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Modeling Human and Organizational Factors for Operational Risk Analysis

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PROJECT / MASTER THESIS

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Preface

This master thesis is written as a completion of the MSc. Program in Reliability, Availability, Maintainability and Safety (RAMS) within the Production and Quality Engineering Department (IPK) at the Norwegian University of Science and Technology (NTNU). This thesis is written during the spring of 2016 and it accounts for 30 credits.

This thesis is from a wide topic called Modeling Instantaneous Risk for Major Accident Prevention (MIRMAP) Project, which is financed by Norwegian Research Council and supported by Statoil and Gassco. By doing the research and work for this thesis, I learned a lot about the topic of operational risk analysis area and how to write a scientific text.

This report is written for the RAMS students or people who have some knowledge of risk and operational area in the oil and gas industry.

Trondheim, 2016-06-10

Liaosha Li

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LS.L.

Summary and Conclusions

In terms of accident sequences in the offshore oil and gas industry, technical factors have been focused on the risk analysis area widely. However, there are still accidents and losses occurred frequently. To understand the impact of other factors on accident sequences, this thesis focuses on human and organizational factors instead of technical factors. The aim is to provide readers a method about how to model human and organizational factors of offshore lifting operation by a case study. Firstly, the risk model consists of Event Tree, Fault Tree and Bayesian network. Then, to measure the risk influence factors in the model, potential indicators are identified by researching the literature information. Next, there is a comparison and evaluation about how to model non-linear effects by Barrier and Operational Risk Analysis and Bayesian conditional probability. We predict that the Bayesian method is a more correct way to model non-linear effects. However, regardless of which method, the biggest challenge is how to obtain available datasets since there is no suitable datasets covering human and organizational factors. Thus, the further work will still focus on collecting reliable datasets.

Contents

Chapter 1

Introduction

1.1 Background

In the early stage of Norwegian oil and gas industry, risk analysis is aiming to provide support for design decisions of offshore installations. With the development of offshore oil and gas area, although technology failures have already been controlled and presented a descending trend by putting a large effort in design, implementation, and maintenance of physical barriers; accidents and losses still occurred frequently. One typical example in the Norwegian Continental Shelf industry shows that there has been no ignited gas leak since 1993, but, a large number of gas leaks still happen because of installation every year (Løge, 2012). This shows that design decisions have not been enough for preventing risk issues from happening. Human errors seem to have an underlying effect on gas leakage in nuclear industry. At this point, Petroleum Safety Authority Norway (PSAN) proposed that risk analysis should support not only design decisions, but also should be related to operational, human and organizational aspects. Therefore, identifying the accidental events which are related to work tasks and activities should be carried out in the risk analysis. Actually, as for human factors, there have been some methods and models developed in the past 20 years, such as I-Risk (Integrated Risk) (Le Coze et al., 2003), SPAR-H human reliability analysis method (Gertman et al., 2005), and SoTeRiA project (Mohaghegh et al., 2009). However, seldom of these methods have been used in the industry authentically due to none of them being flexible enough to reflect the real-time operational risk analysis of human factors in practice. Beyond that, there are still some other existing methods which will be mentioned in chapter 2. The objective of this thesis is to develop a risk model for human and organizational factors combined with a specific work task. At the same time, it focuses on explaining how risk influence factors influence the work performance of human beings.

1.2 Objectives

The main objective of this master thesis is to carry out a case study about modeling human and organizational factors for offshore lifting operations. To achieve this objective, the following sub-objectives have to be reached:

1. Identify relevant human errors and failure modes of lifting operations by task analysis.
2. Identify relevant RIFs (Risk influence factors) for each of the failures or human errors.
3. Build a risk model for the specific work task.
4. Pick a selection of important RIFs and study them in detail. Describe potential indicators for measuring the RIFs and search literature for information on their influence on work tasks.
5. Compare and discuss the methods for modeling non-linear effects.

1.3 Limitations

The scope of this thesis is to model human and organizational factors for operational risk analysis, which means only human and organizational factors will be taken into consideration, technical factors will not be covered in this thesis. In addition, the model is limited to offshore cranes, although there are some similarities between other cranes and offshore cranes, the results may not be suitable for other cranes. Moreover, all of the human errors which we modeled occurred on offshore. In other words, some human errors made onshore will not be considered.

However, since the data sources of human and organizational factors are quite limited, sometimes the relevant data should be judged by experts. The specific calculation result is thus not within the scope of this thesis. The main purpose of this thesis is to make a model and describe a method based on a specific work task.

1.4 Approach

To start with the master thesis, a number of literature reviews have been done to learn about background knowledge and existing methods about operational risk analysis, human factors and offshore cranes, which are introduced in the chapter 2 and 3. Then a detailed case study for modeling human and organizational factors of lifting operation is carried out by using Task Analysis, Event Tree, Fault Tree and Bayesian Network. For the specific aspect of how to model non-linear effects, an evaluation and comparison about BORA (Barrier and Organizational Risk Analysis) and BBN (Bayesian network) methods are carried out in the chapter 5.

An outline illustration is shown in the Figure 1.1

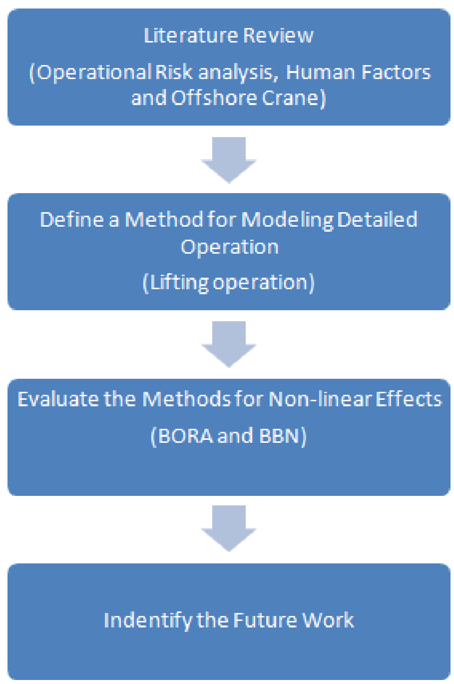

Figure 1.1: Adopted Research Approach

1.5 Structure of the Report

The rest of the report is organized as follows:

- **Chapter 2** introduces relevant background and existing methods about operational risk analysis. Then it gives briefly information about what human factors and human errors are. Finally, this chapter concludes the influence of human factors in the offshore accidents.

- **Chapter 3** documents a detailed description about the offshore crane, which covers types, operation , maintenance and accident examples.
- **Chapter 4** builds a specific risk model for offshore crane lifting operations in order to identify relevant risk influence factors. Then, some of these risk influence factors are selected and studied in detail.
- **Chapter 5** gives a basic introduction about how to model non-linear effects by using BORA and BBN methods. Then, a comparison and evaluation about complexity, data sources, dependency, uncertainty and framework of these two methods are followed.
- **Chapter 6** presents the summary and conclusions for this thesis, and then proposes recommendations for further work.

Chapter 2

Operational Risk Analysis and Human Factors

2.1 Background of Operational Risk Analysis

Looking over the oil and gas industry, risk analysis has more than 30 years history and it has been used to provide support in offshore installation and make risk influencing decisions. With the development of the offshore industry, there is a continual updating about the risk analysis methods. Nowadays, strategic risk analysis and qualitative risk analysis have already been used to analyze a proposed design and operation, evaluate an acceptable risk level and identify potential risk-reducing measures (Haugen et al., 2015). Although qualitative risk analysis is more specific and focuses on a more narrow area than strategic risk analysis, the result of qualitative risk analysis is still to get a quite general and average risk over a long period of time. However, if an action is about to occur in a limited area and needs to be planned for in a short time period or supported by a specific decision, strategic and qualitative risk analysis will not be satisfied.

2.2 Operational Risk

In hazardous industries, when production is carried out in a live plant, it's unavoidable to involve people in the operation and maintenance of the work on the rails. As for the people who work at the frontline, beyond all doubts, they face the incidental risk in the plant area. As a result, operational risk is defined by connecting people and plant together, in other words, operational risk is the interaction of people with the plant (Lehmann et al., 2013).

2.3 Operational Risk Analysis

Risk analysis is a tool and is used for providing decision-making support in many industries. "A risk analysis can help the decision-makers to structure what can be the outcomes of each possible decision alternative, and how likely the outcomes are" (Elliott, 2010). However, if we combine the risk analysis and operation phase together, a kind of risk analysis for operational decision making is called operational risk analysis. Actually, operational risk analysis originated from the oil and gas industry, and there is not a specific definition about it. By convention, risk analysis is in large amount based on generic historical data for a set of installations, and the risk result for getting average data. On the contrary, the operational risk analysis should abandon the generic data and be based on installation specific and sensitive input information in order to get instantaneous results.

Therefore, making operational decisions is becoming a purpose for operational risk analysis. When it comes to the operational decisions, Yang and Haugen (2015) define that operational decisions are linked to take and implement actions within a shorter period. The planning stage is correspondingly short, but long enough to carry out formal risk assessment.

Due to operational decisions being associated with the short period actions, it is important to understand the interaction between different jobs and the risk related to each individual when doing an operational risk analysis. In a word, operational risk analysis aims to make operational decisions for the separate work tasks but not for the whole plant.

2.4 Relevant Risk Models for Operational Risk Analysis

In the past twenty years, many companies in the oil and gas industry had tried many ways to combine risk analysis with operational phase together. However, there is a long way to achieve time-based requirements for the operational risk analysis. To get close to the desired risk analysis in the operational phase, there are some projects and risk models proposed gradually. Among these are ORIM (Organizational Risk Influence Model) (Øien, 2001a), which is based on developing organizational risk indicators for risk control during operation of offshore installation; BORA (Barrier and Organizational Risk Analysis) (Aven et al., 2006) which is related to specific conditions of technical, human, operational and organizational risk influence factors affecting the barrier performance of operational risk analysis; HCL (Hybrid Causal Logic) (Røed et al., 2009) which combined Bayesian network and mainly focuses on the aviation industry of operational risk analysis and Risk-OMT model (Risk Organization Human Technology) (Gran et al., 2012), the model focus on human and organizational factors with an emphasis on how these factors affect the performance of operational barriers. Most of these models have similar structure and steps and combine with Event Tree (ET), Fault Tree (FT), Risk influence diagram (RID) or Bayesian network (BBN), and at the same time ,are used for operational risk analysis in the offshore oil and gas industry.

2.5 Human Factors

In the past, almost 80-90% of industry accidents were recorded in terms of human factors (Gordon et al., 1996). Take the nuclear power industry accidents as an example, there is a statistical survey where 92% of the underlying causes of accidents are attributed to human factors. By dividing the human factors into categories, 43% from deficient procedures or document, 18% because of lack of knowledge or training, 16% results from failure to follow the procedures, 10% from deficient planning or scheduling, 6% because of miscommunication, 3% due to deficient supervision, 2% from policy problems and 2% from others (Gordon, 1998). Thus, it can be seen that human factors should be treated seriously; however, these significant human factors have been ignored by human beings sometimes.

In the current studies, human factors cover two aspects; on one hand, we call organizational and management factors; on the other hand, we call personal factors (Gordon, 1998).

In the offshore oil and gas industry, one part of the organizational and management factors mainly involves inadequacies in company policies and standards, including inadequate company policy, safety planning, operating procedures, training standards, maintenance system, warning, working hours policies and practice, etc. (Gordon et al., 1996). The second part of the organizational and management factors cover management weaknesses such as lack of management job, bad management example, inadequate reference material, etc. All these organizational and management factors above play an important role in the accident risk analysis.

Personal factors are mainly related to the capability, knowledge and experience, lack of skill, stress, and improper motivation. Capability is about the physical factors and personal problems, such as perception, memory, and reaction, which are not easy to control by people themselves. Knowledge, experience, and skill should be obtained from sufficient training. Whichever area in the industry, it would cause dangers if the workers are lacking enough knowledge and necessary skills. Stress is usually because of too high a workload or personnel put pressure on themselves. For instance, personnel want to do a good job with high efficiency, but they focus on work time rather than work quality , so this makes them feel stressed and even worse, it sometimes may put themselves in danger. When it comes to the last part of improper motivation, normally, the importance of the motivation determines whether the workers can do the job as good as they can; however, if the work motivation is improper, workers' work enthusiasm and efficiency will be influenced so that undesired errors may occur with this trend.

☞ **Human Error**: "An out-of-tolerance action or deviation from the norm, where the limits of acceptable performance are defined by the system"(Rausand, 2013).

On the basis of the definition, human error is a kind of undesirable or unwished-for combination between the people and the work situation. In the book of Reason (1990), the human error is divided into three categories: (1) Skill-based slips and lapses, (2) Rule-based mistakes, (3) Knowledge-based mistakes. Normally, slips and lapses are relate to the actions or checking errors and these errors can happen due to attention being diverted, where action is not taken, checks are omitted and so on. A rule-based mistake usually result from retrieval and transmission errors, such as wrong information being received, no information being sent or the information being sent to the wrong places. Knowledge-based mistakes are related to diagnostic and decision errors and currently these kinds of mistakes can be avoided by accepting professional knowledge or necessary training.

In addition, when the human errors are put into the system, there are two kinds of errors involved. Firstly, it's called active errors which occur during contact between humans and some aspect of the system. This kind of error is mostly caused by humans who work on the front-line. The other kinds of errors are called latent errors, in contrast, these may be dormant within the system for a long time and will become evident once they combine with other factors to breach the system's defenses (Gordon, 1998). Latent errors usually pose a serious threat to safety in a system and can be difficult for people to notice since the errors are probably hidden in the organization or design systems.

2.6 The Contribution of Human Factors in the Offshore Area

To understand the role of human factors on offshore accidents and incidents, the United States Coast Guard (USCG) made an investigation and did an analysis based on barges, recreational boats, ferries, fishing vessels, offshore installation, military vessels and public research and training vessels. The investigation covers the accidents data not only from the US Marine Safety Management System, but also from UK, Canada and Australia (Baker and Seah, 2004).

Combing the three databases from Australian Transportation Safety Bureau (ATSB), Canadian Transportation Safety Board (TSB Canada) and United Kingdom Marine Accident Investigation Board (MAIB), which is showed in Figure 2.1, a pie chart is made as Figure 2.2. As you can see from the pie chart, only 16% of all accidents are related with non-human errors. It follows that human errors have become a main role in the offshore accidents. Apart from non-human error group, this risk group (referred in Risk tolerance, Navigation vigilance, Complacency, Substance abuse, Task omission, Lookout failures) consists of 29% which is the biggest percentage of the total amount. Situation awareness and management groups account for the same percentage of 24%. Among these groups, situation assessment and awareness covers the dominant factors in the three different data collection, which is shown in the Figure 2.1. From the theory of Baker and McCafferty (2005), a similar discussion about the databases of marine accidents sums up that the situation awareness failures is attributed to task omissions and many of the task omissions are related to position fixing in restricted waters, with pilots, masters and mates relying on a single means to fix a position, which may suggest high workload and fatigue on the part of those personnel. That is also contributing to a high percentage of the management group in the chart. As a result, it seems clear that paying attention to human errors in the industry area is an essential way to improve maritime safety.

