary

This chapter provides  necessary background knowledge for further evaluation of the content of this thesis as well as assessing research done on relevant topics.

To understand the context of application for the model, risk management practices in fish farming are described, along with the safety challenges related to personal safety. Further, the relevant methods used to develop the risk model, are thoroughly presented, assuring a total understanding of the techniques. This includes the concepts of MARI, Bayesian Networks and conditional probability tables.

The last part of the theoretic background, comprised by section 3.6 and 3.7, evaluates concepts related to developing a risk model. This concerns the importance of capturing the complexity of the human and organisational factors when modelling a complex and dynamic system, as well as research on using indicators to monitor the risk level of a system.

# 4 CASE OPERATION

## 4.1 Introduction

To assess the potential for implementing a new tool for risk assessment of sea-based aquaculture production, it is of vital importance to use a concrete case example from the industry. The case should comprise critical tasks of the operation of fish farms, to assure that the assessment is as reliable as possible. A detailed description of this operation is presented to ensure a holistic understanding of the background for choosing the risk influencing factors.

Crowding of fish was chosen for the case study. This is a common operation, performed with regular intervals at a fish farm. Crowding involves a set of critical tasks and the use of cranes is one of them (Holmen and Thorvaldsen, 2015).

The description is based on information gathered through:

- Reviewing internal memos and reports from SINTEF Fisheries and Aquaculture, by Mjøsund (2014) and Moe et al. (2014)
- Reviewing reports on experience from the industry (Fiskeridirektoratet, 2016)
- Qualitatively obtaining information through the interviews and workshop

## 4.2 Motivation

Choosing an operation for the case study was based on a set of requirements. The operation has to be relatively complex, but not overly complicated. As crowding consist of several tasks, it is easily divided into several levels of activities.

Handling of cranes have been identified as a critical task (Holen et al., in prep). Cranes are a common tool in aquaculture production operations and thus a highly relevant task to include. Therefore, it was an advantage that cranes are used in almost all of the sub-tasks of the crowding procedure.

## 4.3 Description of Case

Crowding is a complex operation, carried out in several steps. It is performed to relocate the fish. This may be for transportation to slaughterhouses, delousing operations or internal relocation of the fish. Different techniques are used depending on the purpose, related to how much of the biomass the fish farmers plan to move. Take transportation of fish to a slaughterhouse as an example. In this case, it is necessary to empty the net cage completely.

The first stage is preparing the net for unloading fish. This involves removing loose components, such as the antibird net, the wrasse hider and cameras. When the net is prepared, the crowding can start. This will usually comprise, use of a casting net in several rounds. When it is necessary, the sinker tube will be lifted to force the fish further up to the surface, making it more accessible for the casting net. To completely empty the net, a sphere chain is used. For the purpose of this analysis, only crowding with casting net will be included. The operation in its entirety is still explained in the following to give a complete overview of what crowding means. Hazards related to each step is briefly commented.

1) *Removing the antibird net*

   All ropes tied to the antibird net have to be undone, before using the cranes and manual work to haul the net on board the workboat (could be several practices). Fish can easily get stuck in the net while performing this task, making this a bothersome and difficult task. There are hazards related to the use of cranes and potential human fatigue.

2) *Removing the wrasse hider*

   This wrasse hider is working as a shelter for the cleanerfish in the net cage. The size of the hider varies between facilities. Some are light and can be removed manually, while others are kept down with weights and have to be removed using cranes. Winches are used for pulling the hiders to one of the net cage's sides.

   There are several hazards related to this step. One of them, being the use of cranes. The weights at the bottom of the hiders is a hazard related to crush-accidents and the use of the winch for pulling the hiders involves hazard of entanglement of hands or fingers.

3) *Removing camera equipment*

   Before removing the camera equipment, it is important to make sure the cable to the camera is not entangled into the landing net for dead fish. The hazards related to this step concern the use of cranes, as well as entanglement.

4) *Lifting weight and dead fish landing net*

The dead fish landing net is pulled to the surface and connected to one side of the net cage to avoid disturbing the task. Using winches and cranes, the weight is lifted. A winch is used to pull the weight to the surface and then cranes are used to lift the weight on board the workboat deck or to tie it securely to the floating ring. The weight of the load varies.

Related hazards to this step are the use of cranes and winches. If the rope is somehow swirled, one have to use cranes to get the weight all the way up to the surface. The rope holding the weight is normally very long which means that it has to be lifted through several steps and by using lifting straps.

Using the capstans involves a risk for entanglement of fingers and hands. Using cranes expose personnel to risk of entanglement and blow by object. When the lifting straps are utilised, there is an additional hazard in attaching the lifting straps correctly. This can increase the risk of dropping lifted object.

5) *Mooring of well boat*

The well boat will usually moor at the side of the net cage that is most suitable taking into account location of feeding tubes, electric cables and so on. The dimensions of the net cage it self will also be an important factor to take into account.

Examples of problems related to mooring can be ropes disturbing the pavement on the floating ring, increasing the risk of slips and lapses. Wrong position of the well boat considering current, may cause the net to drift into the propeller, damaging the net.

6) *Putting out the casting net*

Casting net is set out by the workboat on the opposite side of the net cage from where the well boat is moored. The net is usually assembled with straps to make it more manoeuvrable. The top of the casting net is pulled along one of the sides of the net cage. One rope is connected to the workboat to haul the casting net back on the boat after finishing. Three ropes are connected to the net haulers at the well boat and to the weighted bottom of the casting net. one to each corner and one in the middle. By using the cranes on the well boat, the casting net is lifted. Usually starting with one corner and then moving further in. As the net is lifted, workers have to haul the net in and connect it to hooks at the floating ring to avoid entanglement of the net.

*Figure 4-1 Placement of casting net. Retrieved from Fiskeridirektoratet (2016)*

Hazards related to this could be potential entanglements with the casting net. If the casting net was not properly assembled the last time it was used, one may have problems. The task gets complicated and bothersome if the casting net is entangled.

The floating corks, connected to one side of the casting net, may get stuck in the floater for the antibird net. Some choose to remove them, but as they are often quite large, it will involve hazards for crushing injuries.

Lifting the net can be very tough physically and not good for the workers’ shoulders, back and tendons, causing this step to involve hazards for human fatigue.

A hazard related to lifting the casting net, is the personnel removing/cutting the straps when catching the net, which are especially exposed to potential blow by objects. If the straps are not tied as they should, this will increase the risk for dropping the load in this case. Lack in communication between personnel at the workboat steering the cranes and the worker standing on the floating ring is an important factor to have in mind here.

The capstans on the well boat create a risk for crushing fingers as the ropes connected to the casting net are very heavy. A potential tear of the rope is a present hazard in this step.

7) *Lifting sinker tube*

If the purpose is to empty the net completely, the workers will need to lift the sinker tube. The sinker tube will be lifted to force the fish up to the surface and make it more available for the casting net. This is a very time consuming task and it involves heavy repetitive lifting. Some sinker tubes are made of hard materials, and this makes the tube stiffer and heavier at each lifting point.

Hazards at this step is crush injuries related to using the cranes. Swinging loads, while lifting the chains increase the hazard of blow by object. If the boat is small or unstable, extensive movement can form a hazard by influencing the movement of the lifted object.

8) *Connecting ropes to sinker tube chains*

When tightening the ropes connected to the sinker tube chains, it is important to avoid that they get entangled in the propeller or the sinker tube. Cranes or winches may be used for this purpose.

9) *Setting out sphere chains*

When almost all of the biomass in the net cage is removed, sphere chains are used to make the remaining biomass accessible for the well boat. This involves that the sinker tube and the connecting ropes are lifted all the way up to the surface. Then the sphere chain is pulled on the back edge of the net cage such that it will get under the ropes connected to the sinker tube. When the sphere chain is placed, the crowding can start, using capstans and cranes on board the well boat. The hazards here are similar to what has been mentioned for the previous steps.