Accident Causation by Qualitative Groupings for ATSB Data

Situation Awareness Group	Situation assessment and awareness	15
	Knowledge, skills, and abilities	13
	Commission	2
	Total	30
Management Group	Fatigue	3
	Communications	4
	Bridge resource management	5
	Procedures	5
	Manning	2
	Business management	3
	Watch handoff	5
	Total	27
Risk Group	Risk tolerance	5
	Navigation vigilance	3
	Complacency	3
	Substance abuse	1
	Task omission	16
	Lookout failures	5
	Total	33
Maintenance Human Errors	Maintenance human error	3
	Total	3
Non Human Error Group	Uncharted hazard to navigation	1
	Material failure	6
	Weather	4
	Unknown cause	5
	Total	16

Total causes identified: 109
Mechanical failures, etc: 16
Percent Human Error related: 85%

Accident Causation by Qualitative Groupings for TSB Canada Data

Situation Awareness Group	Situation assessment and awareness	29
	Knowledge, skills, and abilities	13
	Commission	1
	Total	43
Management Group	Fatigue	7
	Bridge management / communications	18
	Procedures	5
	Manning	1
	Business management	14
	Watch handoff	0
	Fatigue	7
	Total	52
Risk Group	Risk tolerance	10
	Navigation vigilance	10
	Complacency	14
	Substance abuse	2
	Task omission	13
	Lookout failures	5
	Total	54
Maintenance Human Errors	Maintenance human error	12
	Design flaw	6
	Inspection error	5
	Total	23
Non Human Error Group	Uncharted hazard to navigation	4
	Mechanical / material failure	10
	Weather	15
	Unknown cause	3
	Total	32

Total causes identified: 204
Mechanical failures, etc: 32
Percent Human Error related: 84%

Accident Causation by Qualitative Groupings for MAIB

Situation Awareness Group	Situation assessment and awareness	16
	Knowledge, skills, and abilities	3
	Commission	3
	Total	22
Management Group	Fatigue	4
	Bridge management / communications	7
	Procedures	1
	Manning	4
	Business management	2
	Watch handoff	1
	Man-machine interface	1
	Total	20
Risk Group	Risk tolerance	4
	Navigation vigilance	5
	Complacency	5
	Substance abuse	1
	Task omission	7
	Lookout failures	7
	Total	29
Maintenance Related Human Errors	Maintenance human error	1
	Design flaw	0
	Inspection error	0
	Total	1
Non Human Error Group	Uncharted hazard to navigation	0
	Material failure	4
	Weather	7
	Unknown cause	5
	Total	16

Total causes identified: 88
Mechanical failures, etc: 16
Percent Human Error related: 82%

Figure 2.1: Marine Accidents Databases from ATSB,TSB Canada and MAIB(Baker and Seah, 2004)

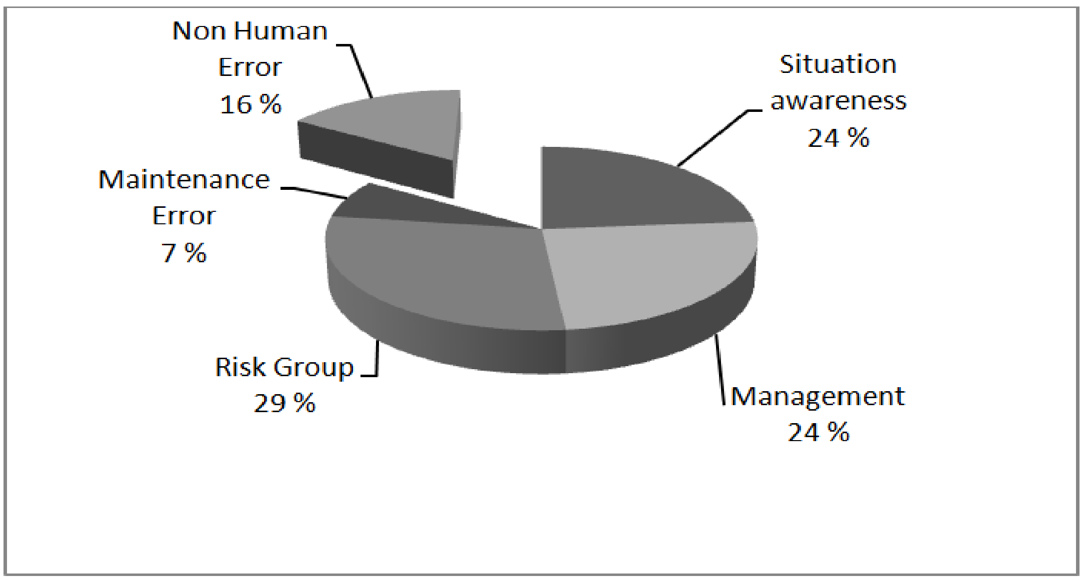

Figure 2.2: Accident Causation by Qualitative three root Groups

Chapter 3

Description of Offshore Cranes

3.1 Introduction

Due to the fast development of the offshore industry, lifting appliances have become a kind of essential equipment in the offshore production chain. Offshore crane is a type of lifting appliance and widely used in raising, suspending, lowering or moving loads from one position to another while suspended or supported (Veritas, 2011).

This chapter will give a basic introduction about the current offshore cranes and describe relevant common sense about the offshore crane operation and maintenance. At the last, a simple review of the crane accidents and incidents which happened the most frequently.

☞ **Offshore Crane**: "In general, offshore cranes are lifting appliances mounted on a bottom supported or floating structure, used in oil drilling and production operations, as well as for moving supplies and materials"(ABS, 1991).

3.2 Three Types of Offshore Cranes

The classification of the offshore crane is from a technical report of Huisman. We take up with the crane categories since Huisman is a world-wide company with rich experience in design and manufacturing heavy equipment in offshore industry.

The first type is called mast crane in the Figure 3.1, which consists of a mast welded to the ship, and the mast is rotated around by a jib. The biggest advantage of this type of crane is that the installation area requires only a small space because a large diameter slew bearing is not needed. The disadvantage is that all the hoisting equipment need to be below the deck.

Figure 3.1: 3000st Offshore Mast Crane(Huisman)

The second type is called pedestal mounted crane in the Figure 3.2, which is the most common type of crane and mounted on a pedestal. This kind of crane requires all the equipments located on the platform or inside the mast; thus, there is more space needed above deck.

The last type is the knuckle jib crane which is showed in the Figure 3.3. This kind of crane is more and more popular on vessels and floating structures nowadays with the advantage of positioning suspension point at a desired limited height above deck by the knuckle boom. However, the knuckle can only open 110 degree; thus, there are existing limitations about lifting very tall items or load located at high levels at a short radius.

3.3 Offshore Crane Terminology

The terminology of the offshore crane is from a technical report of SEATRAX:

- **Auxiliary (whip line or fast line)**: the secondary rope system capable of lifting a lower

Figure 3.2: 300mt Pedestal Mounted Offshore Crane(Huisman)

Figure 3.3: 120mt Knuckle Boom Crane(Huisman)

capacity than the main block.

- **Boom**: connected to the upper structure and supports the hoist tackle.
- **Boom hoist**: raises and lowers the boom.
- **Boom suspension**: the collection of wire ropes, sheaves, shaft blocks and other rigging components used to support the boom.
- **Cab**: where the operator maneuvers the crane's controls.
- **Gantry**: a frame to which the boom support ropes are reeved.
- **Kingpost**: connects to platform and is the centerline of rotation for the upper structure.
- **Pedestal**: the substructure the upper structure is mounted on.
- **Revolving upper structure**: the rotating frame structure and the operating machinery mounted.

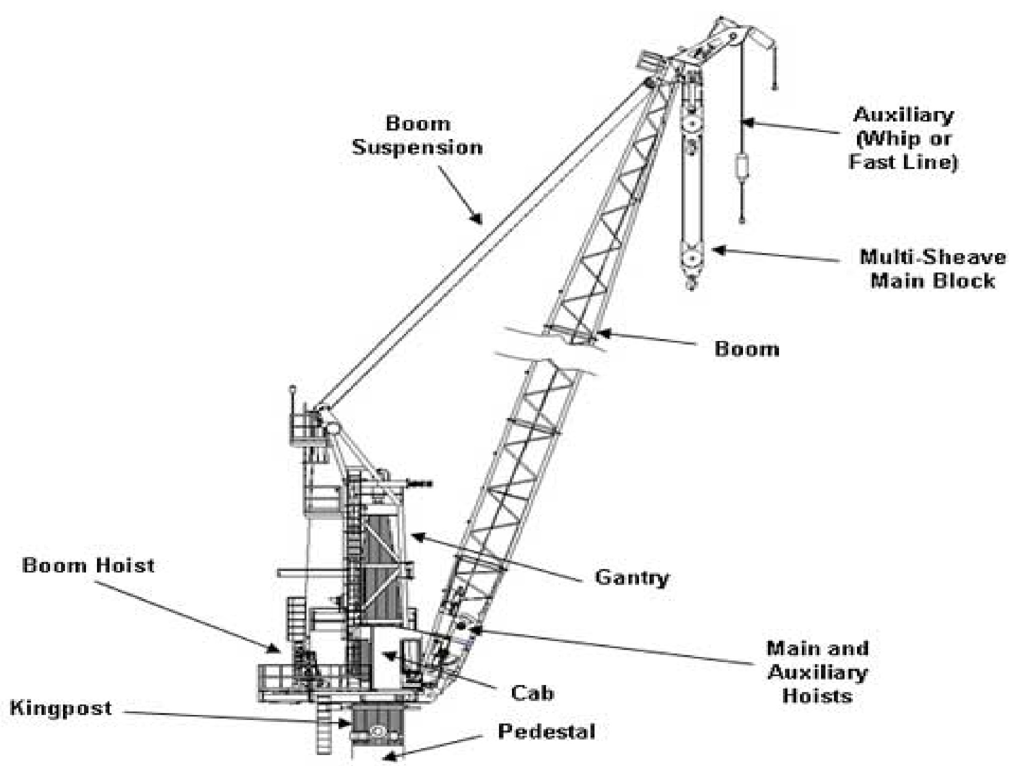

Figure 3.4: The Structure of Offshore Crane(SEATRAX)

3.4 Lifting Operation of Offshore Crane

Offshore crane operation is a dangerous part of the offshore area; it is quite significant to make sure every lift is a safe lift which prevents any injury or incident to personnel and equipment.

3.4.1 Lifting Plan

Lifting plan is an assignable step for lifting operation; it can be several documents or several pages from one document. Usually, a lifting plan is like a job risk assessment and shows an analysis of dealing with all the hazards we may meet and confirming whether everything is applicable during lifting. In a generic lifting plan the following can be covered (Ram, 2013):

- Cultural, communication and language difficulties.
- Weight, size, shape and center of gravity of load.
- Availability of approved lifting points on load.
- Method of slinging/attaching/detaching the load.
- Overturning/load integrity/need for tag lines.
- Suitability and condition of Lifting Equipment to be used.
- Initial and final load positions and how it will get there.
- Ground and underground considerations.
- Lifting over live equipment.
- Number and duration of lift(s).
- Conflicting tasks in area.
- Environmental conditions including weather and permissible limits.
- Lighting in the pick-up and lay-down areas.
- Proximity hazards, obstructions, path of load.

- Working under suspended loads.
- Access and emergency escape routes for the crane operator and load handlers.(e.g. deck man)
- Experience, competence and training of personnel.
- Number of personnel required for task.
- Pre-Use checking of equipment by Operator.
- Visibility of the load at all times by either the crane operator or the person guiding the load.

3.4.2 Pre-use Checking

In the process of pre-use checking, firstly, a lift plan should exist and be held and all personnel involved in the lifting operation should understand their duties throughout lift. A complete range of lift information should be verified in the pre-use checking stage including the weight of the lift, the center of gravity, boom angle and radius, weight of block, and lifting capacity at the final load location.

Then, the pre-checking should be done by any crane operator shift change. Basically, the pre-checking covers checking all the necessary components visually, such as boom and boom appendages, to make sure whether there is any wear or tear. In addition, the pre-inspection also requires checking the conditions of the crane, which includes engine oil level, hydraulic fluid levels and so on. At the same time, the deck men should verify that the sling and shackles are tight enough and free of obstruction. Normally, the frequency of these checking should be determined in the lifting plan stage and it should not be less than once per working day or at the beginning of each shift. Once the faults were detected, a correction should be carried out at once.

3.4.3 Pre-lift Stage

Next, the crane operator should do a pre lift before formal lifting. In this step, the aim is to check whether all the functions of the components is well-behaved. The crane operator is required to test the function of the boom indicator, the load line, the swing capability, the rigging equipment, even the radio, horn and the emergency shutdown device (Energy, 2015). All of the checks should be taken seriously and done carefully, otherwise this may lead to the unwanted results.

3.4.4 Lifting Stage

During the lift, the communication between the crane operator and the deck man should be kept fluently to make sure everything is going well as planned. In addition, the crane operator should take the weather and sea condition into consideration to decide if the lifting can be operated. Moreover, the crane operator is not allowed to operate the crane if he is ill or has any physical problem. If any unsafe condition appears, the crane operator has the authority to stop the lift.

3.4.5 Regular Maintenance Issues

As for the maintenance part, the most basic thing is keeping the crane clean, oiling and lubrication of all the needed components. What's more, all the cranes should be inspected monthly by a qualified crane operator, the crane should be started, boomed up and down, swung 360 degree, tested safety devices and the hoists operations(Energy, 2015). Once something is wrong with the inspection, corrections and repairs should be done by the qualified workers immediately. In addition, the wire ropes, pendent lines and the slings should be stored well and renewed at a regular time.

3.5 Offshore Crane Accidents

In the late 90s and the early 20th century, accidents on offshore cranes occurred quite frequently. Over the seven years from 1996 to 2002, there were at least 10 incidents that happened each year in the offshore areas and led to some workers' deaths (Hull, 2011). In the recent years, there is a decreasing trend about the offshore crane accidents; however, cranes still contribute to accidents in the offshore areas. A review of some of crane accidents will be presented in the end of this chapter.

In August 2011, a worker was killed by a crane which collapsed in the Gulf of Mexico near Galveston. A boom hoist cable failure occurred while a crane was lifting a large piece of equipment from the energy resource technology production platform to a boat. The hoist cable failure caused a crane collision and the worker was struck by the crane's harness and killed (Dlouhy, 2011).

On 20th February 2008, two workers lost their lives in a crane boom failure on an offshore rig in Mexico. See Figure 3.5. It started by the crew installing rope for re-entry into a well in Blackbeard Prospect. A person was lifted with a personnel basket and was tied off to the basket to hang off a boat rope. As the basket was being lifted, the crane boom failed and fell on the deck. One worker died by being hit by the large block , and another person who was on the basket, fell into the sea and died (Casebook, 2008).

Figure 3.5: Crane Boom Failure on the jack-up rig Rowan Gorilla IV in the Gulf of Mexico(Casebook, 2008)

On December 2002, an accident happened on the Norwegian Continental Shelf and caused one person's death. It happened due to two chemical pods, which had been stacked on top of each other. One of chemical pods was supposed to be moved to the deck by the crane, but the pod slings lost connection with the pendant and was stuck between the pod and the pods frame work. Thus, a pod slid, fell down and hit a person during the lifting operation (Dlouhy, 2011).

One accident occurred in 1998, due to the lack of proper training of personnel, preparation and supervision, an improper disassembly of a rental crane caused one worker to be killed and three workers to be injured seriously. In the same year, a platform crane failed while offloading a rental crane and two workers were killed at the same time (Bill Hauser and Rhome, 1998).

There were more than 10 incidents occured in 1996. But fortunately, no one was killed during these incidents. One incident occurred because the crane operator positioned the crane in the wrong place and this led to the crane boom clipped by a helicopter. Another incident was due to lack of communication between a crane operator and the deck man, which led to a damage of a diesel transporter tank and a minor oil spill (Bill Hauser and Rhome, 1998).

Chapter 4

Case Study

The case study aims to build a risk model for the offshore crane lifting operation task. Based on the risk model, several important RIFs will be selected and described in detail.

In order to achieve the above goals, the steps below will be followed:

1. Identify the relevant human errors and failure modes with the task analysis method for offshore crane.
2. Analyze the main failure modes and combine with Event Tree and Fault Tree.
3. Identify relevant RIFs using Bayesian Network, which is based on the basic events from the Fault Tree.
4. Describe potential indicators for measuring several RIFs in detail.

4.1 Identify Relevant Human Errors and Failure Modes

Firstly, a hierarchical task analysis was performed to gather information about what actions the crane operator and relavant deck workers should do to fulfill the goal of a specific task of offshore crane lifting operation. A good insight about the specific task of moving loads is illustrated in Figure 4.1. In order to meet the goal of moving loads, there are seven subtasks to be done: "1.0 Start up crane", "2.0 Move the hook to the cargo", "3.0 Fasten the hook to the cargo", "4.0 Move the cargo to the cargo position", "5.0 Hook release", "6.0 Crane boom swings back to the start position" and "7.0 Crane boom falls down to start position". In addition, there are several sub-subtasks followed under the subtasks of "2.0 Move the hook to the cargo" "3.0 Fasten the hook to the cargo" and "4.0 Move the cargo to the cargo position". Since this thesis is supposed to analyze human errors, the main focus will be on the sub-subtasks from the hierarchical task analysis.

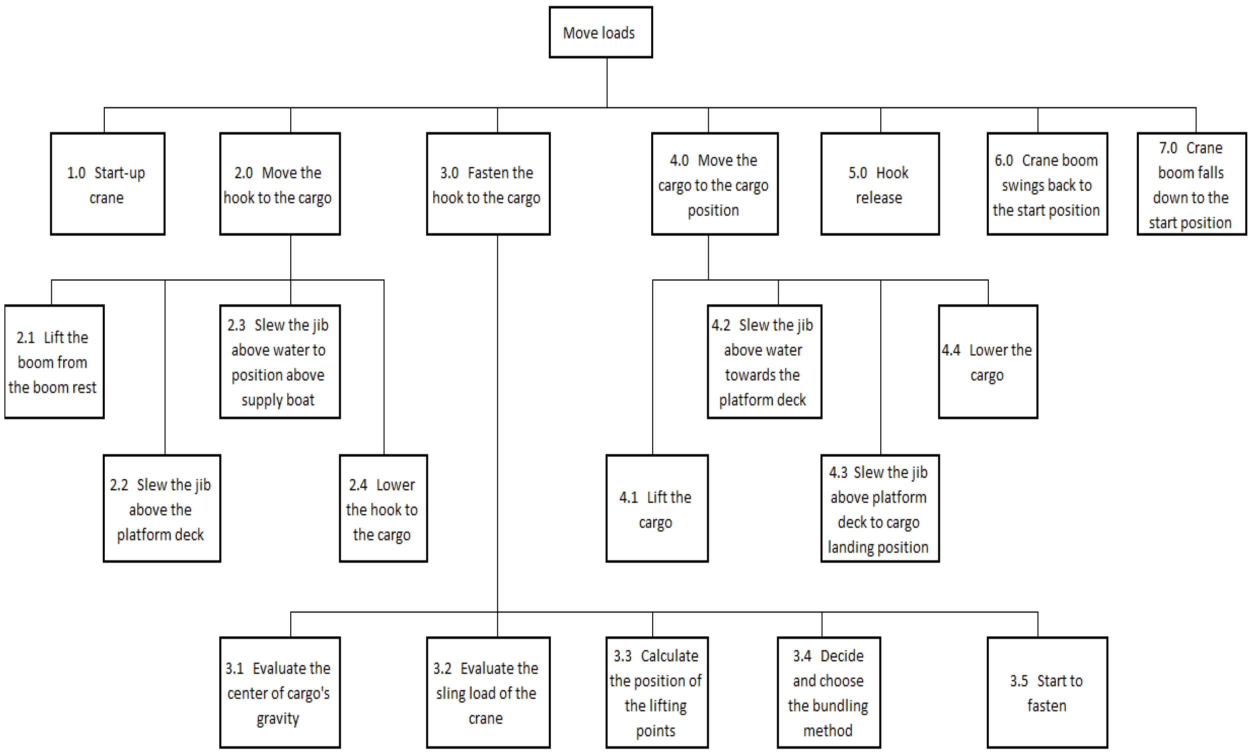

Figure 4.1: Hierarchical Task Analysis of Offshore Crane Operation

A detailed tabular task analysis is showed in Table 4.1, and some possible human errors and failure modes are summarized in the last two columns of the table. Because the failure modes from work task 3.0 (Fasten the hook to the cargo) to work task 4.0 (Move the cargo to the cargo position) can cause the crane structure to be damaged or even humans to get injured, we identify the failure modes from work task 3.0 to work task 4.0 as serious failure modes in this case study. Therefore, the research will focus on studying the specific operational tasks from 3.0 to 4.0.

Three types of serious failure modes from tasks 3.0 to 4.0 of lifting operation are shown:

- Cargo swings

- Cargo falls down
- Buckling or general instability of offshore crane

Human errors which may lead to these serious failure modes from the task analysis are:

- Communication misunderstanding
- Wrong operation by crane operator
- Lack of maintenance of the equipment
- Calculate the center of gravity wrongly
- Evaluate the sling load of the crane wrongly
- Evaluate lifting points wrongly
- Fasten the cargo with the wrong method
- Didn't check the equipment before lifting.
- Lack of lifting plan

4.2 Analyze Main Failure Modes Combined with Event Tree and Fault Tree

First and foremost, an Event Tree (ET) is developed based on the scenarios of failure modes by a set of representative work operations from 3.0 to 4.0. In the Event Tree analysis, the purpose is to identify what kind of consequential events and potential accidents can occur flowing from the primary initiating work operations. The representative work tasks from 3.0 to 4.0 include: (a) fasten the hook to the cargo, (b) lift the cargo, (c) slew the jib above water towards the platform deck, (d)slew the jib above platform deck to cargo landing position.

The Event Tree illustrated in Figure 4.2 includes a set of initiating work operations and seven intermediate events with a sequential trend. In such a case, any events which can lead injured and fatal results or equipment damaged are undesired and need to be taken into consideration.

Table 4.1: Tabular Task Analysis of Offshore Crane Operation

Task No.	Action (description)	Cues	Feedback	Possible human errors	Failure mode
1.0	Start-up crane	Checklist	Communication equipment	No pre-job meeting No pre-use check Handover wrongly	Failure of start-up
2.0	Lift the boom from the boom rest	Checklist Crane operator can see it	Visual observation Communication equipment	Wrong operation by the crane operator	Failure of lifting the boom
	Slew the jib above platform deck	Checklist Crane operator can see it	Visual observation Communication equipment	Communication misunderstanding Wrong operation by the crane operator Lack of lifting plan	Over steer
	Slew the jib above water to position above supply boat	Checklist Crane operator can see it	Visual observation Communication equipment	Communication misunderstanding Wrong operation by the crane operator Lack of lifting plan	Over steer
	Lower the hook to the cargo	Checklist Crane operator can see it	Visual observation Communication equipment	Communication misunderstanding Wrong operation by the crane operator Lack of lifting plan	Hook is not lowered normally
3.0	Evaluate the center of cargo's gravity	Checklist	Visual observation	Calculate the center of gravity wrongly	Cargo swings Cargo falls down
	Evaluate the sling load of the crane	Checklist	Visual observation	Evaluate the sling load of the crane wrongly	Overload
	Calculate the position of the lifting points	Checklist	Visual observation	Evaluate the lifting points wrongly	Overload Cargo swings Cargo falls down
	Decide and choose binding method	Checklist	Visual observation	Fasten the cargo with the wrong method	Cargo swings Cargo falls down
	Start to fasten	Checklist	Visual observation	Communication misunderstanding Cargo bundled not strongly Didn't check before lifting (Screws loosed, non-vertical lifts)	Cargo swings Cargo falls down
4.0	Lift the cargo	Checklist Crane operator can see it	Communication equipment Overload system Rope tension systems Boom tip camera Over speed tip Audible alarm Constant tension system Emergency stop system	Communication misunderstanding Wrong operation by the crane operator Maintenance issues Lack of lifting plan	Cargo swings Cargo falls down Buckling or general instability
	Slew the jib above water towards the platform deck	Checklist Crane operator can see it	Communication equipment Overload system Over speed tip Boom tip camera Constant tension system Audible alarm Emergency stop system	Communication misunderstanding Wrong operation by the crane operator Maintenance issues Lack of lifting plan	Cargo swings Cargo falls down Buckling or general instability
	Slew the jib above platform deck to cargo landing position	Checklist Crane operator can see it	Communication equipment Overload system Over speed tip Boom tip camera Constant tension system Audible alarm Emergency stop system	Communication misunderstanding Wrong operation by the crane operator Lack of lifting plan	Cargo swings Cargo falls down Buckling or general instability
	Lower the cargo	Checklist Crane operator can see it Deck man can see it	Communication equipment Over speed tip Boom tip camera Constant tension system Audible alarm Emergency stop function	Wrong operation by the crane operator Communication misunderstanding Lack of lifting plan	The cargo lowers in wrong place
5.0	Hook release	Deck man can see it Checklist	Communication equipment	Wrong operation by the deck man	Failure of release hook
6.0	Crane boom swings back to start position	Checklist Crane operator can see it	Communication equipment Visual observation	Wrong operation by the crane operator	Positioning the crane boom wrongly
7.0	Crane boom falls down to the start position	Communication equipment Visual observation	Wrong operation by the crane operator	No after-use check	Positioning the crane boom wrongly

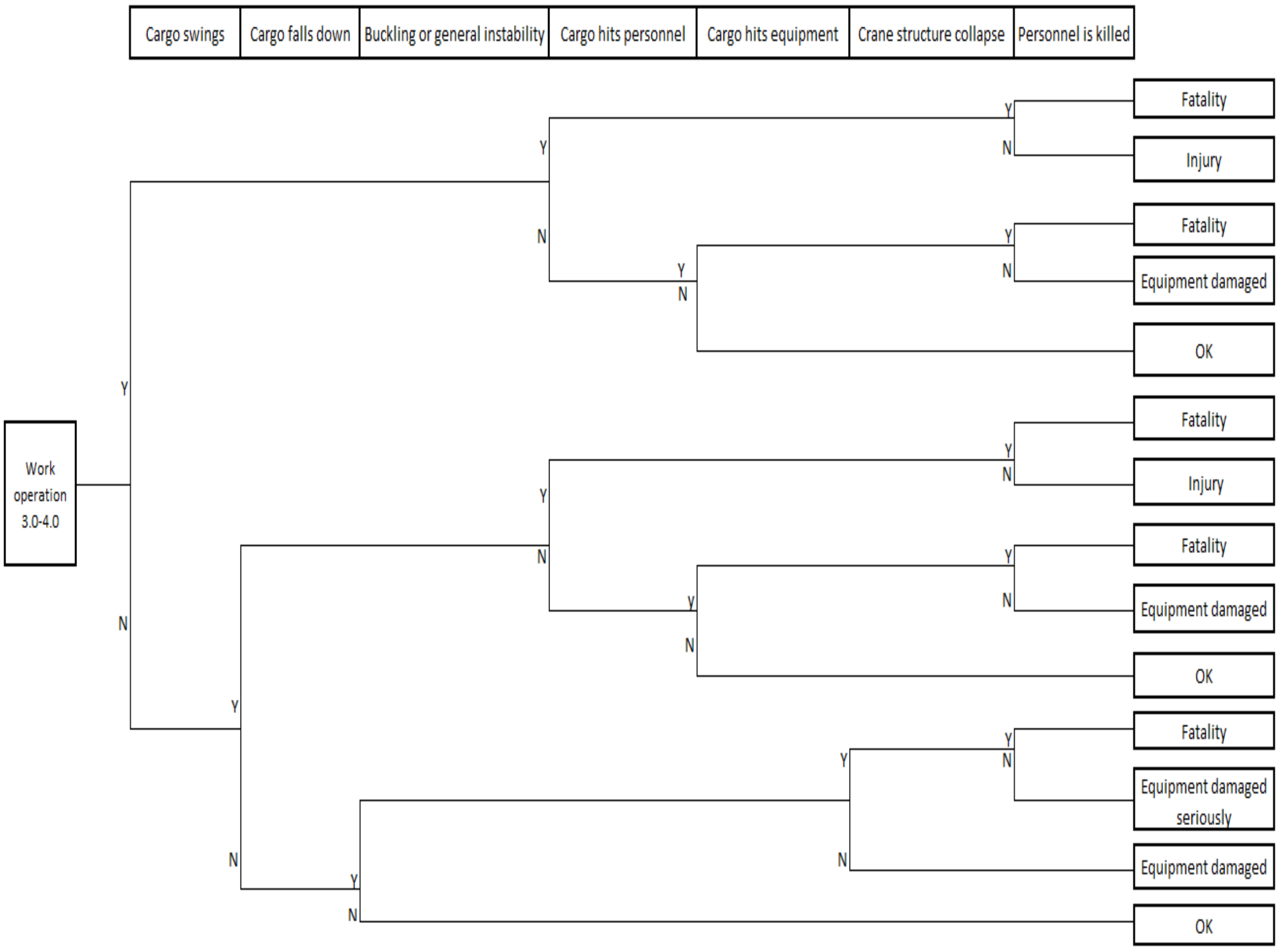

Figure 4.2: Event Tree Analysis of Work Tasks 3.0 to 4.0

In addition, Fault Tree Analysis (FTA) is another general method used in offshore risk analysis area with the clear logical deduction process of the accident events. In this study, FTA will be used to analyze human factors instead of analyzing the influence of the components and subsystems as usual.