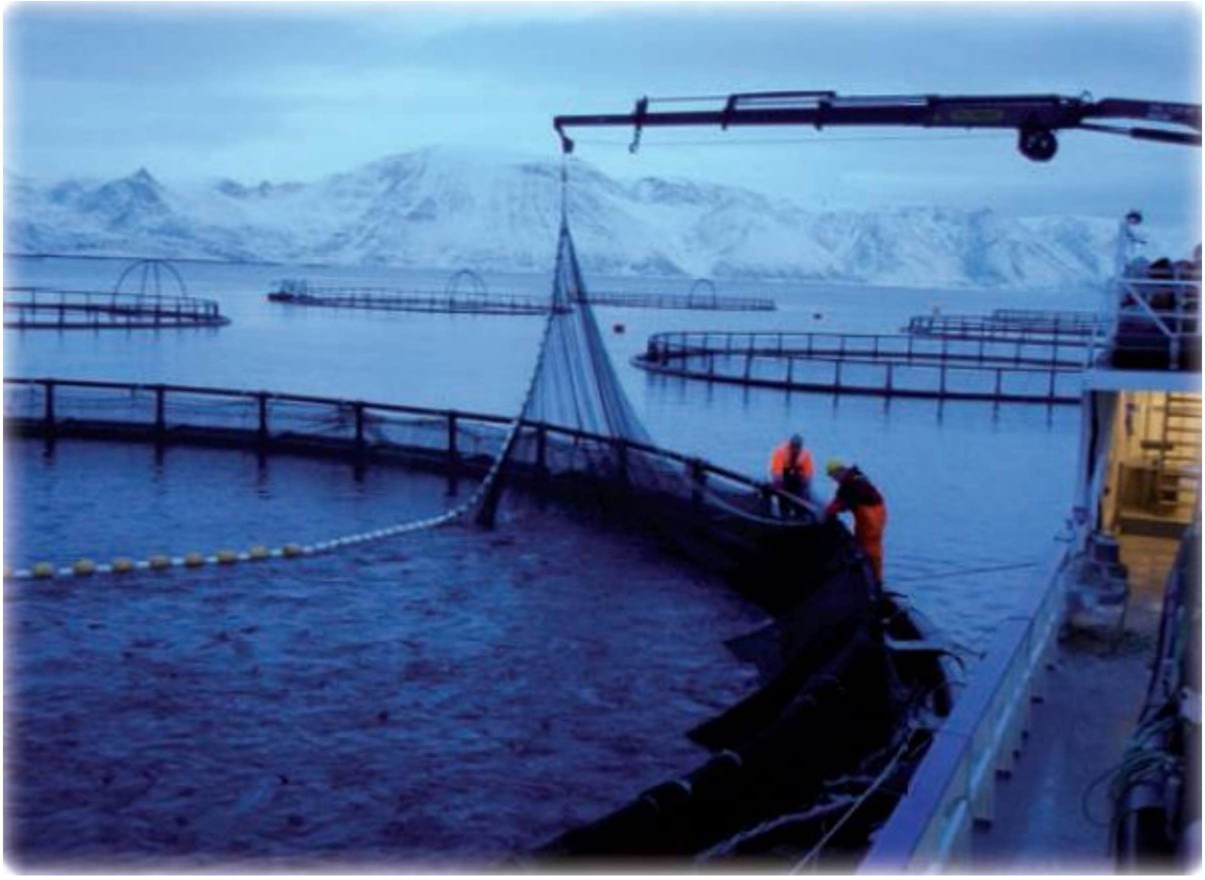


*Figure 4-2  Crowding with casting net. Retrieved from Fiskeridirektoratet (2016)*

### 4.3.1 Crowding with Casting Net

To illustrate the process of crowding with simplifications related to this study, a method called Sequential Timed Events Plotting (STEP) is used. The STEP diagram visualise the interaction between the involved actors and how they are involved in each step of the process. STEP is usually performed as a part of accident investigation, but it can also be used for the purpose of describing a process or operation (Hendrick and Benner, 1986). The diagram can be seen in Figure 4-3. The actors are listed on the left side of the diagram, where each is assigned to its own box. The boxes in the middle of the figure states different activities of the operation. The boxes are arranged after their occurrence along the timeline, starting at the left side evolving to the right to the end event. Arcs assigns subsequent activity.

As seen in the diagram, the simplified description assumes that the well boat is moored at the net cage's side and that all of the other preparations are finished.

To summarise the detailed description, the main concept is shortly repeated in the following.

The workboat set out the casting net using cranes. Personnel will be standing on the floating ring catching the net and cutting of straps holding the net tied together. One rope is connected to the top of the net and to the workboat. This will be used to drag the net back to the workboat when the task is finished.

The other end of the net is weighted to force the net cage to sink. At this side, three ropes are connected. One at each side and one in the middle. These ropes are again connected to capstans on the deck of the well boat.

Using one of the cranes on the well boat’s deck one side of the casting net’s side is lifted and the crowding process starts. The crane will lift further into the middle of the net as the fish is pumped into the hose leading to the well boat.