According to the failure modes which are concluded based on the lifting transportation tabular task analysis, three fault trees are showed from Figure 4.3-4.8. Regarding to the three fault trees, we aim to find out all the direct factors that lead to the upper events, and go gradually through, until the basic root causes. In other words, we use FTA for tracing the basic events

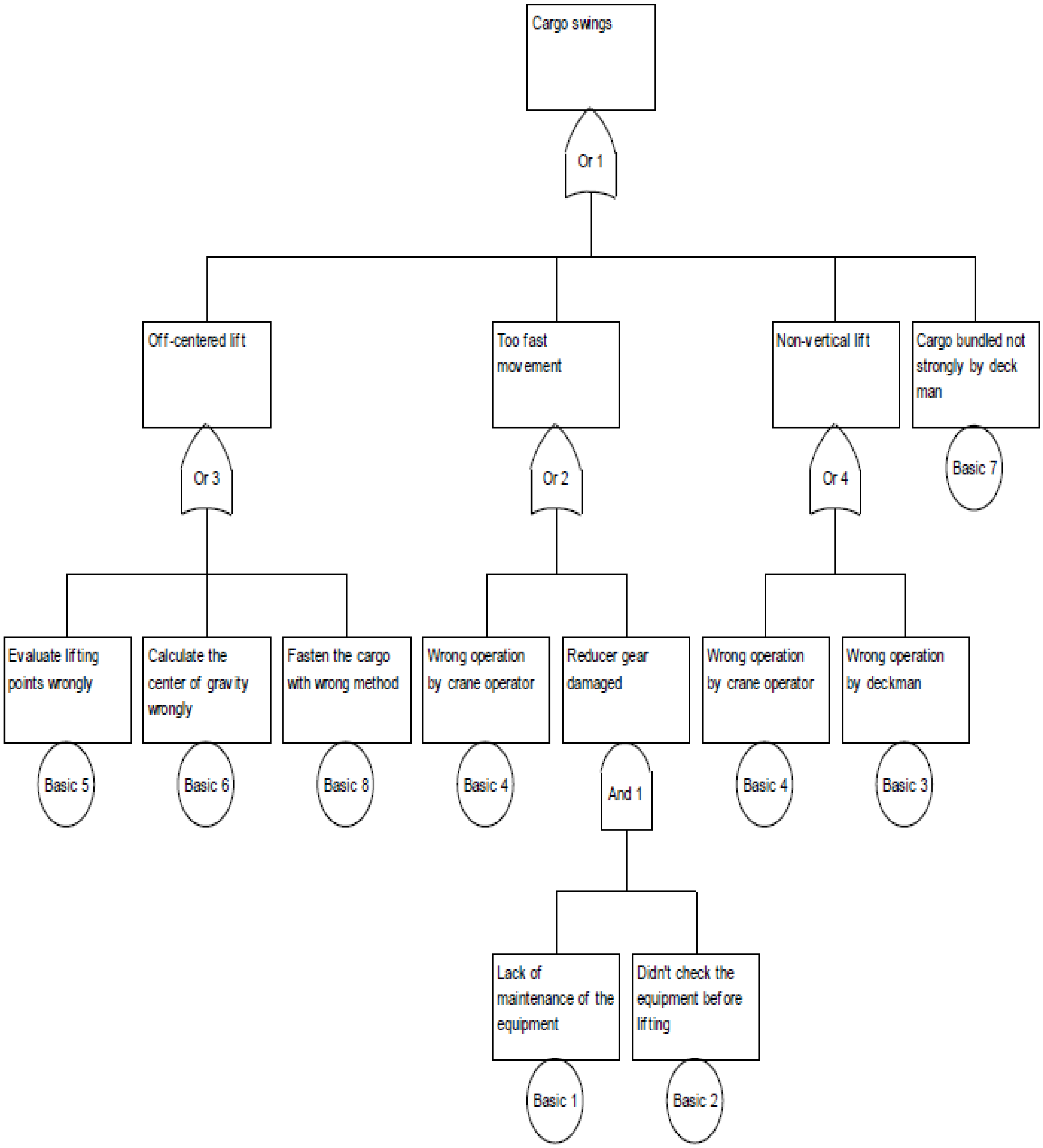

Figure 4.3: Fault Tree for Cargo Swings

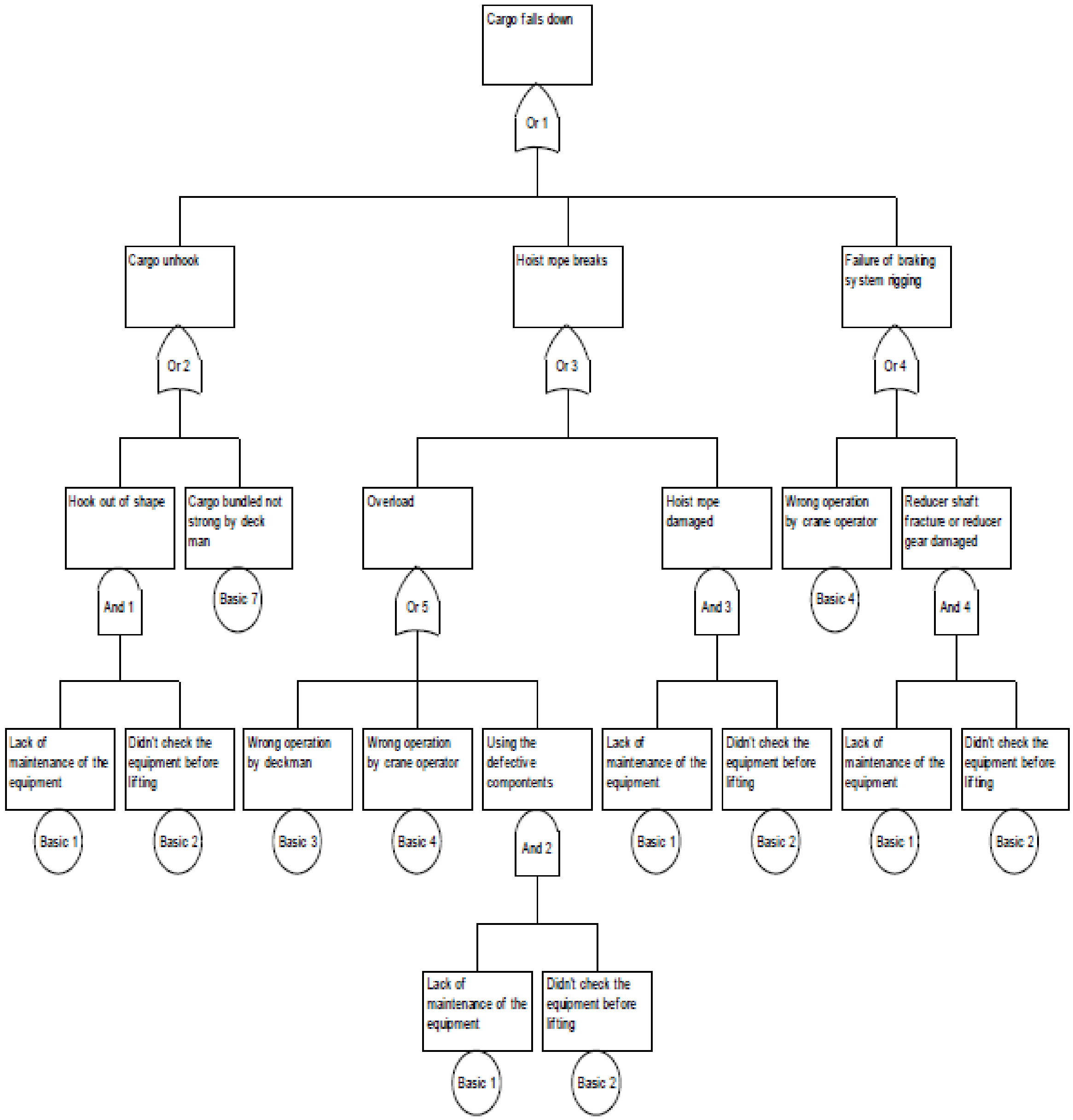

Figure 4.4: Fault Tree for Cargo Falls Down

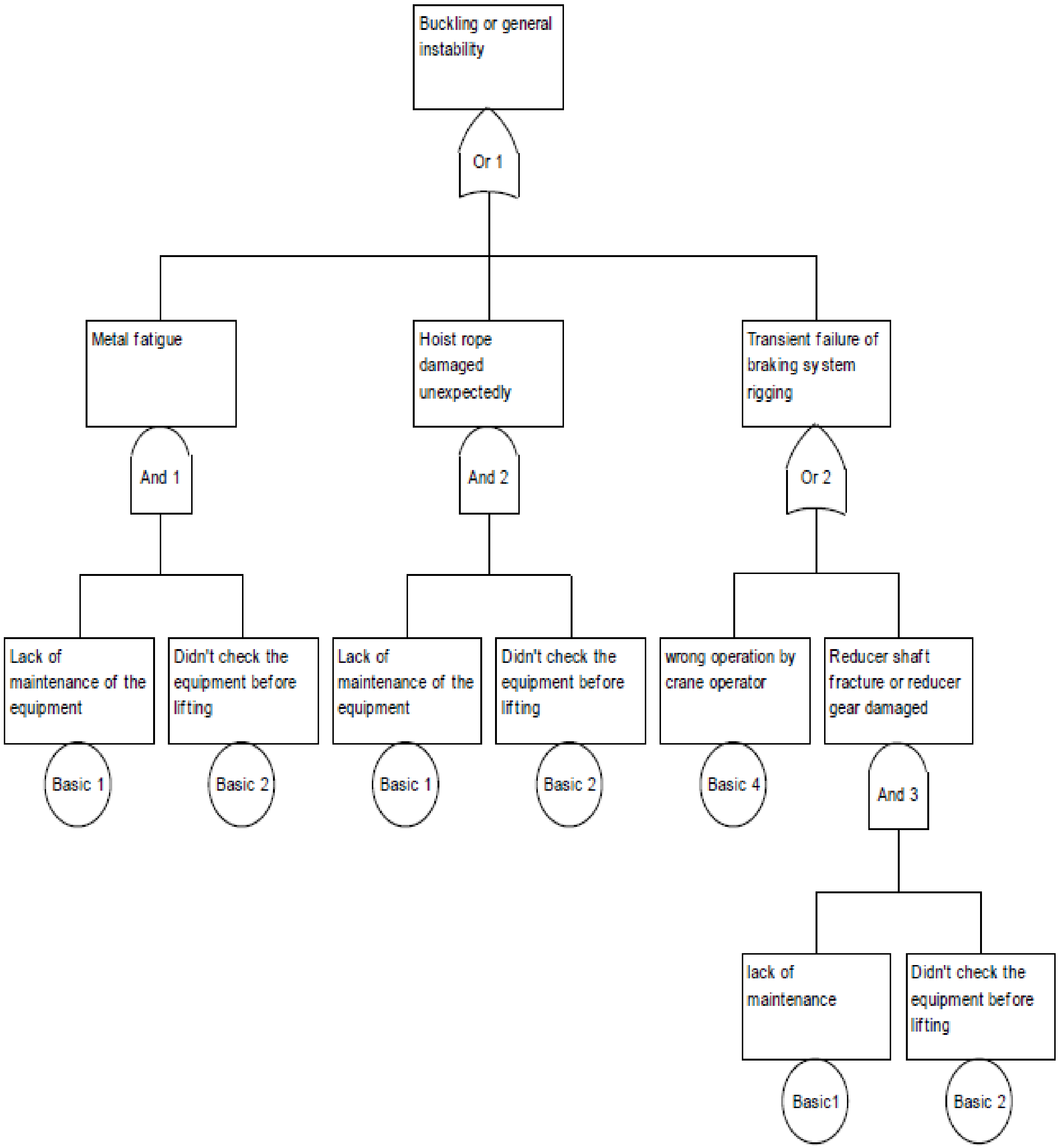

Figure 4.5: Fault Tree for Buckling or General Instability

which could contribute to the hazardous issues.

In Figure 4.3, "Off-centered lift", "Too fast movement", "Non-vertical lift" and "Cargo bundled not strong by deck man" are the most direct reasons for cargo swings. As the Figure 4.4 shows, "Cargo unhooks", "Hoist rope breaks" and "Failure of braking system rigging" are the main causes for cargo falling down. Similarly, the main reasons which cause "Crane buckling or general instability" are "Metal fatigue", "Hoist rope damaged unexpectedly" and "Transient failure of braking system rigging", which is shown in Figure 4.5.

Although the main causes of the top events are different in these three fault tree figures, the basic events are quite similar at the bottom of these fault trees. Here we conclude eight basic events as below:

- Lack of maintenance of equipment
- Didn't check the equipment before lifting
- Wrong operation by crane operator
- Cargo bundled not strongly by deck man
- Wrong operation by deck man
- Fasten the cargo with wrong method
- Calculate the center of gravity wrongly
- Evaluate lifting points wrongly

Due to "Calculate the center of gravity wrongly" and "Evaluate lifting points wrongly" should be done onshore; we take no account of these two basic events here. To make it simple, we conclude the basic events "Cargo bundled not strongly by deck man","Wrong operation by deck man",and "Fasten the cargo with wrong method" into one category and called "Failure of deck man". Thus, in the next part, there will be four Bayesian networks for modeling more specific human and organizational factors for basic events as below:

1 Lack of maintenance of equipment

2 Didn't check the equipment before lifting

3 Wrong operation of crane operator

4 Failure of deck man

4.3 Identify Relevant Risk influence factors with Bayesian Network

Bayesian Network (BBN) is a kind of graphical representation of dependence relations and conditional independence between factors within a domain (Wang, 2007). Jensen and Nielsen (1992) state that a BBN consists of a set of variable nodes and directed arrows. Among these nodes, each of them has a finite set of mutually exclusive states and follows a non-cyclic modeling. In addition, all of nodes in the BBN can be divided into parent nodes and children nodes. Parent nodes usually have an influence on the children nodes. For instance, in the Figure 4.6 , "A" stands for a child node and is influenced by the Parent node "B".

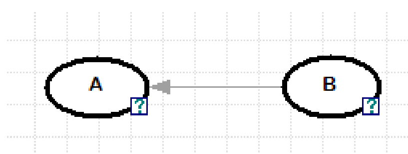

Figure 4.6: The simplest Bayesian Network A and B

In this section, we develop BBN with the purpose of completing a coverage about the effect of human and organizational risk influence factors (RIFs). From Figure 4.7 to Figure 4.10, there are four Bayesian networks and four basic events which are colored with yellow.

By considering the Bayesian networks in this thesis, there are two levels precisely. The level close to the basic events are related to the human factors and colored with light blue. In comparison with all the human RIFs in four networks, most of them are addressed more than once such as "Fatigue", which means they occupy a dominant position for contributing to human errors. In addition, the project involves RIFs dependency in this level . For example, in the Figure 4.7, there is one arrow that stands for the dependent relationship from the RIF "Lack of motivation"

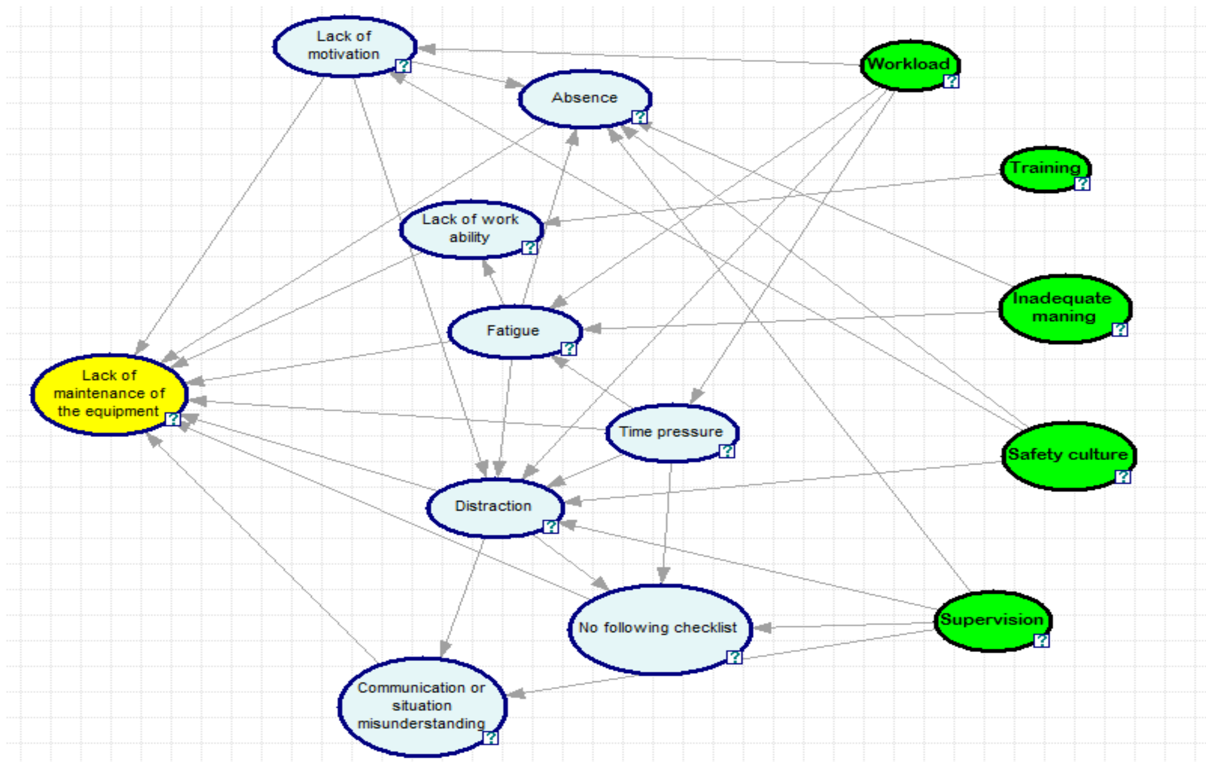

Figure 4.7: Bayesian Network for Basic Event 1

to the RIF "Distraction", which means if the workers work under less motivation, it may be difficult for them to focus on their job, so that they can be distracted and absent-minded. Therefore, when we start to measure these RIFs in the next section, we have to consider about dependency.

What's more, all the RIFs in the color green in the second level are related with organizational factors, such as "Training", "Safety culture", and "Supervision". Normally, organizational RIFs can be used to measure human RIFs in the first level. However, because most organizational RIFs are too general and cover a wide range of scope, this method is not specific enough. In the next section, there will be a more specific method to measure human RIFs by using indicators instead of organizational RIFs. Thus, putting these organizational RIFs in these BBN networks is a method for reducing uncertainty.

4.4 Describe Potential Indicators for Measuring RIFs

As we know, a large number of RIFs we identified in the Bayesian network. It is impossible to cover and measure all of them in this master thesis. Thus, we just select three human RIFs and

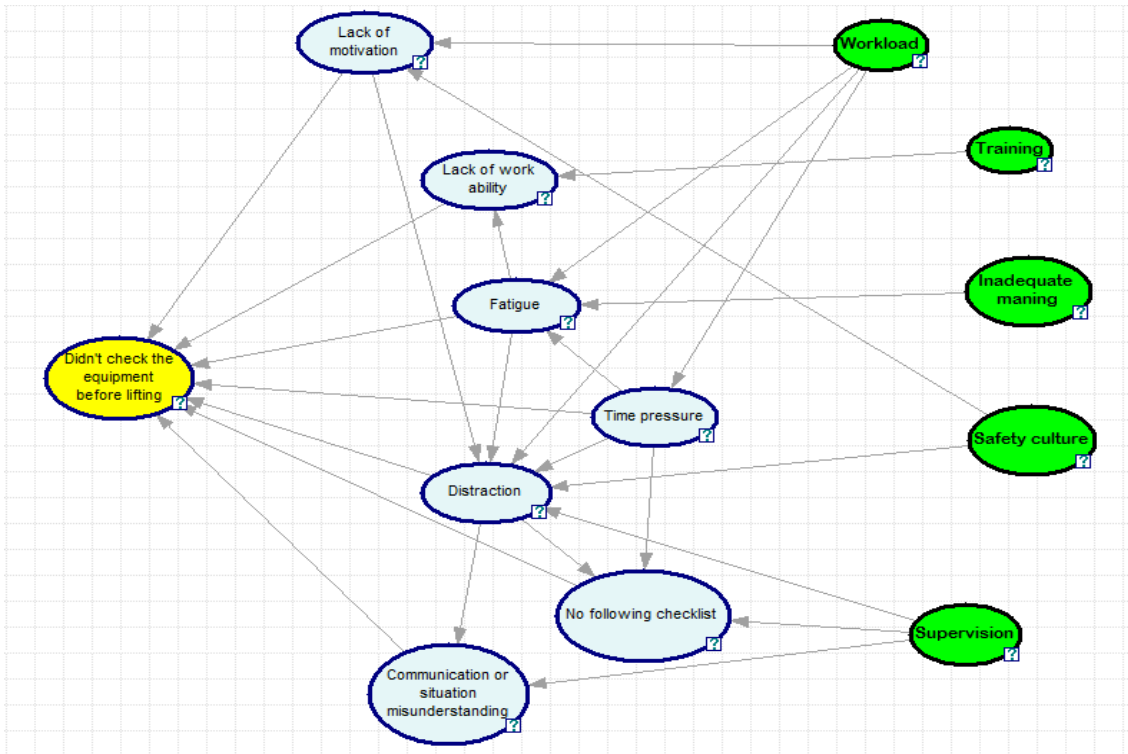

Figure 4.8: Bayesian Network for Basic Event 2

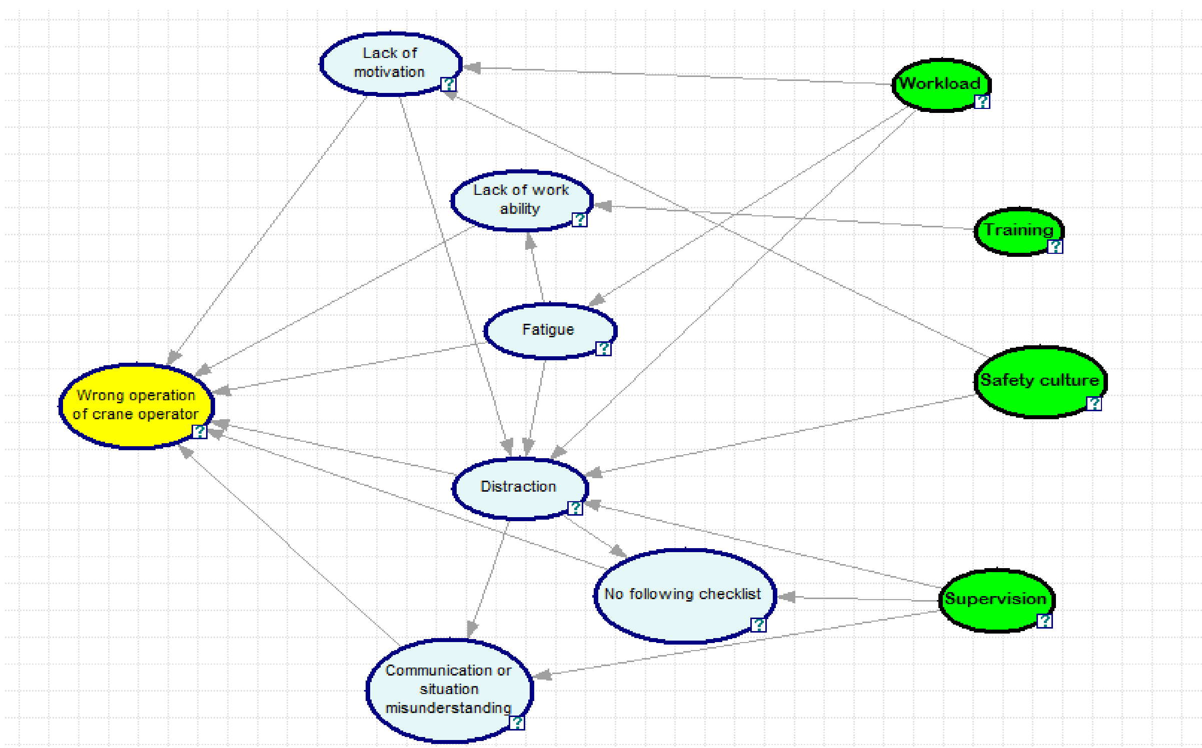

Figure 4.9: Bayesian Network for Basic Event 3

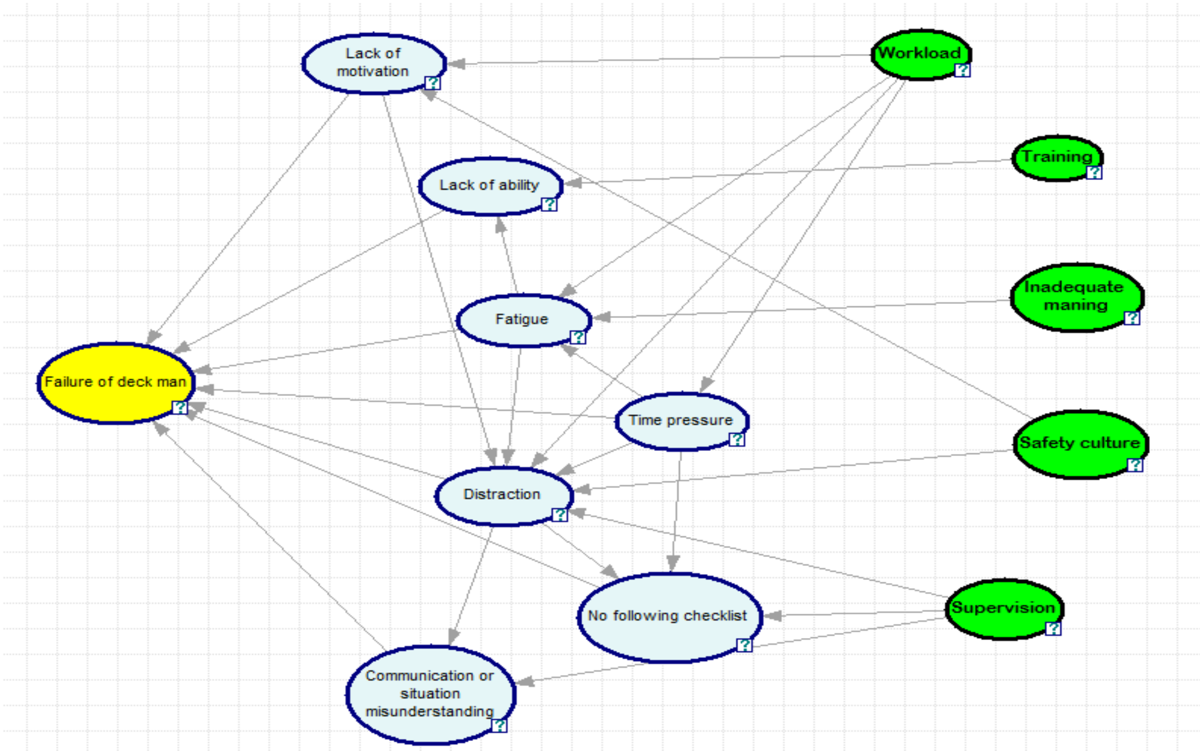

Figure 4.10: Bayesian Network for Basic Event 4

analyze them in detail. Firstly, explicit information about indicators should be stated. Øien (2001b) defines that RIFs are theoretical variables and it is difficult for them to be measured directly, so operational variables are defined for helping to measure the theoretical variables, which are called risk indicators. See Figure 4.11. Actually, we don't think there is an essential difference between indicators and RIFs since they are different variables with the same purpose for influencing risk. In other words, numerical RIFs are equivalent to indicators.

In this thesis, most relevant and important indicators will be discussed for measuring human RIFs. What's more, since there are dependency between human RIFs as we have mentioned before, the influence from one RIF to another one will be also counted.

4.4.1 Measure Method

To make it simple, "Time pressure", "Work ability", and "Fatigue" are selected for measuring in detail, the steps shown as follows:

Step 1 Make an order for the dependent relationship for each RIF. See Figure 4.12.

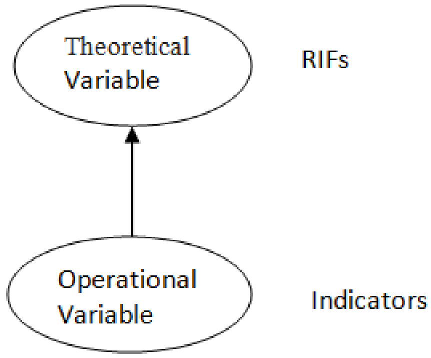

Figure 4.11: General measurement model

Through this step, we can figure out which RIF influences other RIFs. So, it should be measured first. It can be explained with the example in the Figure 4.12. "Time pressure" has an effect on the "Fatigue". Thus, before we measure "Fatigue", we have to measure "Time pressure". Similarly, "Lack of work ability" should be measured after "Fatigue".

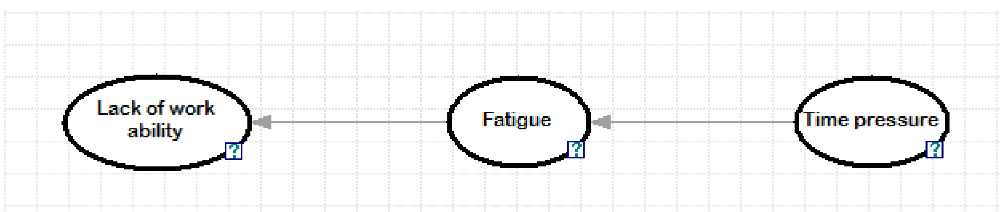

Figure 4.12: Three general RIFs

Step 2 Collect risk indicators.

Since there are a large number of indicators related to RIFs, it is impossible to cover all of them in this thesis. Hence, the most relevant and important indicators will be selected.

Step 3 Combine the measured RIF with the indicators.

In this step, we only combine measured human RIFs. Organizational RIFs will not be taken into cosideration.

In the rest of this chapter, more detailed theoretical measurements will be shown.

Time Pressure

What is time pressure? The general explanation usually considers that time pressure is a kind of psychological stress that results from the amount of work that has to be completed within a given period of time (Shipp and Fried, 2014).

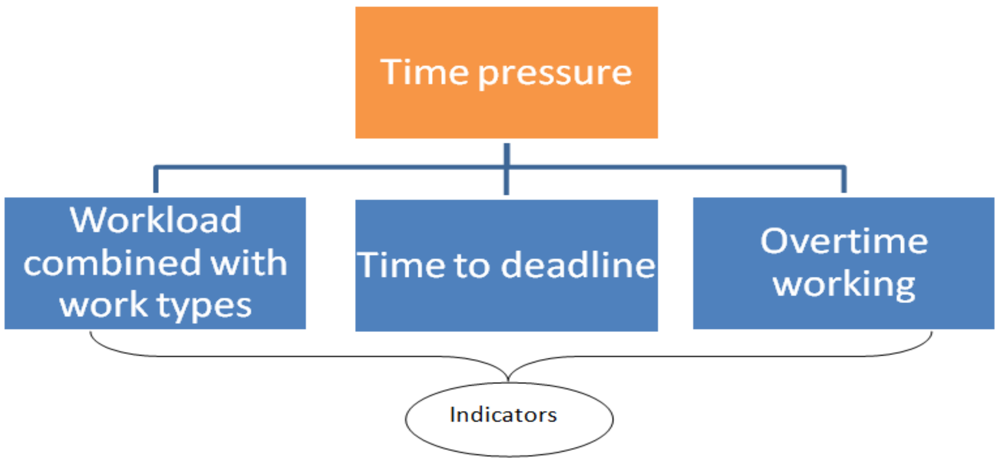

Figure 4.13: Indicators for Measuring Time Pressure

This thesis will measure time pressure by three indicators:

- Workload combined with work types, which can be measured by how many hours the workers contribute to their job per day.
- Time to deadline, which can be measured by how many hours the workers are required to finsh the job per day.
- Overtime working, which can be measured by how many hours the workers work beyond the normal working time per day.

The illustrated information is shown in Figure 4.13. Specific explanation is as follows.

In the offshore industry, workers, usually work under excessive workload associated with unrealistic time pressure. When workers have the awareness that they are not able to finish the work within the deadline, it will make workers work under pressure. In this situation, workers may focus on speed rather than working quality. In this respect, workers may have the job behaviors as shown below (Authority, 2013):

- Ignoring some signals or responsibilities that are not seen as immediately relevant or necessary.
- Limited capability for the consideration of other possibilities, or to process information correctly.
- Delaying required action/responses in the hope that they will be able to catch up as the task progresses.
- The tendency to automatically confirm a decision they have made, ignoring other information to the contrary.
- Near enough becomes good enough.
- Reverting to a previously well-learnt procedure or action which may or may not be appropriate for the current task.

Therefore, it can be seen that if the workload is too high, not only can it influence working quality, but it can also even lead to work accidents. In consequence, we consider that in a certain period of time, the more contribution needed, the higher time pressure workers will experience. When the workload is fixed, the shorter the time required, the higher the time pressure. However, since different jobs have different job specifications, we should make a difference before measuring.