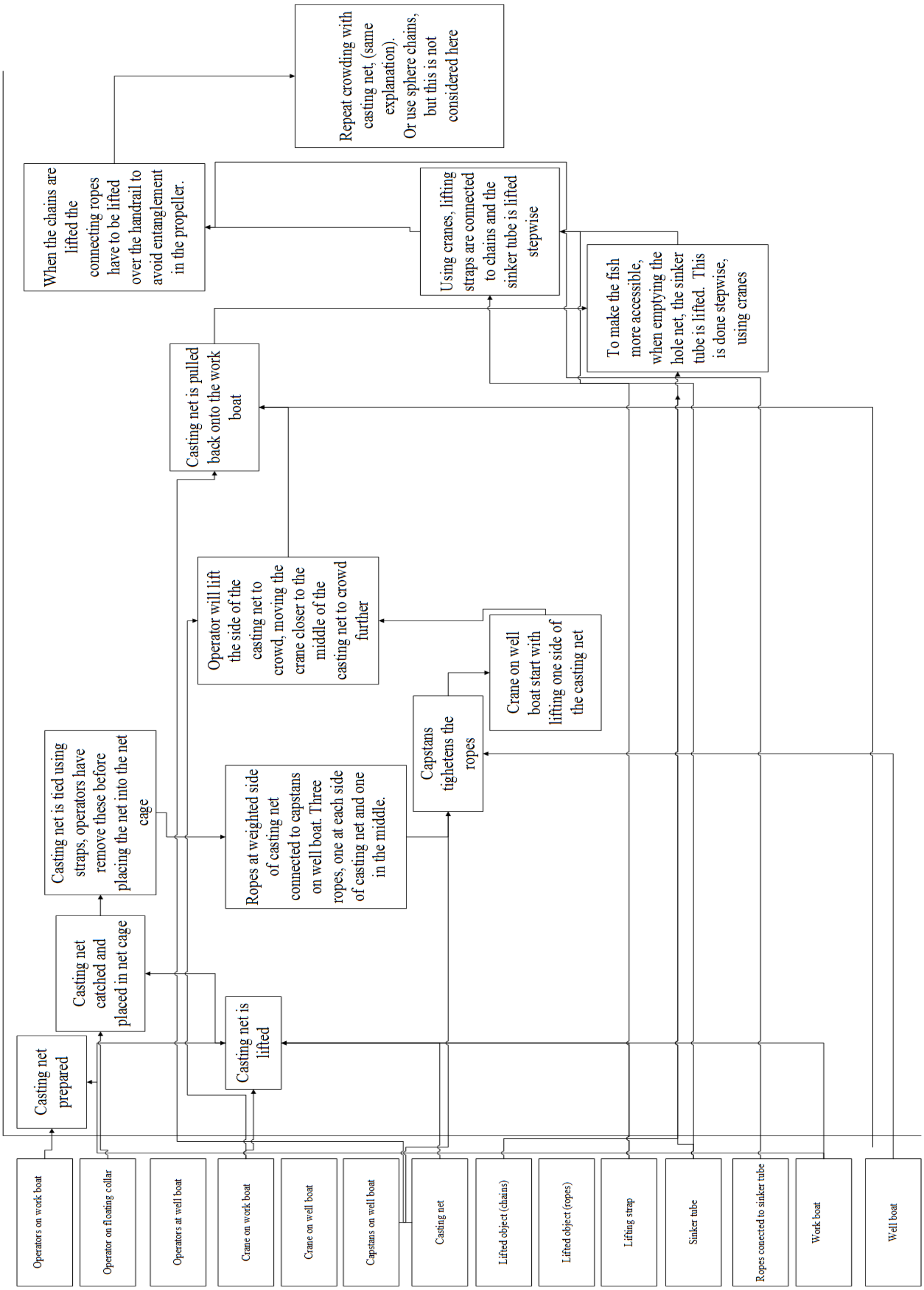


*Figure 4-3 STEP-model of case operation*

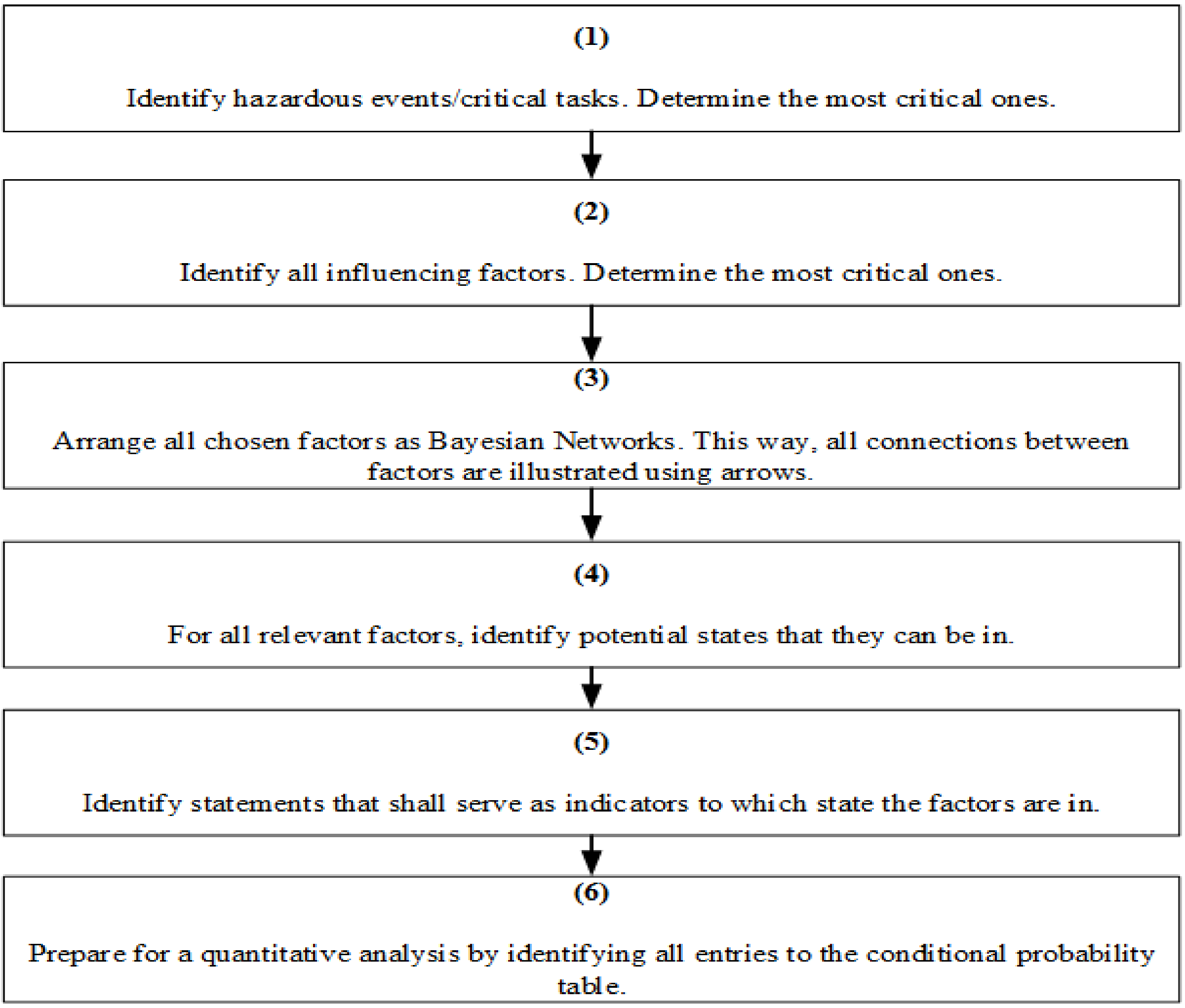
# 5 DEVELOPMENT OF RISK MODEL

## 5.1 Introduction

The thorough description of the case presented in chapter 4, is used as a basis for developing the risk model that will be presented in this chapter.

The case study was carried through on a general level, such that the collected data is limited and the results will be somewhat superficial. This is due to the scope and time limitations of the report.

One of this research’s objectives is to provide an approach for developing a risk model, and this will be covered in this chapter. Figure 5-1 presents the simplified steps when following the MARI approach. This should also give a good grasp of the structure of the chapter, as the following sections will follow these steps.



**(1)**
Identify hazardous events/critical tasks. Determine the most critical ones.

**(2)**
Identify all influencing factors. Determine the most critical ones.

**(3)**
Arrange all chosen factors as Bayesian Networks. This way, all connections between factors are illustrated using arrows.

**(4)**
For all relevant factors, identify potential states that they can be in.

**(5)**
Identify statements that shall serve as indicators to which state the factors are in.

**(6)**
Prepare for a quantitative analysis by identifying all entries to the conditional probability table.

*Figure 5-1 Development of risk model in steps*

## 5.2 Choosing Hazardous Events

Following the approach from figure 5-1, the first step is to define hazardous events. In the theoretical background of MARI in section 3.5.1, it was explained that after assessing the relevant knowledge of the considered system, the users should determine critical areas of the system. With the basis from the case operation crowding and the critical areas, a set of hazardous events are identified. This is an important part of the analysis, as it will form a basis for development of the entire model.

A hazardous event is defined by (Rausand, 2011) as: “ the first event in a sequence of events that, if not controlled, will lead to harm to some asset”. The hazardous events can be seen in table 5-1. Further, all influencing factors are identified and the most critical ones are used as basis for constructing the diagrams.

*Table 5-1 Hazardous events*

| Resource | Hazardous events |
|---|---|
| Crane | Dropped load<br>Swinging load |
| Capstans/winches | Hands/fingers at wrong place |
| Personnel at floating ring and deck of workboat. | Slips/lapses |

The evaluation process behind the identification of critical tasks, hazardous events and risk influencing factors includes:

- Evaluation of accident number and statistics of unwanted events related to relevant tasks, (Holen et al., in prep, Sandberg et al., 2012)
- Feedback from experienced personnel operation (interviews and workshop)
- Evaluation of theoretical description of the case by Mjøsund (2014) , Moe et al. (2014)
- Evaluation of descriptions of failure modes of cranes (BAE Systems, 2002)

The feedback is somewhat superficial as the personnel did not have the time or chance to evaluate it in depth. The feedback is still an important validation of the content. This will be an important part of further evaluations and adaptions of the model.

## 5.3 Identifying Factors

When all risk influencing factors are identified, the most relevant ones are chosen to use for further modelling. Table 5-2 lists all the identified risk influencing factors for all four of the hazardous events. The table only shows the factor once, such that factors that are similar for several events will only be listed under the first event in the list where it is relevant. The root causes of the hazardous events are almost identical, thus these are only described under the event "dropped load". * Direct cause (Parent node), ** Indirect cause (Grandparent node), ***Root cause (Ancestor node)

*Table 5-2 Description of factors*

| **Factor** | **Description** |
|---|---|
| | **Dropped load** |
| Lifting strap tears* | Direct cause of a dropping load |
| Hook fails/breaks during lift* | Direct cause of a dropping load |
| Structural failure of crane – detached boom* | Direct cause of a dropping load |
| Failure in brake system* | Direct cause of a dropping load |
| Failure in hydraulic hose** | Technical failure, which may stop the crane from working |
| Degradation of equipment** | Concerning aspects as fatigue, corrosion and damage |
| Unexpected motion of crane * | Direct cause of a dropping load |
| Disturbance from personnel** | Concerning interruptions during the operation that may lead to an increase in risk of a hazardous event |
| Human error – Operating the crane wrong** | Can be caused by several factor related to human interaction with technology or in other aspects of the operation |
| Insufficient assessment of weight of lifted object** | Can cause a tearing of lifting-equipment |

| | |
|---|---|
| Wrong evaluation of the stability of the workboat** | Evaluating wrong may result in heeling which will impede the operation and cause a hazardous event |
| Slips/lapses** | Different factors may cause slipping as the work tasks are performed on unstable surfaces. This may disturb other aspect of the operation or result in a hazardous event on its own |
| Attached insufficient ** | Related to several situations during crowding. Lifting casting net, lifting one side of casting net, lifting ropes connected to sinker tube |
| Large movement of vessel** | Concerning the situations were external factors influence the stability of the vessel and hence influence the risk of a hazardous event |
| Weather Conditions*** | Comprising all factors related to weather condition that might disturb or impeding the operation. I.e. winds, waves, current, rain-/snowfall, visibility |
| Communication*** | Sharing of knowledge and necessary information before and during the work task to ensure safe operation |
| Competence*** | Related to the personnel’s skills, knowledge and ability to perform the task and/or solve an eventual acute problem |
| Work Practice*** | Concerning how work tasks are performed under normal circumstances |
| Maintenance*** | Concerning maintenance of equipment to avoid degradation and less reliable systems |
| Mental load *** | Available time and resources may affect the personnel’s decisions |
| Physical Work Environment*** | Concerning the workload and design of workplace and practices for performing work tasks |
| **Swinging load** | |
| Technical failure – movement interrupted* | Unspecified technical failure that will stop the crane from working and hence induce a swinging load |
| Crane operator have to avoid hitting object/personnel in the way* | Object or personnel are not in assigned place, and the crane has to manoeuvre to avoid hitting this. Which may cause a swinging load |
| **Hands/fingers crushed** | |
| Fingers at wrong place on capstan when it starts* | Direct cause of hands/fingers getting crushed |
| Fingers entangled in rope over handrail on floating ring* | Direct cause of hands/fingers getting crushed |
| Hands entangled in lifted object* | Direct cause of hands/fingers getting crushed |

| | |
|---|---|
| Fingers at wrong place on handrail on deck of vessel when capstan/crane starts * | Direct cause of hands/fingers getting crushed |
| Wiring on capstan not working correctly** | Undesired state during operation, may lead to an uncontrolled situation were the hazardous event can occur easily |
| **Fall** | |
| Slipping when moving from deck to floating ring* | Direct cause of fall |
| Slipping when moving on deck of work boat/well boat* | Direct cause of fall |
| Slipping when moving on floating ring* | Direct cause of fall |
| Obstacle at deck/floating ring** | Might lead to a slip when personnel has to avoid obstacle |

## 5.4 Drawing the Bayesian Networks

Following Figure 5-1, the next step of developing the model is to arrange the hazardous event and the chosen influencing factors as Bayesian Networks (BN).

BN is a graphical method for illustrating the interactions between causal factors leading up to a hazardous event (Rausand, 2011). The diagrams are constructed using nodes and directed arcs, where the nodes represents the influencing factors. The factors can be of one or several potential states. The interaction between these nodes are illustrated using arcs (arrows) that indicate direct influence between two connecting nodes. A more thorough description of the method is given in section 3.5.2.

The status and interactions of the factors will influence the risk of the events. The factors are arranged hierarchically in a bottom-up perspective. Starting with the root causes at the left side and continuing up to the end node on the right side.

In practice, a software called Genie is utilised to draw the Bayesian Networks. Genie is developed to design Bayesian Networks, making the process of constructing the diagrams easier. The version used here is an academic version of the program (Bayes Fusion, 2016).

The final diagrams of the four hazardous events are presented in Figure 5-2 to Figure 5-5.