But beyond that, a survey has shown that 65 % of workers are working under pressure as a result of working extra hours in UK (ILM, 2014). Regarding why overtime working can lead to pressure, one reason is that too much workload pushes workers to work more than the required time per day. In such a case, workers feel under time pressure when they find themselves in a high-strung mental state due to being extremely exhausted during work. Furthermore, once workers refuse to work overtime, they will realize they couldn't finish their job within the deadline since there is still a large amount of work to be finished tomorrow. In this situation, they will have more time pressure when approaching the deadline so that they have to do extra effort. Besides, some workers work overtime in order to earn some threshold value or get the support from leaders and staff (Van Echtelt et al., 2006). Therefore, they push themselves to finish an outstanding job in a short time. In either case, overtime working leads to a direct influence in time pressure of workers. However, having been exposed to high time pressure for a long time, workers will not have enough time to take care of their body (Klein, 2010). It will potentially put workers' bodies at risk; more seriously, some accidents may be caused by human errors.

Fatigue

In the article of Darby and Walls (1998), they define fatigue as a temporary inability or decrease in ability or a strong disinclination to respond to a situation, because of inadequate recuperation from previous over-activity.

Generally, human fatigue results from being awake for a long time (BC, 2014), but sleep disruption, circadian disruption, shift-work, nutrition and physical condition could also lead to human fatigue. However, since all of the indicators should be related to quantitative analysis, although some factors can lead to worker fatigue, there is no way to regard them as numeric indicators. As a result, in this thesis, we will measure fatigue from four indicators and one RIF. See Figure 4.14.

- Working hours, which is combined with workload and measured by how many hours the workers work per day.
- Shift rotation hours, which may be measured by how many hours outside their normal shift hours the workers work per day.
- Sleeping, which can be measured by how many hours the workers sleep per day.
- Physical Problems, which can be measured by how serious the workers are sick.
- Time pressure.

For working hours, as one indicator for measuring fatigue, it is widely accepted that the more hours worked, the more fatigue workers get. However, most people have no idea that less working hours can also make a contributive impact on fatigue.

In the Norwegian offshore oil and gas industry, offshore workers usually work by a 2-4 pattern. It means offshore workers continuously work for two weeks and then have 4 weeks shore leave. Normally, whether it is day workers or day/night shift workers, the working duration is 12

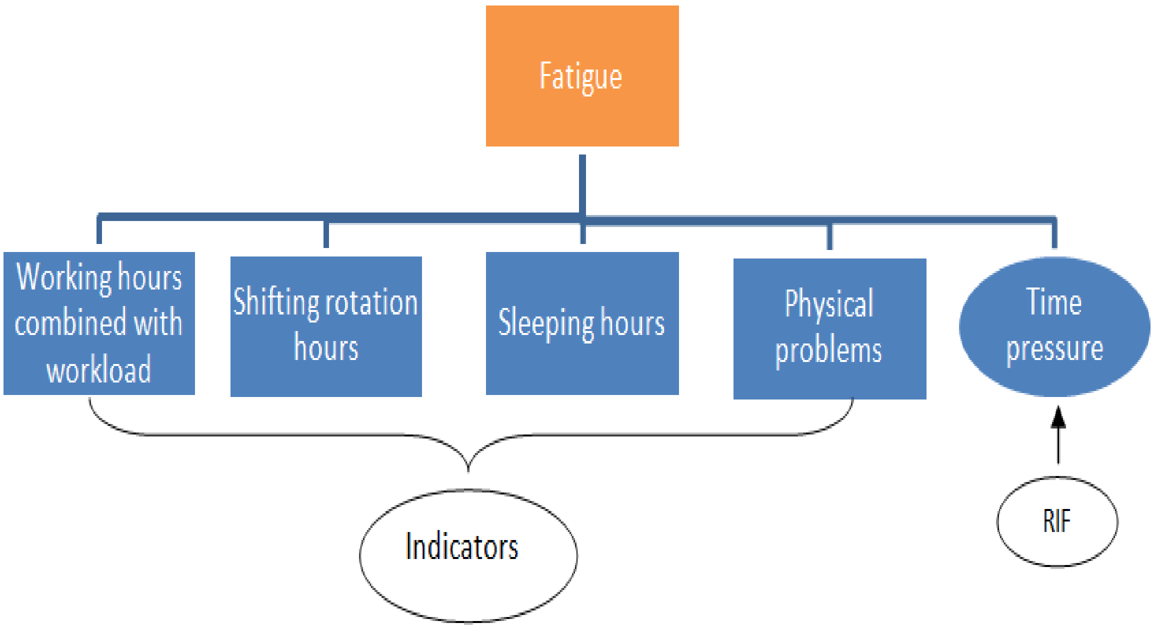

Figure 4.14: Indicators for Measuring Fatigue

hours one day, and at least 168 hours for two weeks (Parkes, 2007). Therefore, offshore workers normally toiled longer hours than the workers in other fields. When combining working hours with workload, several situations need to be considered. Firstly, when there is a large amount of workload, workers have to work quite long hours to finish the job. This is what we call it overtime working. In this situation, the more hours workers work, the more fatigue is caused. The second situation is when there is still a lot of workload but the workers are required to finish the job in a limited time; in such a case, the less working hours required, the more fatigue workers get. In effect, this situation gives the same explanation of the influence between time pressure and fatigue. To simplify, this thesis will not explain how time pressure influences fatigue extensively. In addition, one more situation where less workload can make workers fatigued, is when workers don't have too much work to finish, they may have plenty of free time with nothing to do. In such a case, workers can feel bored and even sleepy, so that they become fatigued.

When it comes to shift rotation, Parkes (2007) states that there are three types of shift rotations for offshore workers in general, 14 day shifts, 14 night shifts and 7 day/ 7 night shifts. Except for 14 day shifts which is only involves working in day, 14 night shifts and 7 day/ 7 night shifts can lead workers to circadian disruption or sleeping problems to some extent. There is one experiment in the article of Halberg et al. (1977), which compares the influence of exposing mice to regular day/night cycles and to reversed day/night cycles once a week. The result shows that the mice on regular cycle lived longer than the mice on the changing cycle.

As a result, shift rotation plays a decisive role for workers' fatigue, but, measuring should be specific for variable shifting types.

As for the indicator of sleeping hours, on the offshore platform, workers usually sleep in simple and crude cabin, and most of the time, they fall asleep with noise. In the report of Spencer et al. (2006), it shows that normally having seven or more hours sleep per night can maintain the working duty for 14 consecutive days; however, if the sleeping hours are reduced by one hour per night, workers can easily experience sleepiness during work. Belenky et al. (2003) points out that four hours has been suggested as the minimum amount of sleep hours at which performance can be sustained. If workers sleep less than four hours per night, it may lead to human errors in performance. In addition, most of the offshore workers have to work by a shift rotation; as a result, offshore workers who work during the night have to catch up sleep in the day time. That can make workers get sleep disorder or circadian disruption. In the laboratory of Lamond et al. (2003), an experiment shows that sleep during the day following the night shift is approximately 35 minutes less than the equivalent sleep at night.

Regarding the physical problem, we know that if a person has bad health condition, he or she may easily feel tired and cannot fully focus on the job. So they will have low efficiency. Generally, in this thesis, workers' physical problems can be evaluated by two aspects. Oneside is from mental, such as nervous, depressive disorder, etc. The other one is from body, for instance, headache, dizziness, overweight, or heart attract. As we all know, when a person has some physical problems, he or she will feel uncomfortable and even in pain. On this occasion, the discomfort will make people tired more easily than healthy people. What's more, to make it easy to measure, relevant evaluation is necessary to divide physical problems into several stages like slight, moderate, serious, or very serious.

Work Ability

Work ability, we regard it as a kind of ability to transfer working knowledge and skill into the job area. In this respect, this thesis will measure work ability by two indicators and one RIF. See Figure 4.15.

- Training stage, which is combined with different work types and measured by specific stage.
- Work experience, which can be measured by how many years the workers have already worked in relevant area.
- Fatigue

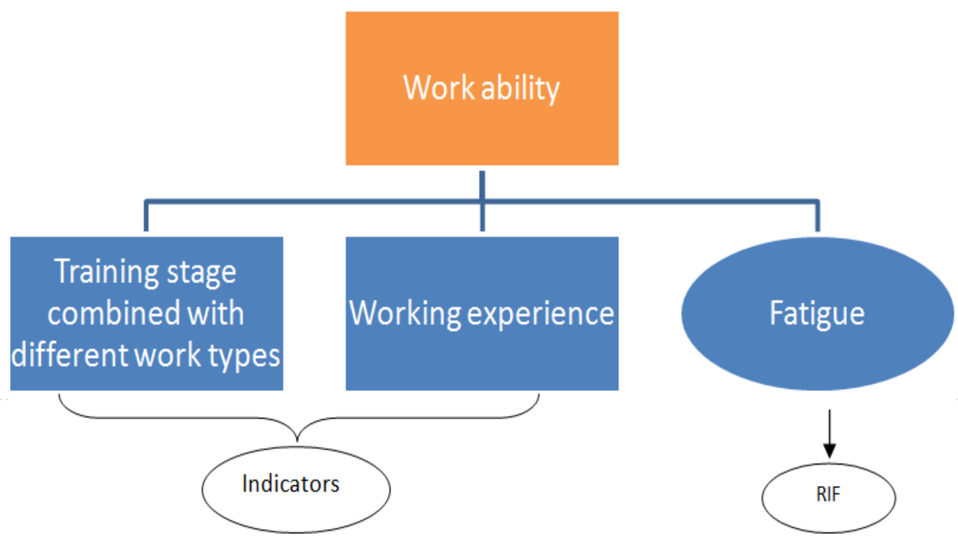

Figure 4.15: Indicators for Measure Work Ability

First of all, we consider that accepting training to obtain related knowledge and skills is prerequisite for offshore workers to have the work ability. Take offshore crane operators for example, there are three training stages required for individuals. The stage one is to studying basic knowledge and skills for individuals who have little or no crane operational experience. Stage two is prepared for the individuals who passed the stage one. They have to finish a set of supervised workplace tasks in order to gain more relevant experience. There is a higher requirement in the stage three. Individuals who passed the stage three can be more professional in crane operating area (OPITO, 2012). For all the three stages' trainings, individuals can be judged by theory test and practical evaluation. As a result, a higher training stage and a higher training evaluation test result can stand for better work ability.

What's more, offshore workers cannot just get the theoretical and practical knowledge from the training part; they also need to go into the work. By doing the job, they can gain more and more experience and skills. After some time, they will become very familiar with every aspect of the work, and even become experts. This is so called work experience. Thus, the second indicator for measuring work ability is work experience. Schmidt et al. (1986) state that work experience may have a direct and indirect effect on work ability. As for new workers, whether there is a training program or not, they must learn the work skills and methods over a period of time before they start the formal job. In this situation, the amount of experience has a direct effect on work ability. On the other hand, work experience leads to an impact on improving job knowledge and work performance. In this sense, the more work experience means the more job knowledge and the better the work performance. Doubtlessly, work experience plays a positive role on work ability in an indirect way as well.

Table 4.2: The Relationship between Fatigue and Work Ability

Fatigue levels	Phenomenon	Work ability
Mild fatigue	Increased operation time	Low efficiency Work quality unchangeable
Moderate fatigue	Increased reaction time Inability to concentrate	Low efficiency Work quality decreased
Serious fatigue	Inability to stay awake Increased forgetfulness Increased errors in judgment	Low efficiency Work quality rapidly decreased

Finally, the research will focus on how fatigue influences work ability. When people are fatigued, they will have many different symptoms, like systemic weakness, limbs, neck pain and numbness, visual disturbances, disordered thinking, and memory difficulties. Some people even become sluggish, and their control and attention are largely reduced. All of these will decrease people's work performance and productivity (Health and Regulator, 2015).

To make it more clear, this thesis divides fatigue into three levels: mild fatigue, moderate fatigue, and serious fatigue. See the detail in Table 4.2.

In mild fatigue, worker's body functions have some disorder, which is manifested in deteriorated activity as extended time to complete certain operations is required (Zhang, 1998). But because of the strong willpower, workers still can keep themselves maintaining a normal work quality.

With the further development of fatigue, it will become moderate fatigue. In this condition, body functions continue to decline, willpower declines significantly, and efficiency is largely reduced. The frequency and duration of the deviation from the task are increased. In this stage, workers start to lose concentration on the job and become slow in reacting, further increasing the chances of making errors.

Without any treatment, it may develop to serious fatigue. During this time, efficiency continues to decrease and the number of errors further increases. The attention and work ability are sharply declined, which may lead to accidents.

Chapter 5

Model Non-linear Effects

In general, human and organizational RIFs result from a person's perception, consciousness, thoughts, and background etc. In effect, for human's behaviors, the influence of human and organizational RIFs usually don't follow a standard linear relationship, but they lead to a non-linear effects sometimes. In this chapter, a description about the non-linear effect will be stated at the beginning. Moreover, this chapter aims to describe BORA and BBN as two methods for modeling non-linear effects. To be specific, a comparison between the advantages and disadvantages of these two methods will be discussed in the rest of this chapter.

5.1 Non-linear Effects

Firstly, it is necessary to understand what the linearity is before understanding non-linearity. As we all know in a mathematical method, two variables "y" and "x", if the influence between "y" and "x" follow a straight line, we say variable "y" and "x" have a linear effect. It can be expressed by the function $y = kx + b$. k and b are constants. In effect, just as its name implies, non-linearity means the influence between two variables do not follow a straight line. It can be curvilinear or with uncertain relationships. Figure 5.1 gives several examples for non-linear effects.

In this chapter, we aim to model the non-linear effects between different human RIFs and human errors (The basic events in the Bayesian networks). For example, according to the Yerkes Dodson Job Performance Curve in the Figure 5.2, this curve illustrates a relationship between arousal and human's work performance. It can be seen that too little or too much arousal gives

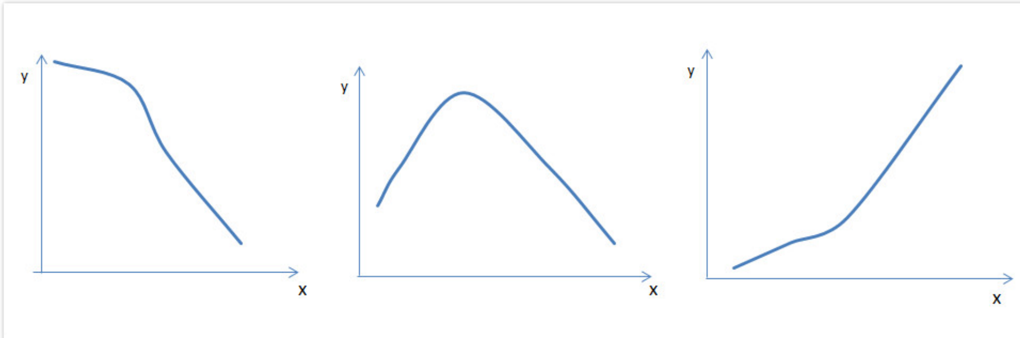

Figure 5.1: Non-linear Effects Examples

negative influence to job performance, as the arousal is appropriate, job performance goes up to the best state. As for human and organizational RIFs, most of the influences are similar, like what the Yerkes–Dodson Job Performance Curve shows. Exactly, this is one type of non-linear effect we want to model.

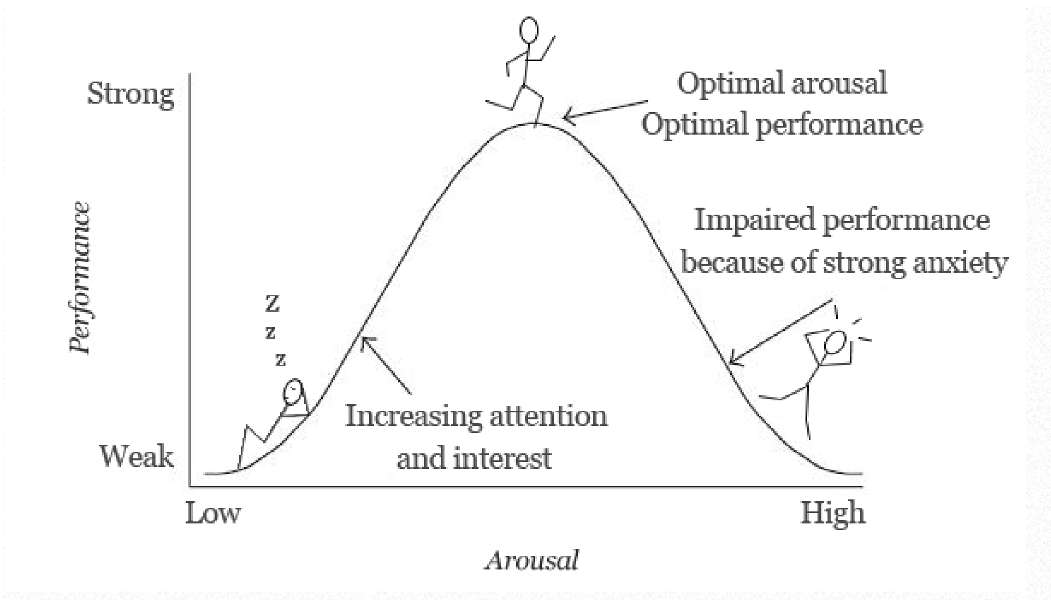

Figure 5.2: Human Performance and Stress Curve (Yerkes and Dodson, 1908)

5.2 Method for Modeling by BORA

BORA (Barrier and operational risk analysis) is a method presented by (Aven et al., 2006), which is for qualitative and quantitative risk analysis of the platform specific hydrocarbon release frequency. It is a convenient method for modeling technical, human, operational, and organizational RIFs of the barrier performance. The specific steps are as follows:

Weight and Score for RIFs

To start with the BORA method, it is necessary to assess the status of the RIFs on the platform. BORA takes measures by weighting and scoring each RIF in order to assign the RIFs' status. Here, weighting the RIFs with the purpose of judging to what degree the RIFs influence the failure of the probability for initial events. Generally, the higher weight stands for the stronger influence. (Bourareche et al., 2015)

The weighting procedure is done by expert judgment. Generally, the RIFs are given relative weights with a five point scale and transferred to a quantitative scale 10 – 8 – 6 – 4 – 2. Firstly, the most important RIF should be determined according to general discussions, and given the value equal to 10. Then, comparing the importance of the other RIFs with the most important one, enable us to give them relative weights on the scale 8 – 6 – 4 – 2. Last of all, the sum of the normalized weights for the RIFs influencing a basic event should be equal to 1 (Aven et al., 2006). In the Table 5.1, there is an example about the weighting procedure by BORA.

Table 5.1: Weighting procedure by BORA

RIF	Importance (weight)					Normalized weight
	10	8	6	4	2	
RIF1					X	0.09
RIF2	X					0.45
RIF3				X		0.18
RIF4			X			0.27
Weight	10	0	6	4	2	1.00
Sum	22					

The scoring procedure of the RIFs aim to assign scores to identified RIFs in the risk influence diagrams. For each RIF, it will be given a score from A to F, where score A corresponds to the best standard in the industry, score C corresponds to industry average, and score F corresponds to worst practice in the industry. In general, there are three methods for scoring : (1) assigning the status of RIFs directly; (2) assigning the status of RIFs based on the result of TTS projects and (3) assigning the status of RIFs based on the result of RNNS (Risk Level on the Norwegian

Continental Shelf) project. Regardless of which method should be use, it is dependent on a specific situation. Sometimes, it need to combine the three methods together to reach a good score procedure. A generic scheme for scoring RIFs is shown in Table 5.2.

Table 5.2: Scoring Procedure based on TTS Projects

Sore(Q)	Description of safety level
A	Status corresponds to the best standard in industry
B	Status corresponds to a level better than industry average
C	Status corresponds to the industry average
D	Status corresponds to a level slightly worse than industry
E	Status corresponds to a level considerably worse than industry average
F	Status corresponds to the worst practice in industry

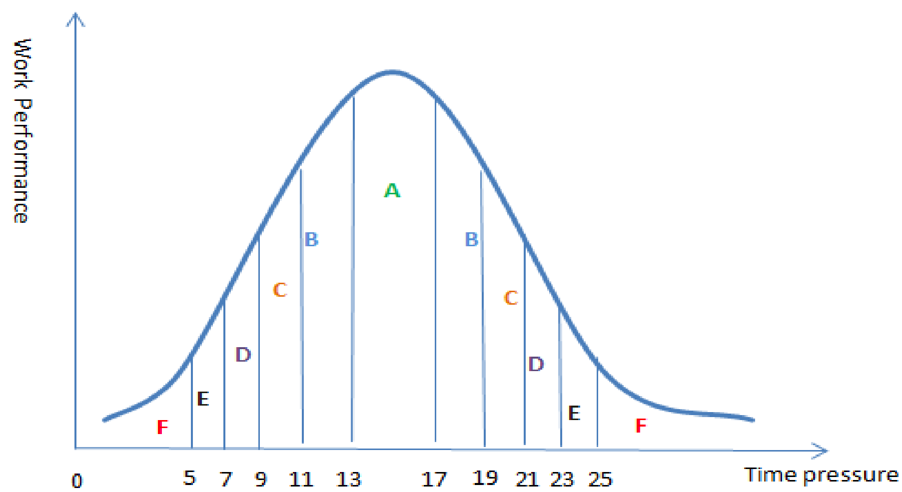

Figure 5.3: Scoring for Non-linear Relationship of Time Pressure and Performance

In terms of the BORA method, non-linear effects can be modeled through a scoring procedure. Based on Figure 5.2, if we suppose arousal to the RIF of time pressure, and combine with the scoring procedure by TTS project, the relationship between time pressure and performance can be divided into six different areas. As is shown in the Figure 5.3, in the area A, workers have the best performance with moderate time pressure; B areas stand for the better performance under time pressure. C areas correspond to average performance with time pressure. E and F areas stand for the worse and worst human performance under different amounts of time pressure. In this section, we use numbers to assume different levels of time pressure. To make it clear, a detailed scoring procedure is shown in the Table 5.3. As a result, all of the RIFs we defined can be scored in this way.

Table 5.3: Score Procedure for Time pressure

Time pressure scope	Score
13-17	A
11-13/17-19	B
9-11/19-21	C
7-9/21-23	D
5-7/23-25	E
0-5/25-	F

Calculating the Specific Installation Probability

$$P_{rev}(A) = P_{ave}(A) \sum_{i=1}^{n} w_i Q_i \tag{5.1}$$

After the weighting and scoring processes for all the RIFs, the equation 5.1 is for calculating the specific probability of installation. P_{ave} is the industry average probability. w_i denotes the weight for each RIF. Q_i is a measure of the status of RIF no. i, and n stands for the number of RIFs. To assign the value of Q_i, we need to associate a number to each of the status scores A - F. Then, Q_i is determined as follow (Aven et al., 2006):

- Determine $P_{low}(A)$ as the lower limit for $P_{rev}(A)$ by expert judgment.
- Determine $P_{high}(A)$ as the upper limit for $P_{rev}(A)$ by expert judgment.
- Then, put for i =1, 2, ... n.

$$Q_i = \begin{cases} P_{low}/P_{ave} & \text{if } S_i = A, \\ 1 & \text{if } S_i = C, \\ P_{high}/P_{ave} & \text{if } S_i = F. \end{cases}$$

Where S denotes the status of RIFs. In order to assign values to Q_i for $S = B$, we assume a linear relationship between $Q_i(A)$ and $Q_i(C)$, and use $S_A = 1$, $S_B = 2$, $S_C = 3$, $S_D = 4$, $S_E = 5$, and $S_F = 6$. Then, we can get $Q_i(B)$ by Equation 5.2

$$Q_i(B) = \frac{P_{low}}{P_{ave}} + \frac{(S_B - S_A)\cdot(1-\frac{P_{low}}{P_{ave}})}{S_C - S_A} \tag{5.2}$$

Similarly, in order to assign values to Q_i for $S = D$ and E , we assume a linear relationship between $Q_i(C)$ and $Q_i(F)$. Then, $Q_i(D)$ and $Q_i(E)$ can be calculated by Equation 5.3 and Equation 5.4.

$$Q_i(D) = 1 + \frac{(S_D - S_C)\cdot(\frac{P_{high}}{P_{ave}} - 1)}{S_F - S_C} \tag{5.3}$$

$$Q_i(E) = 1 + \frac{(S_E - S_C)\cdot(\frac{P_{high}}{P_{ave}} - 1)}{S_F - S_C} \tag{5.4}$$

5.3 Method for Modeling by BBN

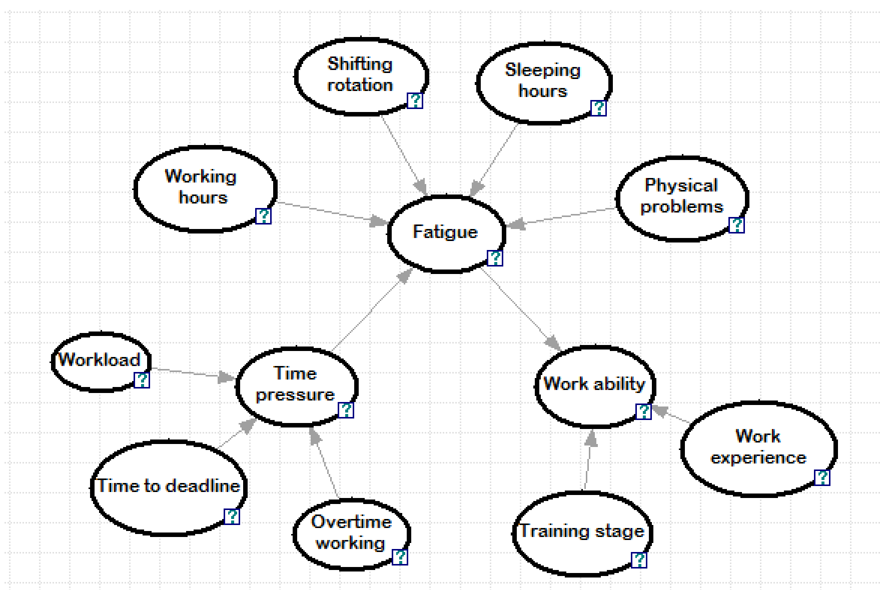

Figure 5.4: An example of BBN model

As for modeling non-linear effects by the Bayesian method, compared to the BORA method, Bayesian focuses on using historical probability instead of weighting and scoring procedures. As we have mentioned in Chapter 4, Bayesian networks consist of a large number of nodes and arrows. In terms of different nodes, we can assign different states for each other in order to model random node variables. Thus, in order to get a joint probability result, the only thing we need to know is the prior probabilities of all the root nodes at different states. Actually, in this way, both linear and non-linear effects can be modeled together. Next, there is an introduction about the detailed steps.

Set up a BBN Model

In this step, we need to identify the RIFs and the dependency between RIFs, then use the arrows to connect each node. To make it simply and in an easy way to understand, this thesis will choose three RIFs which we already measured from last chapter as child nodes and set a simple model so as to illustrate how BBN works. In the BBN model, there is not a strict rule about the types of variables among these nodes. Hence, theoretical and operational variables can be combined in the same model, which means not only RIFs, but indicators also can also be modeled directly into the BBN model. The example is shown in the Figure 5.4

Assign Condition Probabillity Table

So, how to assign the conditional probability table (CPT)? Firstly, because making a complete CPT is quite complicated, in this step, we only focus on a pat of the network from Figure 5.4, which is shown in the Figure 5.5.

From Figure 5.5 we can see that the BBN consists of three nodes "Work ability", "Training stage", "Work experience". Here we use "WA" to stand for work ability, "TS" to stand for training stage and "WE" to stand for work experience. Among these nodes, the child node is "WA", and it is influenced by two parents nodes "TS" and "WE".

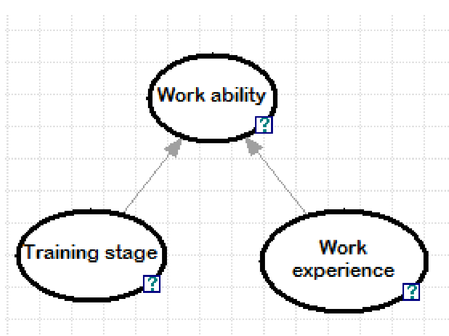

Figure 5.5: An example of BBN model

Assume that nodes "WA", "TS", and "WE" have three states a, b ,c separately. State "a" is accordance with the reference level, state "b" is acceptable with the reference level, and state "c" is unacceptable with the reference level. There will be 3^3 different parent configurations and the CPT will consist 27 probability distributions. See Table 5.4. By calculating the conditional probability, the initial probability for each node related with each state should be assigned. Normally, with regard to the human and organizational factors, the source of initial probability are also judged by TTS projects or RNNS (Risk Level on the Norwegian Continental Shelf) result.

Table 5.4: An example of CPT

	Work experience (WE)		Work ability (WA)		
			P(WA=a)	P(WA=b)	P(WA=c)
Training stage (TS)	a	a	P(WA=a/TS=a,WE=a)	P(WA=b/TS=a,WE=a)	P(WA=c/TS=a,WE=a)
	a	b	P(WA=a/TS=a,WE=b)	P(WA=b/TS=a,WE=b)	P(WA=c/TS=a,WE=b)
	a	c	P(WA=a/TS=a,WE=c)	P(WA=b/TS=a,WE=c)	P(WA=c/TS=a,WE=c)
	b	a	P(WA=a/TS=b,WE=a)	P(WA=b/TS=b,WE=a)	P(WA=c/TS=b,WE=a)
	b	b	P(WA=a/TS=b,WE=b)	P(WA=b/TS=b,WE=b)	P(WA=c/TS=b,WE=b)
	b	c	P(WA=a/TS=b,WE=c)	P(WA=b/TS=b,WE=c)	P(WA=c/TS=b,WE=c)
	c	a	P(WA=a/TS=c,WE=a)	P(WA=b/TS=c,WE=a)	P(WA=c/TS=c,WE=a)
	c	b	P(WA=a/TS=c,WE=b)	P(WA=b/TS=c,WE=b)	P(WA=c/TS=c,WE=b)
	c	c	P(WA=a/TS=c,WE=c)	P(WA=b/TS=c,WE=c)	P(WA=c/TS=c,WE=c)

As a result, after assigning the CPT, we can calculate the joint probability, for any combination of the stats of "WA", "TS" and "WE" by the Equation 5.5

$$P(WA, TS, WE) = P(WE) \cdot P(TS) \cdot P(WA/TS, WE) \tag{5.5}$$

For example, when "WA" is in the state "a", "TS" is in the state "c", and "WE" is in the state "b". The joint probability is :

$$P(WA = a, TS = c, WE = b) = P(WA = a/TS = c, WE = b) \cdot P(TS = c) \cdot P(WE = b)$$

5.4 Evaluation of BORA and BBN

5.4.1 Complexity

There is no doubt that BORA is an easier way to model non-linear effects. The BORA method is convenient but not specific enough for human and organizational analysis. In contrast, BBN is more complicated and needs a large amount of work for assigning the conditional probabilities, but it gives more rigorous solutions than the BORA method.