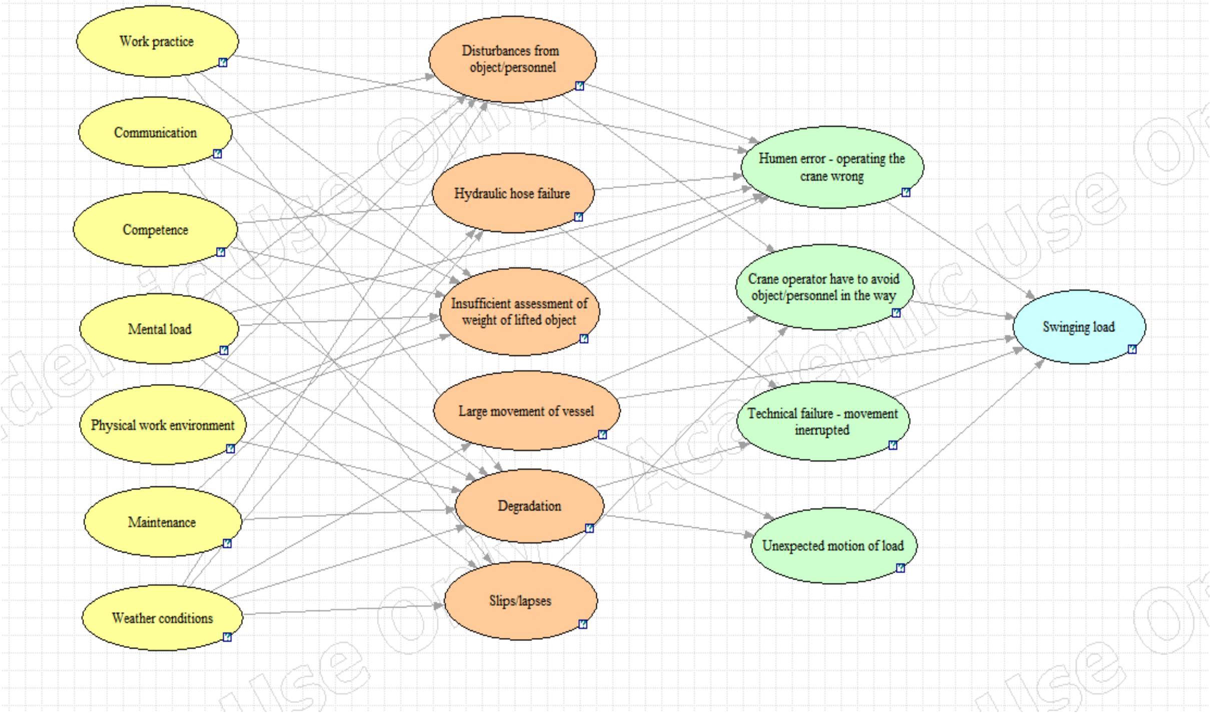


*Figure 5-2 BN-model of event, Swinging load*

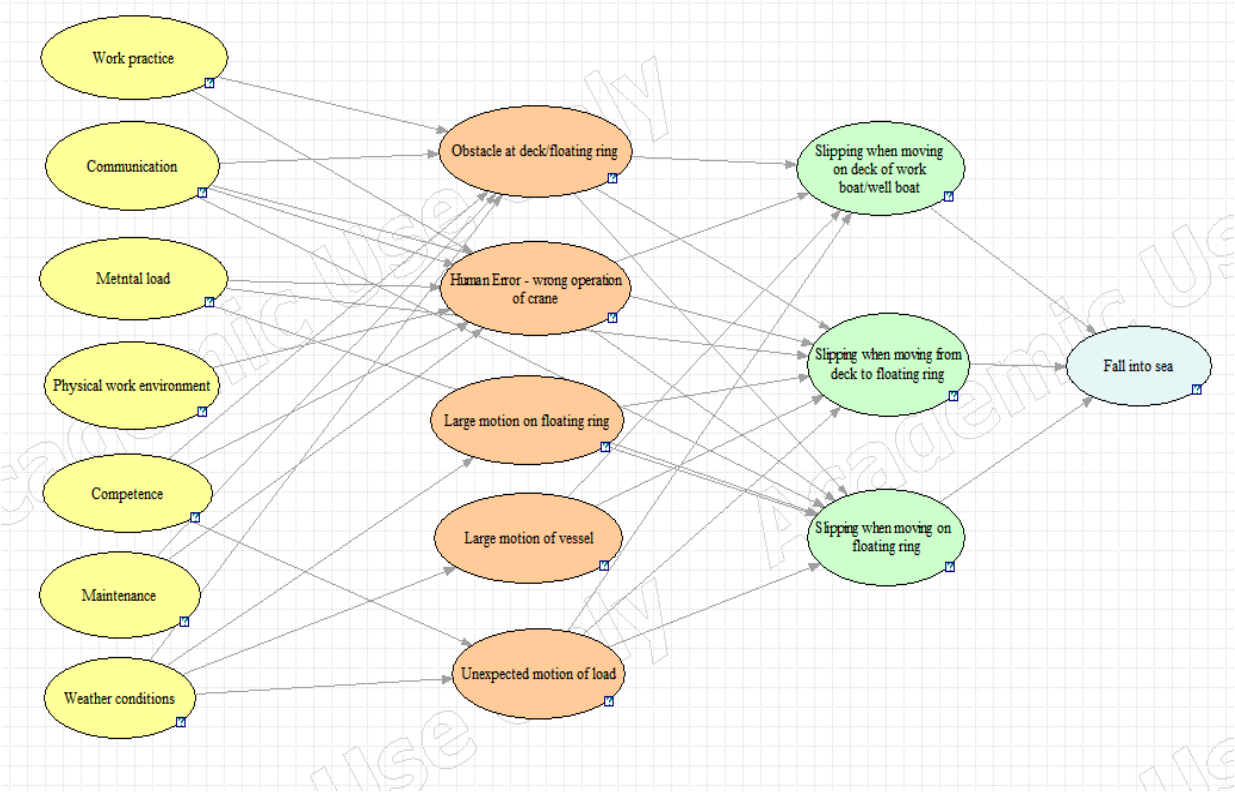


*Figure 5-3 BN-model of event Fall into sea*

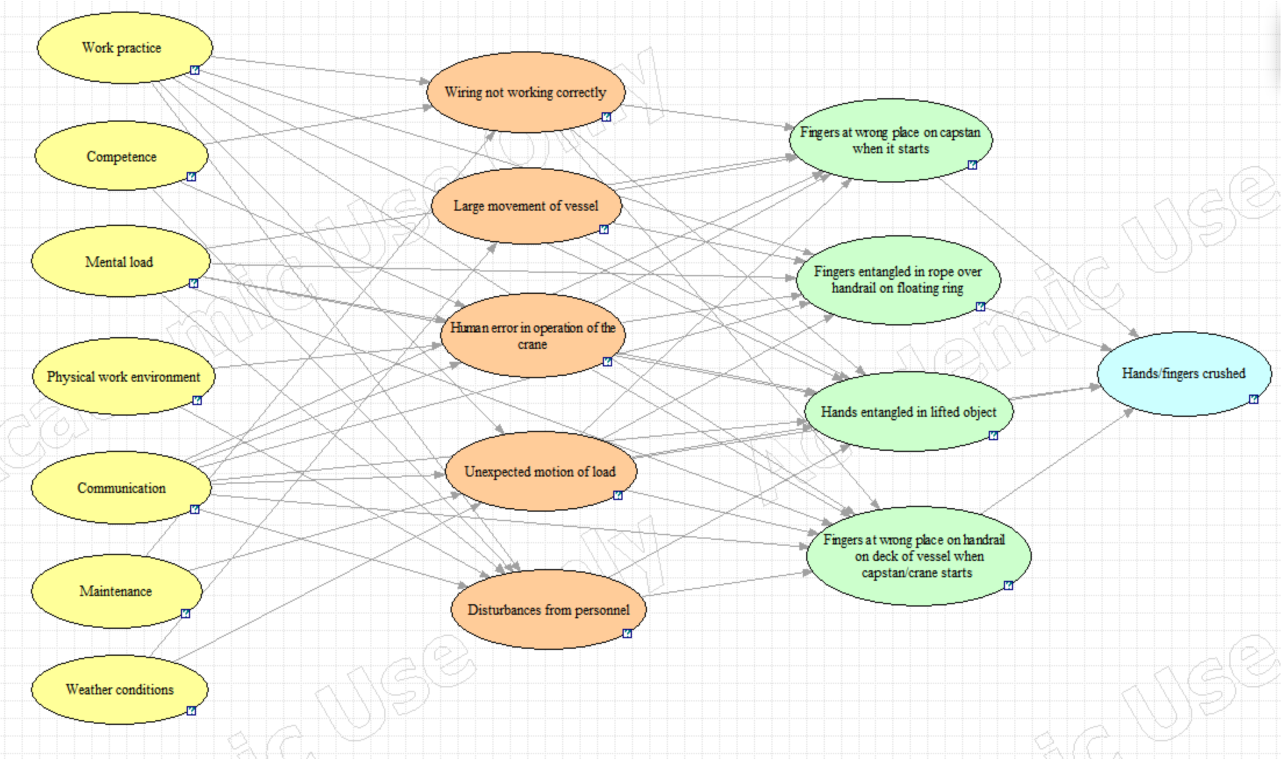


*Figure 5-4 BN-model of event Hands/fingers crushed*

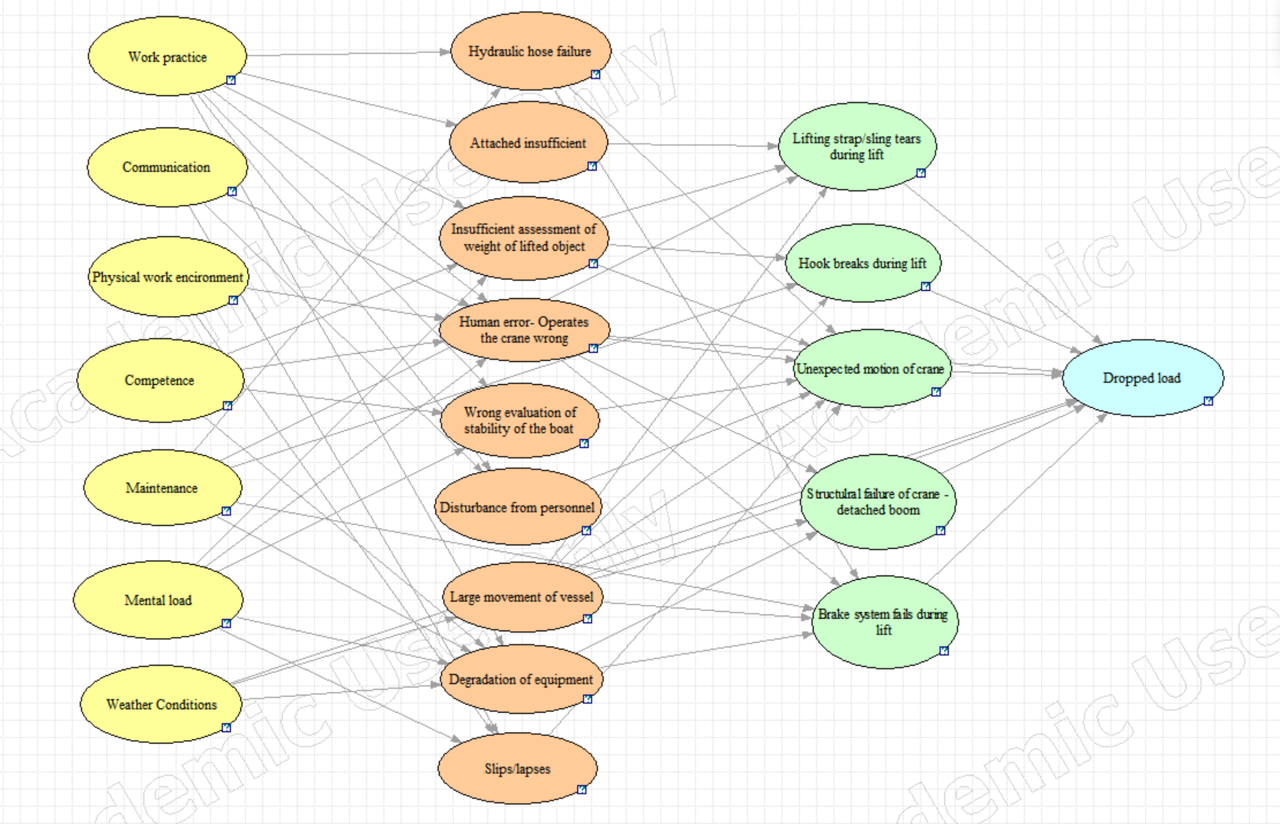


*Figure 5-5 BN-model of event Dropped load*

## 5.5 Aspects specific for the Case

As mentioned, the hazardous event could be used on a general level, as the events are relevant for a wide range of procedures at fish farms. This is due to that the most critical parts of the case operation is also present in many other operations at a fish farm. The author’s opinion is that this is a positive aspect, strengthening the model.

The implementation from the case study will however differ from a potential implementation in other procedures. The differences will be related to the states of the factors. The factor “Physical work environment” may be a good example. Crowding of fish often implies long working hours and stress for the operators. This increases the risk of a hazardous event.

Examples of aspects in the case operation that certainly will influence the risk is listed as follows:

- Weight of load
- Duration of procedure
- Repetition of tasks
- Involvement from external actors

## 5.6 Analysing the Model

Before initiating an analysis of the networks, a more extensive understanding of the impact of the factors are necessary. Following Figure 5-1, this section will present a suggestion on how the practitioners may use the model as a quantitative analysis.

After constructing the Bayesian Networks, the users should be able to further evaluate the results. As described in section 3.5.2., Bayesian Networks allows several potential states of each factor. To determine which state each factor is in, the researcher suggests using statements. The statements will be listed in a checklist and will work as indicators of each factor’s status. Establishing a Conditional Probability Table (CPT) will further allow the users to evaluate the impact the different states have on the hazardous events, by comparing the changes in risk level. These three aspects will be discussed through this section, including examples of how the checklists may look like in Table 5-4 and Table 5-5. At this point, the suggested approach will be on a purely qualitative level.

### 5.6.1 Basis for Determining Potential States

Developing a checklist requires detailed knowledge about the operation. One should put together a multidisciplinary team with experience from the operation to ensure that all aspects are considered, such that relevant states are determined for all influencing factors.

Important considerations and premises for setting the different states are discussed in the following bullet list:

- The direct or technical factors are in most cases easily assessed. Take a hydraulic hose failure as an example. Either the failure has occurred or it has not. The organisational factors will be more dynamic and complicate the identification of states.
- One aspect to consider is the system's functionality in a real life case. It should be easy to use and understand. This is the background for considering three different levels or states, good, medium and bad. Introductory, it was pointed out that Bayesian Networks is a good visual tool for raising awareness of influencing factors. Colour coding might increase these visual effects, and could be useful to have in mind when considering states. The disadvantage of choosing all three states, is that it might be too easy to choose the medium category. With that argument in mind, another consideration was to remove the medium part and remaining with being in either a good or a bad state. In this way, the colour coding aspect would still be possible to apply with only two different levels. It is, however decided by the author that the states good, medium and bad is a good basis for states, and then it is further evaluated for each factors what is most adequate.
- It might not be that all of the factors are suitable for assigning in either good/bad or good/medium/bad. E.g., for the factor "large movement of vessel", one might rather want to distinguish between whether the movements of the vessel are big enough to influence the risk or they are simply ignorable.
- It is important to underline that the factors in the same level do not have to be categorised by the same states. This should be adjusted after what is most suitable for the specific state.

With this in mind, the user should assign potential sates that suits the specific factors and are easily recognisable and understandable. Another aspect to have in mind, is that the quantitative analysis of the networks will increase in complexity when adding states. The need for adding more states, should therefore be evaluated carefully.

### 5.6.2 Basis for assigning Statements

Determining the factors' states should be done by following a list of predetermined criteria. The author suggest using a checklist with statements as a guide to how to determine states. The statements will function as indicators to which state the certain factor is in. Considerations around choosing statements are discussed in the following bullet points:

- How many different statements the user are able to identify will affect the states. If a factor can be judged by a checklist containing, e.g., 6 different statements, it will be easier to separate between the three states good, medium and bad, compared to if it is only two statements. However, one statement could be defined by e.g. a score with a range of 0-5. Then, the user will have a wider range of score to define the states.
- All fish farming companies have some sort of system for reporting unwanted events or deviations from normal operation. This should indicate whether any trends in the operation are positive or negative. Thus, there should be a statement related to if there are any events that may give the user any indication of the factors' status.
- The implementation is also important to consider. The statements should be easily understandable to all potential users, and leave no room for interpretations.
- When determining the state of a factor, the decision is based on the score from the statements. It will be important to include all practitioners when implementing and adapting the model, such that they feel ownership to the final results.

The evaluation around determining the potential states for each factors is described in Table 5-3.

*Table 5-3 Basis for assigning Statements*

| | **Evaluation of potential states** |
|---|---|
| **Work practice** | Work practice is a wide term and it will be easy to define a list of statements to assess the state. Thus, it might be adequate to be able to separate between good, medium and bad. |
| **Physical work environment** | Following the arguments of the node work practice, good, medium and bad was evaluated as suitable. |
| **Mental load** | Following the arguments of the node work practice, good, medium and bad was evaluated as suitable. |
| **Competence** | Following the arguments of the node work practice, good, medium and bad was evaluated as suitable. |
| **Maintenance** | Following the arguments of the node work practice, good, medium and bad was evaluated as suitable. |
| **Communication** | Following the arguments of the node work practice, good, medium and bad was evaluated as suitable. |
| **Weather conditions** | Weather conditions at fish farms is a factor of great significance. It will often be the main reason for cancelling a procedure and it will often influence the procedure and thus, affect many of the other factors. Weather factors are dynamic and it is difficult to determine any exact boundary values to safe operation. Most companies will use an experience based evaluation on the conditions. Some companies have however developed such criterions, these are used more as supporting guideline than a strict limitations.<br>In this case study, the author chose to set a simple division between the states. Three different statements were chosen, corresponding to the three states; good, medium and bad. This makes the evaluation easier and as there data basis was limited, other solutions would be challenging. |

### 5.6.3 Forming Examples of the Model

Experienced people or a multidisciplinary team have not validated the statements directly. This affects the credibility of the presented results, but the report mainly aims to show a potential approach and should only be viewed as an example. However, it is important that the case study is of relevance, for it to be considered as a suitable method.

Such a risk model will have to be carefully adapted to each locality before it can be integrated as a part of the safety management system and all users should be involved in the process of adapting the model.

In the following, two tables are presented. Table 5-4 shows an example of the checklist to determine the state of the root causes, while Table 5-5 includes all the factors for the entire network. Both tables are related to the hazardous event, dropping load. The tables related to the remaining hazardous events are not presented here, as they are considered to be relatively similar. At least the root causes would be almost identical, and the checklist tables for the remaining events would be redundant examples.

A suggestion to how a checklist may look like is shown in Table 5-4. The nodes are referred to in the first column, while the second lists all the statements relevant for the given node. The next column allows the user to assign a score. The score range is modified to suit the single statement, such that it may vary from statement to statement. After all statements are listed, the total score is added up along with a predefined list, where the score corresponds to a given state. This is presented in the last column.

Statements are only listed for the factors that have an unclear line between the potential conditions. For the factors that only have two different outcomes, e.g., either a failure occur or it does not, it is not necessary with additional statements to choose state. Thus, Table 5-4 only includes the root causes as they are the only factors with several states for the first hazardous event.

The statements that relate to a negative output are written with negation, such that the positive means will be weighted, e.g., “no deviations recorded”. The high scores will therefore imply that the factors are in a good state.

*Table 5-4 Checklist for determining status of factors*

| | **Statements** | **Score** | **State** |
|---|---|---|---|
| **Work practice** | Are all procedures gone through? | 0-3 | *Total score:*<br>Good: 8-6<br>Medium:5-4<br>Bad: 3-0 |
| | Is the task's risk assessed? (Standard risk analysis or SJA) | 0-1 | |
| | Is the procedure verified during the last six months? | 0-3 | |
| | No deviations recorded | 0-1 | |
| **Physical work environment** | No tight schedule that might induce stress for the workers to complete the procedure. | 0-1 | *Total score:*<br>Good: 5-4<br>Medium: 3<br>Bad: 2-0 |
| | No registered deviations the latest days expressing negative trends | 0-1 | |
| | Are the working hours regulations followed by all participators? | 0-1 | |
| | Is the procedures well modified concerning ergonomic means? | 0-1 | |
| | The procedure does not involve a high level of manual labour. (Fatigue is not a relevant aspect to consider?) | 0-1 | |
| **Mental load** | No recorded deviations that imply negative trends or any events that could affect the workers mental health | 0-1 | *Total score:*<br>Good: 3<br>Medium: 2<br>Bad: 1-0 |
| | Attitude to safety management is good. Safety of personnel should always be first priority. | 0-1 | |
| | Time schedule is not of a manner that will impact the workers mental condition. | 0-1 | |
| **Competence** | Have all participators been through sufficient safety training related to this procedure? | 0-2 | *Total score:*<br>Good: 5-4<br>Medium: 3<br>Bad: 2-0 |
| | Have all the participators been through sufficient training on how to performing the procedures? | 0-2 | |
| | If any new employees attend, are they connected to a more experienced employee? | 0-1 | |
| **Maintenance** | Maintenance routines followed, as they should. | 0-2 | *Total score:*<br>Good: 4<br>Medium:3<br>Bad: 2-0 |
| | No recorded deviations that might imply lack in maintenance or degradations of equipment. | 0-1 | |
| **Communication** | Do all participants understand each other? | 0-1 | *Total score:*<br>Good: 4-3<br>Medium:2<br>Bad: 1-0 |
| | Are all relevant information from the period before the procedure handed over? | 0-2 | |
| | Are all participants well informed about the procedure? | 0-1 | |
| | Weather conditions can be ignored | Good | *Total score:* |

| | | | |
|---|---|---|---|
| **Weather conditions** | Weather conditions affect the operation, but not | Medium | Good<br>Medium<br>Bad |
| | The weather conditions are harsh, uncertainty to whether or not the operation can be completed. | Bad | |

Table 5-5 is constructed to provide an example of how all of the factors and states may be presented. Table 5-4, shows the checklist with statements, which only concerns the root causes, while Table 5-5 presents all of the influencing factors. After evaluating the statements in Table 5-4, the users can continue with the checklist in Table 5-5, and filling out the states of each factor. The root causes are repeated, but should already be assessed and the remaining factors should allow the users to determine states without any corresponding statements, since they, in this example, are straight forward.

*Table 5-5 Model of all influencing factors and states*

| | **Potential states** | **State result from checklist** |
|---|---|---|
| *Yellow nodes* | | |
| **Work practice** | Good | |
| | Medium | |
| | Bad | |
| **Physical work environment** | Good | |
| | Medium | |
| | Bad | |
| **Mental load** | Good | |
| | Medium | |
| | Bad | |
| **Competence** | Good | |
| | Medium | |
| | Bad | |
| **Maintenance** | Good | . |
| | Medium | |
| | Bad | |
| **Communication** | Good | |
| | Medium | |
| | Bad | |

| | | |
|---|---|---|
| **Weather conditions** | Good | |
| | Medium | |
| | Bad | |
| *Orange nodes* | | |
| **Hydraulic hose failure** | Failure | |
| | No failure | |
| **Attached insufficient** | Attached insufficient | |
| | Attached correctly | |
| **Insufficient assessment of weight of lifted object** | Insufficient | |
| | Assessed correctly | |
| **Wrong evaluation of the stability of the boat** | Incorrect evaluation | |
| | Correct evaluation | |
| **Human error** | Error | |
| | No error | |
| **Disturbance from personnel** | Disturbance | |
| | No disturbance | |
| **Large movement of vessel** | Movements are big enough to have an effect the operation | |
| | The movements are not big enough to have any effect the operation | |
| **Degradation of equipment** | Degradations are present and not dealt with. | |
| | Degradation is present, but measure are performed. | |
| | No degradation are recorded | |
| **Slips/lapses** | Slips | |
| | No slips | |
| *Green nodes* | | |
| **Lifting strap tears during lift** | Tear | |
| | No tearing | |
| **Hooks breaks during lift** | Break | |
| | Hook ok | |
| **Unexpected motion of crane** | Unexpected motion | |
| | No unexpected motion | |
| **Structural failure of crane** | Failure | |

| | | |
|---|---|---|
| | No failure | |
| **Brake system fails during lift** | Failure in breaking system | |
| | No failure | |
| *Hazardous event* | | |
| **Dropped load** | Dropping load | |
| | No dropped load | |

After going through the statements in the last column, the users should have gained a complete understanding of all influencing factors and their states. Now, the idea is that the users should be able to see how these states will affect the risk of the hazardous event. To be able to assess the effect the different states will have on the hazardous event, a CPT is utilised. The next section will describe how the table is used and how it will benefit the risk model.

### 5.6.4 Conditional Probability Tables

A Conditional Probability Table is a table with probabilities assigned to all of the potential states of the nodes in Bayesian Network. In section 3.5.3, the theoretic basis behind the CPTs is described in detail.

By using a CPT, the model will provide a quantitative result of the impact the status of the factors have on the risk. This will increase the validity of the result, and should therefore be included. The alternative would be a purely qualitative evaluation of the impact of the factors' status. Whether or not it still would be a useful tool is difficult to evaluate at this point.

One aspect that is necessary to underline is that the CPT's complexity will increase with the number of states of a node and the number of influencing nodes (Rausand, 2011). Thus, the CPT for this case study would have been relatively complex. As this research has limited scope, the CPT will only be presented with an example to illustrate the result that the practitioners would receive.

A fictional example is constructed for the purpose of showing the concept of the CPT and presented in Table 5-6. The first column expresses the states of the node "Hydraulic hose failure". In the first row, the different states of the child node "Work practice" is listed. The table shows how the different states of the parent node influence the outcome of the child node.

This way it is easy to see that the state of an organisational factor may influence a technical failure.

*Table 5-6 Example of conditional probability table*

| Hydraulic hose failure | Good work practice | Medium work practice | Bad work practice |
|---|---|---|---|
| Failure | 0.2 | 0.30 | 0.4 |
| No Failure | 0.8 | 0.7 | 0.1 |

It is important to underline that the construction of the CPT, will only be a part of the preparation and adaption of the model. Considering the utilisation phase, the practitioners will not have to evaluate the CPT entries every time the model is used. However, it is important that these entries are updated regularly, to ensure reliable outputs from the model.

## 5.7 Uncertainties

At this stage, it is difficult to assess the level of uncertainty in the final model. The aspects that will involve most of the uncertainties are discussed in the following bullet points:

- The number of nodes and the accompanying states will increase the complexity of the system. A more complex system will also be more time consuming and demanding to use for the practitioners.
- The CPT will involve uncertainties. The idea is, as stated, that the CPT entries will be based on an evaluation of the registered unwanted events. The uncertainty related to this aspect will concern several factors. One of them being the quality of the system for reporting deviations. If deviations have been recorded over a longer time period, the data will include less uncertainty than if the users do not register all deviations. If the system for registered of unwanted events is not working optimal, there will probably be a lot of underreporting related to the deviations and the uncertainty of the probability will increase.
- The validation from experienced staff from the specific locality is important to ensure that the model is adapted with the specific characteristics of the locality and that no details are missed. Fish farms in Norway are widely spread and they will be exposed in different ways. The industry itself is dynamic, and often develops new solutions to problems. It is therefore important that this model is modified to suit the locality of application.

## 5.8 Summary

This chapter suggests an approach on development of a risk model that can be used to assess the risk level of certain hazardous events related to fish farming operations. The idea is that this might be a helpful tool for raising awareness around causal connections and risk influencing factors of hazardous events, when planning an upcoming operation. The chapter follows the steps of development shown in Figure 5-1.

With a basis from the operation in the case study, critical parts of the operation are identified. The critical tasks are further evaluated and four hazardous events are chosen. For each event, a careful assessment is done to identify all risk influencing factors. These were further modelled as Bayesian Networks, potential states are assigned to each factor. Relevant statements connected to each factor works as indicators on the factors' status. By constructing CPT tables, one get a quantitative result from the Bayesian Networks. This way the user is able to measure how the different factors' different states can influence the probability of the hazardous events.

The hazardous events will be relevant in most operations at a fish farm, such that the risk model may be relevant as a standard template for risk evaluation of planned operations. It will however be necessary to adapt the model to each operation and context of application., to ensure a satisfying result. As a planning tool, it could be an efficient mechanism for raising awareness of important influencing factors.

The scope does not allow an in-depth analysis on the development of the model, but one approach was described and further thoughts and recommendations around the implementation are discussed in section 6.3

# 6 DISCUSSION

## 6.1 Introduction

One of the objectives of this research is to provide a tool that will support the decision-makers in the planning phase of an operation at the fish farm. A potential approach for developing such a model was presented in chapter 5. This chapter will evaluate the potential of the method considering further applications, as well as the range of application.