5.4.2 Data sources

Firstly, regardless of BORA or BBN method, both of them lack the advantage of getting reliable data sources of human and organizational factors. TTS projects and RNNS results seem to be the most frequently-used dataset in the current situation. When it comes to TTS projects, some of the data is not carried out from all the platforms of the NCS and it focuses on the technical aspects more than the human and organizational aspects. Although some data is useable, they are quite out of date and not fresh enough. In addition, The data from RNNS questionnaire is based on the survey and accident investigation. They are not very representative and convincing since the data about the human and organizational factors are from a limited group of employees. Therefore, sometimes, expert judgment should be taken into consideration when we use BORA to score the RIFs or use BBN to assign the CPT.

5.4.3 RIFs Framework

The BORA method requires a quite limited structure for the hierarchy details of RIFs, which is only limited to analysis at one level of RIFs. However, BBN network is more flexible with the multi-level structure. In our case, multi-level BBN structure is better than one level risk influence diagram on the occasion of making a specific and comprehensive risk analysis about human and organizational factors.

5.4.4 Dependency

BORA-Release are considered independent conditions of the RIFs (Aven et al., 2006), which means we can't model the dependency relationships among one RIF to another one in this method. However, human and organizational RIFs are nonrepresentational and in a quite high number usually, they may spread influence and dependency one by one. If we ignore the dependencies of RIFs, the risk result will become meaningless. In terms of this point, BBN method takes mutual dependent RIFs into consideration, which is one more advantage than BORA.

5.4.5 Uncertainty

BBN network has a large advantage by decreasing the uncertainty by a vast number of conditional probabilities distributions. RIF in BBN combined with multi state variables is quite convenient for updating the prior probabilities when new data is available. Thus, a higher degree of certainty can be achieved in this model. However, BORA method doesn't have this advantage.

To sum up, BBN method is more suitable for modeling non-linear effects of human and organizational factors.

Chapter 6

Summary and Recommendations for Further Work

6.1 Summary and Conclusions

In recent years, operational risk analysis has gradually become of greater focus in the offshore oil and gas industry. However, the existing methods for quantitative risk analysis mainly cover the technical area and are not adequate to support operational decisions. The goal of this thesis is to model human and organizational factors for operational analysis. In order to achieve it, the work has been assigned as follows:

- The first three chapters aim to provide information about background knowledge and relevant information of the research study. These parts provide a foundation for understanding and setting an offshore lifting operational risk model for analyzing human and organizational factors.
- The main objective in chapter 4 is to address a case study about how to model human and organizational factors for offshore crane lifting operations. This objective is finished by breaking down all the work operations of offshore cranes according to Task Analysis, Event Tree, Fault Tree, and Bayesian network. Then, in order to measure important RIFs, a method was stated with three steps and showed in the section 4.4.1. Due to limited sources for collecting available data, this thesis described the influencing relationships

between indicators and RIFs in theory instead of offering data support.

- The goal of chapter 5 is to evaluate a specific method for modeling non-linear effects. It has been done by comparing the BORA method and the BBN combined with the aspects of data sources, structure, dependency, complexity and uncertainty. Summing up these aspects, it has been concluded that BBN is a more suitable method for analyzing non-linear effects.

6.2 Discussion

The discussion is divided in four parts: the risk model, measure method for risk influence factors (RIFs), data and expert judgment, and practical applications.

6.2.1 The Risk Model

Combined with the case study in the chapter 4, a risk model is made up by ETA, FTA, and BBN network with the purpose of analyzing the influence from human and organizational factors to offshore crane lifting work tasks. We believe that it is a feasible and comprehensive framework for modeling human and organizational factors. On one hand, the model provides more accurate and credible resolution in consideration of the human RIFs dependency and causal relationships. On the other hand, a BBN network allows for unlimited RIFs levels and provides an aid for handling uncertainty.

However, although a complete model is set up, it is still a big challenge to simulate the final result. A huge BBN network generates the CPT in a large number. It makes the calculation process more complicated and unmanageable. So, reducing the quantity conditional probability tables may be a feasible way on the basis of retaining the original BBN network. Actually, in the paper of Røed et al. (2009), a simple semi-mechanizing method for simplifying CPT has been proposed. This method assigns the CPT depending on determining the R index and the "distance" between the state of the parent node and the child node. But we think a big shortcoming in this method is that the sensitivity of the data is weakened. For example, nodes "A" and "B" have a, b, c, d, e, f six states. The distance between a to d is three states, and the distance between d to f is also three states. However, it is not possible to tell the difference since both distances of them are equal to 3 numerically. Thus, a traditional method for assigning CPT is chose in this thesis instead of using the semi-mechanizing method.

6.2.2 Measure method for Risk Influence Factors

The main method for measuring human RIFs is based on risk indicators in this thesis. We believe that using indicators provides a more credible and accurate value compared with other methods. Actually, as for human RIFs, they can be predicted by evaluating different relevant organizational RIFs instead of risk indicators. The advantage is that human RIFs can be measured before the operational task occurred. Nevertheless, this method can only get a predicted value. Once the operational task is carrying out, human RIFs may have to be reappraised as the result of some unexpected factors have an effect on human behaviors. However, if we use relevant risk indicators, human RIFs can be measured while the operational task occurred. According different operational activities and work tasks, indicators can be more flexible and practical since they are related to the specific and realistic conditions, and the measurement result can be more practical and accurate.

6.2.3 Data and Expert Judgment

In terms of data source, it is quite difficult to search for sufficient available data for human and organizational factors as we have mentioned in the section 5.3.2. Probability, using expert judgment to quantify RIFs is the only way we can do at this time. Yet experts are human too, and can make mistakes just like everybody else. It is difficult to guarantee that there is no bias in the views of expert judgment. If expert judgment is not specific enough, the final risk result will be incredible. However, we couldn't find other available methods except for using expert judgment. Therefore, to minimize experts' mistakes and bias, some measures should be taken such as using a group of experts instead of several experts and therefore, increase the authority of experts.

6.2.4 Practical Applications

The purpose of this thesis has been to develop a risk model that can be used for providing a solution about quantitative analysis of human and organizational factors in offshore lifting operational areas. The risk result is evaluated by a large number of human and organizational risk influence factors, which are measured by risk indicators. In terms of using this model in practice applications, the biggest challenge is to solve the problem about lack of human and organizational data sources. If relevant data are available, we believe that this model is useable for Norwegian offshore lifting facilities.

6.3 Recommendations for Further Work

6.3.1 Short-term goals

There are three steps expecting to be done as the short-term goal:

1 Measure the rest of RIFs defined in the chapter 4. Describe potential indicators and combine with literature information and available data sources.

2 Choose a specific method to assign conditional probability tables. Since there are several methods for assigning CPT, a comparison can be carried out.

3 Search available data sources or combine expert judgment to quantify RIFs.

6.3.2 Long-term goals

The long-term goals will focus on improving our risk model, and expand the model to wider offshore lifting operation areas.

1 Explore solutions to simplify complicated risk models, for example reducing dependency among RIFs.

2 Explore solutions for human and organizational data sources in order to achieve real-time updated and decision support for operational risk analysis.

Appendix A

Acronyms

RAMS Reliability, availability, maintainability, and safety

PSAN Petroleum Safety Authority Norway

RIFs Risk influence factors

BBN Bayesian network

ORIM Organizational risk influence model

BORA Barrier and organizational risk analysis

HCL Hybrid causal logic

Risk-OMT Risk organization human technology

FTA Fault tree analysis

HOF Human and organizational factors

RNNP Risk Level on the Norwegian Continental Shelf

I-Risk Integrated risk

SoteRiA Social-technical risk analysis

RID Risk influence diagram

USCG United States Coast Guard

TSB Canada Canadian Transportation Safety Board

MAIB United Kingdom Marine Accident Investigation Board

Bibliography

ABS (1991). Guide for certification of cranes. Technical report, American Bureau of Shipping, https://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA

Authority, C. A. S. (2013). Safety behaviours human factors resource guide for engineers.

Aven, T., Sklet, S., and Vinnem, J. E. (2006). Barrier and operational risk analysis of hydrocarbon releases (bora-release): Part i. method description. *Journal of hazardous Materials*, 137(2):681–691.

Baker, C. and McCafferty, D. (2005). Accident database review of human element concerns: What do the results mean for classification? In *Proc. Int Conf.Human Factors in Ship Design and Operation, RINA Feb*. Citeseer.

Baker, C. C. and Seah, A. K. (2004). Maritime accidents and human performance: the statistical trail. In *MARTECH 2004, Singapore, September 22-24, 2004*, https://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA20Repository/References/TechnicalMa

BC, W. (2014). The dangerous of fatigue in the workplace. http://www2.worksafebc.com/.

Belenky, G., Wesensten, N. J., Thorne, D. R., Thomas, M. L., Sing, H. C., Redmond, D. P., Russo, M. B., and Balkin, T. J. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. *Journal of sleep research*, 12(1):1–12.

Bill Hauser, B. L. and Rhome, W. (1998). Findings and recommendations of the crane accident workgroup. Report, Engineering & Operations Division, http://pbadupws.nrc.gov/docs/ML0110/ML011020015.pdf.

Bourareche, M., Nait-Said, R., and Ouazraoui, N. (2015). Implementing bora in oil and gas process case study: Algerian industry. In *Industrial Engineering and Operations Management (IEOM), 2015 International Conference on*, pages 1–8. IEEE.

Casebook, B. C. M. A. (2008). One dead, one missing as offshore crane fails. https://maritimeaccident.wordpress.com/2008/02/28/one-dead-one-missing-as-offshore-crane-fails/.

Darby, F. and Walls, C. (1998). Stress and fatigue: Their impact on health and safety in the workplace. *Occupational Safety & Health Service of Department of Labour*.

Dlouhy, J. A. (2011). Worker killed in offshore crane accident near galveston. http://fuelfix.com/blog/2011/08/18/worker-killed-in-offshore-crane-accident-near-galveston/.

Elliott, M. A. (2010). *Contributions to risk-informed decision making*. PhD thesis, Massachusetts Institute of Technology.

Energy, F. (2015). Offshore crane operation and maintenance program. Technical report, Fieldwood Energy, https://semsportal.fieldwoodenergy.com/Public/Safe

Gertman, D., Blackman, H. S., Marble, J. L., Byers, J., Smith, C., et al. (2005). *The SPAR-H human reliability analysis method*. Division of Risk Analysis and Applications, Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission.

Gordon, R. P. (1998). The contribution of human factors to accidents in the offshore oil industry. *Reliability Engineering & System Safety*, 61(1):95–108.

Gordon, R. P., Flin, R. H., Mearns, K., Fleming, M. T., et al. (1996). Assessing the human factors causes of accidents in the offshore oil industry. In *SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference*. Society of Petroleum Engineers.

Gran, B., Bye, R., Nyheim, O., Okstad, E., Seljelid, J., Sklet, S., Vatn, J., and Vinnem, J. (2012). Evaluation of the risk omt model for maintenance work on major offshore process equipment. *Journal of Loss Prevention in the Process Industries*, 25(3):582–593.

Halberg, F., Nelson, W., and Cadotte, L. (1977). Living routine shifts simulated on mice by weekly or twice-weekly manipulation of light-dark cycle. *Proc XII Int Soc Chronobiol*, pages 133–138.

Haugen, S., Vinnem, J., Brautaset, O., Bye, R., Nyheim, O., Seljelid, J., and Wagnild, B. (2015). Risk information for operational decision making in oil and gas operations. *Safety and Reliability of Complex Engineered Systems: ESREL 2015*, page 405.

Health, W. and Regulator, S. E. S. O. W. C. (2015). Effects of fatigue. https://www.worksafe.qld.gov.au.

Huisman. Heavy lifting equipment. Technical report, Huisman, https://www.huismanequipment.com.

Hull, J. P. (2011). Offshore industry focuses on crane safety. http://www.offshore-mag.com/articles/print/volume-63/issue-11/technology/offshore-industry-focuses-on-crane-safety.html.

ILM, N. (2014). Workplace pressure fuels uk overtime culture. Technical report, Institute of Leadership and Management.

Jensen, F. V. and Nielsen, T. D. (1992). Bayesian networks and decision graphs. *Statistics*.

Klein, S. (2010). Working overtime may harm the heart, study says.

Lamond, N., Dorrian, J., Roach, G., McCulloch, K., Holmes, A., Burgess, H., Fletcher, A., and Dawson, D. (2003). The impact of a week of simulated night work on sleep, circadian phase, and performance. *Occupational and Environmental Medicine*, 60(11).

Le Coze, J.-C., Plot, E., Hourtolou, D., and Hale, A. (2003). Comparison between two organisational models for major hazard prevention. In *International Conference on Safety and Reliability (ESREL 2003)*, pages 431–438.

Lehmann, S., Neill, M., et al. (2013). Closing the operational assurance loop to establish line of sight on cumulative risk and improve safety performance. In *SPE Americas E&P Health, Safety, Security and Environmental Conference*. Society of Petroleum Engineers.

Løge, F. A. (2012). Development of a new framework for consideration and incorporation of human and organizational factors in the lifecycle of an engineering project.

Mohaghegh, Z., Kazemi, R., and Mosleh, A. (2009). Incorporating organizational factors into probabilistic risk assessment (pra) of complex socio-technical systems: A hybrid technique formalization. *Reliability Engineering & System Safety*, 94(5):1000–1018.

Øien, K. (2001a). A framework for the establishment of organizational risk indicators. *Reliability Engineering & System Safety*, 74(2):147–167.

Øien, K. (2001b). Risk indicators as a tool for risk control. *Reliability Engineering & System Safety*, (2).

OPITO (2012). Opito approved standard.

Parkes, K. R. (2007). Working hours in the offshore petroleum industry. *Department of Experimental Psychology*.

Ram, N. (2013). Guidelines for controlling reversing vehicle. Guideline, Petroleum Development Oman L.L.C, http://www.pdo.co.om/hsems/Documents/Guidelines/GU

Rausand, M. (2013). *Risk assessment: theory, methods, and applications*, volume 115. John Wiley & Sons.

Reason, J. (1990). *Human error*. Cambridge university press.

Røed, W., Mosleh, A., Vinnem, J. E., and Aven, T. (2009). On the use of the hybrid causal logic method in offshore risk analysis. *Reliability engineering & System safety*, 94(2):445–455.

Schmidt, F. L., Hunter, J. E., and Outerbridge, A. N. (1986). Impact of job experience and ability on job knowledge, work sample performance, and supervisory ratings of job performance. *Journal of applied psychology*, 71(3):432.

SEATRAX. Technical report, http://www.seatrax.com/cranebasics.html.

Shipp, A. J. and Fried, Y. (2014). *Time and Work, Volume 1: How Time Impacts Individuals*. Psychology Press.

Spencer, M., Robertson, K., and Folkard, S. (2006). The development of a fatigue/risk index for shiftworkers. *Health and Safety Executive Report*, 446.

Van Echtelt, P., Lindenberg, S., and Glebbeek, A. (2006). Time, stress and fun: Why work overtime and what harm does it do? dissertaties rijksuniversiteit groningen.

Veritas, B. (2011). Rules for the certification of lifting appliances onboard ships and offshore units. Rule note nr 526, Marine Division, http://www.veristar.com/portal/rest/jcr/repository/collaboration/sites

Wang, C. (2007). *Hybrid causal logic methodology for risk assessment*. ProQuest.

Yang, X. and Haugen, S. (2015). Classification of risk to support decision-making in hazardous processes. *Safety science*, 80:115–126.

Yerkes, R. M. and Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of comparative neurology and psychology*, 18(5):459–482.

Zhang, J. (1998). Fatigue's influence on crew's efficiency. *Journal of Shanghai Maritime University*.