Section 6.2 discusses the process of developing the model, while section 6.3 reviews the potential approach for further implementation of the model. Limitations are discussed in section 6.4 and 6.5 assess considerations around the range of application that this model may have.

## 6.2 Developing the Model

The approach started with identifying hazardous events from the selected case operation. For each of these events, risk influencing factors were identified and the most critical ones, were modelled in a Bayesian Network. Checklists were developed with statements to indicate the states of the chosen influencing factors. Knowing the states of the factors the users can further be used to evaluate the impact these states will have, by using the conditional probability table.

### 6.2.1 Risk Influencing Factors

Through the literature study in section 3.6, it became clear that when considering risk-influencing factors, it is important to have a systematic approach to reveal all organisational and operational factors. Human errors are seldom the sole causal factor of an accident. Blaming human errors as a direct factor of an accident may influence the cognitive condition of the workers, potentially increasing stress related to making mistakes in the operational context.

Modelling factors of a dynamic system is a challenging task, as shown in Figure 3-5. It involves a range of aspects. It will thus be important to allow careful adaption and preparations to ensure the quality of the model.

As described in section 3.6, using a bottom-up approach, including practitioners that are involved in the procedures on a daily basis, is a critical part of succeeding with the implementation. This aspect was taken into consideration when evaluating the model in this research and is thus suggested as a suitable approach when preparing the model for testing and implementation.

### 6.2.2 Modelling

In section 3.2.2, basic concepts related to risk management were addressed. This considered basic concepts, such as risk acceptance criteria. Risk acceptance criteria could be a challenge in many cases, as it may be difficult to determine the acceptable risk. The risk acceptance principle ALARA was described. ALARA promotes that risk reducing measures should always be implemented as long as reasonable and beneficial. Using the model as a decision support tool may be such an effective measure, and its potential for fish farming operations is therefore reviewed.

In section 3.6, research related to the use of indicators as a part of the safety management processes was evaluated. Assessments of previous research were presented, and further used as a part of the evaluation of this model.

In the evaluation of premises and suggestions from Seljelid et al. (2012), Bayesian Networks were considered as a suitable tool for modelling the influencing factors of the defined hazardous events. Seljelid et al. (2012) underlines that BN is a strong visual tool that is well suited for raising awareness to important causal factors, motivating the researcher to test it.

## 6.3 Approaches for further Implementation in Practical Case

As the model is presented in this research, it illustrates a potential approach for development and preparation to specific cases. This example could be used as a template for how to develop the model. However, the users will need to go through further steps before a final test in an operational context can be executed. Considerations of these steps are discussed in this section.

First, an implementation of this model will need a careful adaption to make sure that the model will suit the specific locality. This concerns all aspects of the approach; identifying the most critical influencing factors, defining states of these, assigns suitable statements to indicate the states and determining the entries of the conditional probability table.

As mentioned in section 5.6, the model will enhance its validity if the preparation of the method is executed by an experienced and multidisciplinary team, including the workers that will utilise the model on a daily basis.

### 6.3.1 Practical testing

When the model is adapted sufficiently to fit the context of application, it will be ready for testing. A test period should involve an actual implementation of the model during a predefined period of time, e.g. six months. It is important that configuration of the model is done prior of the test period, such that the preparations do not take up too much of the test time. A potential approach could be to set aside the first month to prepare everything, and then the rest of the period would be the actual testing. The localities that test the model will have to go through detailed surveys about how their experience is with using this as a tool in their workday. These results should further be used as a basis to decide whether or not the model is a suitable tool for fish farming facilities.

Another aspect to consider will be how often the model should be used and prior to which operation. This is an aspect that will have to be discussed thoroughly. To find the best approach, a suggestion is to test several ways of implementation.

There may be several approaches on how to implement the model as a part of the safety management system of the facilities. As stated, the aim is to use the model as a tool in the planning procedure of the facilities. The practitioners will need to evaluate or test how it is best suited as a part of routines for planning operations. This could be an everyday routine, as a start-up meeting for the day, or maybe it will suit better to integrate it as a part of a safe job analysis (SJA). SJA was described in section 3.3, presenting its main application. As the case operation is a typical operation where the companies perform a SJA, it may be wise to integrate the risk model as procedure performed simultaneously for a number of reasons. Examples are, SJA meetings gathers external service providers and workers performing the task and the SJA is already an integrated procedure at most fish farms, making it easier to find time for the risk model.

The hazardous events will be relevant during many tasks at a fish farm, but the risk of the hazardous events may only be critical during a few of them. Thus, this needs to be considered in an evaluation of how often it should be carried through.

Using a software will certainly simplify the everyday use as well. Considerations related to this aspect are discussed in section 6.5.

### 6.3.2 Potential for Standardisation

In chapter 5, aspects around the application of the model was briefly mentioned. One of them being the model's potential for standardisation. The development of the model was based on the case operation, crowding of fish. The identified hazardous events are however highly relevant during most procedures at sea-based fish farms. Thus, the model has a lot of potential for standardisation. An aspect that will change is, as described in section 5.5, the input of the model. This means that the practitioners would have to specialise versions for different procedures even though the hazardous events may be the same for different operations. The same concept will concern applying the model at different facilities; the model should always be specialised for its application. After evaluating the results from the test period, the user should evaluate if it is necessary or desirable to develop models for additional hazardous events, and if so, which.

## 6.4 Limitations

Up to now, considerations around the further application have been considered, but it is also important to be aware of the limitations and uncertainties of the model at the current point in time before any final evaluation is done. It is necessary to evaluate the limitations in comparison with the benefits, that the risk model may have.

Uncertainties of the model were considered in section 5.7. One of the most important aspects discussed was the available data at the different localities. If the facility is started up recently or if the recording system for deviations is not functioning as well as it should, it could be underreporting of unknown magnitude in the databases. This will, as stated, affect the uncertainty of the model. Applying the model with high level of uncertainty will not be of anybody's interest, as the results would be unreliable. The uncertainty of the available data would therefore have to be evaluated as a prerequisite of a quantitative analysis of the model.

As described in section 3.7, lack of data was expressed by Norddal (2010) as the main reason for why indicators were evaluated as unsuitable for expressing personal risk at fish farming facilities in their research.

As stated by Kongsvik et al. (2010), described in section 3.6, capturing the complexity of the social process and interactions is a challenge. Thus, preparing the model will require substantial resources, such as human experience, time and costs.

The complexity of the model may become a challenge. As described in section 3.5.3, the complexity of the CPT will increase extensively with the number of influencing factors and the number of potential states of each factor. The four hazardous events from the case study provides models where all of the events have several influencing factors in each activity level (the arrangement of influencing factors). This implies that the CPT, and thus the application of the model, will be complex.

Implementing the model will require a substantial amount of time. This concern the preparations before testing of the model, evaluating the result of the test period and then the potential implementation to daily operations. Accordingly, the model will be rather time demanding in the preparations and implementation phase. The conceptual idea is that the model should not be perceived as too time demanding in the use-phase. This statement is however related to the consideration that the model is integrated as a software. Then, the practitioners will only have to go through the checklist of indicators and evaluate the output. If the software application is not feasible, the model will require more time in the utilisation stage.

## 6.5 Range of Application and Ideas to Further Development of the Model

Integration as a software was mentioned as an advantage to support the CPT, but the author is of the opinion that an implementation of the entire model as a software will aid the process of implementing the model. This concerns several aspects of model. One of the premises of developing the model was the wish for a tool that would be easy to interpret and utilise for the practitioners. If the model could be implemented as an electronic application, it might be easier to sell to the practitioners. This would simplify the everyday use of the model. If the user could go through the checklist on a smartphone or tablet, time could be saved. Further, it would be advantageous if the results of the input to the checklist would be presented directly to the user. The user should get information about how the states of the factors will influence the risk of the hazardous events. If the application is able to compare the result with normal operating conditions, it may be easier to interpret the result and hence benefit the ability of working as a decision support tool.

An aspect that was brought up in section 5.6.2 was that it might be a good idea to use colour coding to enhance the visual effects of the Bayesian Networks. This aspect should be evaluated further when considering a software implementation of the model. The potential for colour coding would improve the model's ability to raise awareness around important states and interconnections.

Another interesting consideration for further work and application of the model is to what extent the model is able to take previous experiences into account. By previous experience, the author refers to events that have occurred under similar conditions before. This is of course only an idea for a long-term perspective of the model. The thought, is that this will enhance the strength of the model as decision support tool, as well as providing further statistical background to the companies. This will require further development of the method, and the experience of the occurred events during all previous conditions would have to logged into the same system, to provide a data basis. Software engineers is therefore required to take part in further development of the model. This idea is based on the research of Tidemann et al. (2011), described in section 3.7. The Case Based Reasoning (CBR) system may even have the potential of predicting future trends by combining low sensor data with historical data, which is an interesting aspect that should be researched further in the future.

It may also be of interest to apply the model to a wider range than the scope has been in this thesis. This research has been limited to only focusing on personal risk. In practice, there are other aspects related to safety than personal safety at a fish farm, such as structural safety for preventing escapes, fish welfare and the quality of the product. If the model succeed for the purpose of increasing personal safety, it may also be suitable for a wider scope.

# 7 CONCLUSION AND RECOMMONDATION TO FURTHER WORK

## 7.1 Introduction

This research describes important aspects around challenges of the safety management systems at fish farming facilities. It provides a suggestion on how to develop a new risk model for fish farming operations

The objectives are repeated to give an overview of what have been the purpose of the thesis:

(1) Describe relevant research on using indicators to express risk.
(2) Describe important considerations on modelling of influencing factors.
(3) Carry out a case study, describing a common operation at sea-based production sites.
(4) Based on the findings in the case study, suggest an approach to develop a risk model, that aim to raise awareness on the impact of risk influencing factors to support decision makers in the planning phase of an operation.
(5) Evaluate feasibility of a further implementation of the model at fish farms, including recommendations to an approach to future testing and range of application.

As presented in table 1-1, all objectives are covered through the research. This chapter shall present a conclusion based on the discussions in the previous chapter. In addition, it should account for the significance of the field, as well as recommendations to further work.

## 7.2 Conclusion

Table 7-1 gives an overview of arguments related to a further application of the suggested risk model. The model as presented in this research is not ready to base a final decision on whether or not to implement it to daily operations. It is recommended that a real life test in an operational context is performed, and that these results are considered before a final decision is made.

*Table 7-1 Evaluation of risk model*

| **Risk model** | |
|---|---|
| *Advantage* | *Disadvantage* |
| - Easily understandable and should be easy to use<br>- Has a great potential for standardisation<br>- Visual tool for raising awareness around causal factors and interconnection<br>- Potential for functioning as a decision-support tool in the planning phase of certain operations. Decreasing stress of the decision makers<br>- It may decrease accusations of sole human errors, due to a broad perspective on the chains of causal organisational factors | - The CPT's complexity increase extensively with the number of influencing factor and state<br>- Testing, adapting and preparing the model require a considerable amount of resources, such as human, time and cost<br>- The model will contain some uncertainties. This relates to the quality of the data and the quality of the evaluation of the available data. Thus, the level of uncertainty will vary from locality to locality |

What this research does provide however, is motivation to do further research on the topic. The model does, as stated, have disadvantages, and further evaluation may reveal its true applicability for fish farming operations. It is the author's opinion that the model has potential to serve as a useful resource in the safety management systems of sea-based production sites. The implementation may contribute to a safer workday for the fish farmers by decreasing stress related to decision-making, and raising awareness around important influencing factors and thus avoiding operating under unsafe conditions.

Being able to affect these aspects will be of significance to the industry, especially considering vast operations like crowding. Operations involving crowding are long-lasting and demanding operations, that will wear on the workers and that depend on a solid organisational management to avoid too long working hours and stress of the workers. If the practitioners can get support from a risk-informed base, it may be easier to determine the acceptable risk level in the operation, and hence when the activity should be cancelled.

As discussed in section 6.4, there is a wide range of additional aspects that could be added when considering potential application of the model. This will require further research as some of the conceptual ideas that are mentioned are only relevant for a long term perspective, and some may not be feasible in a real life application at all.

As discussed in section 6.4, the model will include uncertainties of unknown magnitude. It will be important that this aspect and the considered limitations are thoroughly evaluated and compared with the benefits that the model provide.

### 7.2.1 Significance to the Field

In section 1.3, considerations on the significance to the field was stated. The presented example of the model does not leave any final conclusion related to the expected benefits. Yet, it did increase the impression of the impact of some the suggested factors, such as the potential of raising awareness around important causal factors and interconnections. The model should also be able to establish clearer boundaries of safe operations as well as involving all practitioners, contributing to broader perspective of the importance of factors at an organisational level.

As a part of reviewing future test result, it is recommended to perform a survey related to the practitioners' perception of the model, such that one are able to say with certainty whether or not the expected benefits are valid.

### 7.2.2 Recommendations to Further Work

Recommendations for further work is related to a real-life test of the model. This is a necessary step to complete the evaluations of the feasibility of the model. A set of necessities and potential approaches for testing was discussed in section 6.3. This mainly concerned the aspect of preparing the model for a test period, as this will be a critical part of succeeding with the implementation. It would be beneficial if one is able to test the model at several localities spread along the coast simultaneously. This will allow a comparison on how the conditions at the different localities along the coastline affect the results.

In addition, a thorough survey on how the model is perceived is recommended. This will enable a validation of the stated benefits, as well as revealing unknown challenges.

Section 6.5 presented ideas related to the range of application of the model. The researcher’s opinion is that the model has a lot of potential and many interesting aspects concerning its range of application, however, requiring further work to test the ideas’ feasibility.

# REFERENCES

Bae Systems 2002. Beyond lifetime criteria for offshore cranes. http://www.hse.gov.uk/research/otopdf/2001/oto01088.pdf.

Bayes Fusion. 2016. *genie_academic_setup.exe* [Online]. http://download.bayesfusion.com/files.html?category=Academia. [Accessed March 2016].

Cohen, D. & Crabtree, B. 2006. Qualitative research guidelines project.

Exposedaquaculture.No. 2015. *About exposed* [Online]. http://exposedaquaculture.no/om-exposed/. 2016].

Fao 2014. The state of the words fisheries and aquaculture.

Fenstad, J., Osmundsen, T. & Størkesen, K. V. 2009. Fare på merde?

Fiskeridirektoratet. 2016. *Arbeidsoperasjoner -PM3.1-levering av fisk* [Online]. http://www.fiskeridir.no/Akvakultur/Drift-og-tilsyn/Roemming/Erfaringsbase/Matfiskproduksjon: Fiskeridirektoratet.

Globalgap.Org. 2016. *The GlobalGAP Aquaculture standard* [Online]. http://www.globalgap.org/uk_en/for-producers/aquaculture/index.html. [Accessed 9.5.2016 2016].

Hansen, J. H., Holmen, I. M. & Reinertsen, R. E. 2010. Offshore Fleet workers and the circadian adaption of core body temperature , blood pressure and heart rate to 12-h shifts: A field study.

Haugen, S., Seljelid, J., Mo, K. & Nyheim, O. M. 2011. Major Accident Indicators for Monitoring and Predicting Risk Levels.

Haugen, S., Vinnem, Bye, B., Nyheim, O. M., Seljelid, J. & Wagnild, B. R. 2015. Rapport Living Risk Analysis

Hendrick, K. & Benner, L. 1986. *Investigating accidents with STEP*, CRC Press.

Holen, S. 2015. Risk perception and communication in fish farm operations involving service providers.

Holen, S. M., Utne, I. B., Holmen, I. M. & Aasjord, H. in prep. Occupational safety in aquaculture – Part 1: Injuries in Norway.

Holmen, I. M. & Thorvaldsen, T. 2015. Godt sikkerhetsarbeid - eksempler fra ulike næringer. *SINTEF Report A26675*.

Johansen, I. L. 2010. Foundations and Fallacies of Risk Acceptance Criteria.

Karlsson, C. 2009. *Researching Operations Management*

Kongsvik, T., Almklov, P. & Fenstad, J. 2010. Organisational safety indicators: Some conceptual considerations and a supplementary qualitative approach. *Safety Science,* 48**,** 1402-1411.

Ministry of Labour and Social Affairs 2013. The internal control requirement. https://lovdata.no/dokument/SF/forskrift/1996-12-06-1127.

Mjøsund, A. 2014. Avlusning med bilete. *SINTEF Memo (internal)*

Moe, H. K., Bjelland, H. V., Svendsen, E., Holmen, I. M. & Salomonsen, C. 2014. MarinSim AP1 – Havbruksoperasjoner og deres risikofaktorer. *SINTEF Memo (internal)*.

Myers, M. L. & Durborow, R. M. 2012. Aquacultural Safety and health.

Norddal, T. 2010. Risikomodell havbruk, Forhold som påvirker personsikkerhet og risiko for rømming av fisk. *Research report RAMBØLL*.

Nordtvedt, H. 2015. Risk Assessment in Aquaculture. *Pre-master Research NTNU*.

Noy, C. 2008. Sampling Knowledge: The Hermeneutics of Snowball Sampling in Qualitative Research. *International Journal of Social Research Methodology,* 11**,** 327-344.

Rasmussen, J. 1997. Risk management in a dynamic society: A modelling problem.

Rausand, M. 2011. Risk Assessment - Theory, Methods and Applications.

Salomonsen, C. 2010. HMS i havbruk. *SINTEF Memo (Internal)*.

Sandberg, M. G., Lien, A. M., Sunde, L. M., Størkersen, K. V., Stien, L. H. & Kristiansen, T. 2012. Erfaringer og analyser fra drift av oppdrettsanlegg på eksponerte lokaliteter. *SINTEF Report A22528*.

Seljelid, J., Nyheim, O. M., Haugen, S., Sklet, S. & Jansen, E. 2012. Methodology for development of major accident risk indicators. *ST-03520-3*.

Sklet, S., Ringstad, A. J., Steen, S. A., Tronstad, L., Haugen, S., Seljelid, J., Kongsvik, T. & Wærø, I. 2010. Monitoring of Human and Organizational Factors Influencing the Risk of Major Accidents.

Standard Norge 2008. NS5814 Requirements to risk assessment. www.standard.no.

Standard Norge 2009. NS9415 Marine fish farms. Requirements for site survey, risk analyses, design dimensioning, production, installation and operation. www.standard.no.

Thorvaldsen, T., Holmen, I. M. & Moe, H. K. 2015. The escape of fish from Norwegian fish farms: Causes, risks and the influence of organisational aspects. *Marine Policy,* 55**,** 33-38.

Tidemann, Bjørnson & Aamodt 2011. Case-based reasoning in a system architecture for intelligent fish farming.

Utne & Schjølberg 2014. Reducing risk in aquaculture by implementing autonomous systems and integrated operations.

Wachter, J. K. & Yorio, P. L. 2013. A system of safety management practices and worker engagement for reducing and preventing accidents: An empirical and theoretical investigation.

Yin, R. K. 2009. Case study research: Design and methods, 4th. Sage Inc CA.