



Universitetet
i Stavanger

DET TEKNISK-NATURVITENSKAPELIGE FAKULTET

MASTEROPPGAVE

| | |
|---|--|
| Studieprogram/spesialisering: Master i Risikostyring/Offshore sikkerhet | Vårsemesteret, 2011 Åpen / Konfidensiell |
| Forfatter: Silje Røsnes | (signatur forfatter) |
| Fagansvarlig: Terje Aven (UiS) Veileder: Ole Magnus Nyheim (Safetec Nordic AS) | |
| Tittel på masteroppgaven: Risk indicator model – Application to dropped loads due to crane operations Norsk tittel: Risikoindikatormodell - Anvendelse for fallende last grunnet kranoperasjoner | |
| Studiepoeng: 30 | |
| Emneord: Risk indicator model Crane operations Dropped loads | Sidetall: 91 + vedlegg/annet: 7 Stavanger, 15. juni 2011 |

*How is it possible to see when a routine lift is gradually changed to a non-routine job?
When you are exposed to a hazardous environment over some time you gradually become less aware of the dangers around.*

Anne Drinkwater, leader of the business unit, after a fatal crane accident on Gyda 2002

Preface

This paper is the result of my Master's Thesis in Risk Management with a specialisation in Offshore Safety. It was executed over 18 weeks during spring of 2011 and is the final step in graduating with a M.Sc. degree in Risk Management at the University of Stavanger. The Thesis was carried out at the Department of Industrial Economics, Risk Management and Planning in collaboration with Safetec Nordic AS.

The aim of this paper was to develop and test a risk indicator model for dropped loads due to crane related operations.

Last semester I got the chance to write a report on risk associated with lift operations in arctic conditions after a course on Svalbard with Kristine Prøsch. And when I had a chance to write a Thesis on a combination of risk indicators and dropped loads due to crane operations the subject fell very naturally to me. The knowledge on arctic climate conditions is from this unpublished report on risk associated with lift operations in arctic conditions. The different factors in the developed risk model are inspired from the risks that were examined in the same report.

I would like to thank my two supervisors, Terje Aven at UiS and Ole Magnus Nyheim at Safetec Nordic AS for patiently reading and giving good advice during the preparation of this report.

Many thanks to Finn Inge Thomassen and Kenneth Kråkstad at Rogaland Kranskole (Rogaland Crane School) for answering my questions and giving me a better understanding of lift operations and valuable input to my Thesis.

The report had not been as successful without their assistance.

Abstract

Today crane and lifting operations contribute significantly to the risks in the petroleum industry. They are responsible for a minor percentage of serious injuries, but have a large number of fatalities in relation to unwanted events. Nine out of ten fatal accidents that have occurred during petroleum activities on Norwegian shelf since 1994 have occurred in connection with lifting operations.

There has been recent development in triggering causes for falling loads, this years RNNP report has re-categorized the causes for dropped objects due to crane related operations and there is a need to test models which monitors the risk due to these new causes. One element in monitoring is by measuring a set of risk indicators.

The purpose of the Thesis is to develop and test a risk indicator model for dropped loads due to crane related operations through a literature review and case study. The newly developed MARI model was found to be suitable for this purpose. This is a new area of application for this risk indicator model that should be further explored.

The case study showed a change in risk of dropped objects during offshore operations in different geographical locations in the North Sea and the Barents Sea, and that this could be measured with the developed indicators. Changing the risk level in factors and associated risk indicators in an early phase, pre-condition and planning phase does not necessarily end in an unacceptable high-risk level for the event. If the indicators in the later phases are good and low risk, they reduce the risk transferred on to the event.

These factors were adjusted to have the highest risk through the case study in the Barents Sea:

- Environmental conditions
- Maintenance plan and procedures
- Economy
- Design of Crane
- Regulations

For the location in the North Sea this only applies for environmental conditions and maintenance plan and procedures.

The information in the developed indicators can help monitor risk and be used for several purposes for different groups. Personnel on all levels concerned with the day-to-day operations can use the information as a basis for improvement of their own work. It will increase their knowledge and understanding of the hazards around them. Management can be helped to make informed decisions about risk reducing measures and the effect of these.

Table of Contents

| | | |
|-------|---|----|
| 1.0 | Introduction | 1 |
| 1.1 | Background..... | 1 |
| 1.2 | Objective | 2 |
| 1.3 | Limitations..... | 2 |
| 1.4 | Structure..... | 2 |
| 2.0 | Theory on Risk Indicators..... | 4 |
| 2.1 | Definitions of risk indicators..... | 4 |
| 2.2 | Leading and lagging risk indicators..... | 6 |
| 2.3 | Formal requirements for risk indicators..... | 10 |
| 3.0 | Risk indicator model..... | 12 |
| 3.1 | The MARI model..... | 12 |
| 3.2 | Adaption of risk indicator model to new field..... | 16 |
| 4.0 | New field – Background information | 18 |
| 4.1 | Characteristics of crane operations..... | 18 |
| 4.2 | Accident statistics..... | 19 |
| 4.3 | Environmental conditions in the North Sea and Barents Sea | 31 |
| 4.3.1 | Wind condition | 31 |
| 4.3.2 | Polar lows | 32 |
| 4.3.3 | Currents | 32 |
| 4.3.4 | Ice condition and icing..... | 33 |
| 5.0 | Case Study..... | 36 |
| 5.1 | The sites in the North Sea and the Barents Sea | 36 |
| 5.2 | Effect on lift operations in the Barents Sea..... | 37 |
| 5.3 | Factors influencing falling loads related to crane operations | 39 |
| 5.3.1 | Pre-conditions..... | 39 |
| 5.3.2 | Planning | 41 |
| 5.3.3 | Activity – level..... | 44 |
| 5.3.4 | Activity – performance | 46 |
| 5.3.5 | Activity – control functions..... | 47 |

| | | |
|-------|--|----|
| 5.4 | Developing Potential Risk Indicators | 49 |
| 5.4.1 | Pre-conditions | 50 |
| 5.4.2 | Planning | 52 |
| 5.4.3 | Activity - level | 53 |
| 5.4.4 | Activity - performance | 54 |
| 5.4.5 | Activity – control functions | 55 |
| 5.4.6 | List of factors, indicators and properties | 56 |
| 6.0 | Results | 62 |
| 7.0 | Discussion | 74 |
| 7.1 | Generally on risk indicators | 74 |
| 7.2 | Contribution to risk indicator model and area of application | 76 |
| 8.0 | Conclusions | 78 |
| 8.1 | Further studies | 78 |
| 9.0 | Bibliografi | 80 |

Figures

| | | |
|--------------|--|----|
| Figure 2.2-1 | Leading and lagging indicators | 7 |
| Figure 2.2-2 | Process safety indicator model | 9 |
| Figure 2.3-1 | Indicators measuring parts of a factor | 11 |
| Figure 3.1-1 | Illustration of the MARI model | 12 |
| Figure 3.1-2 | Layers of factors | 13 |
| Figure 3.1-3 | Risk model | 16 |
| Figure 4.1-1 | Offshore crane | 18 |
| Figure 4.2-1 | Percentage of incidents per work process, 2002-2010 | 20 |
| Figure 4.2-2 | Staffing in the area where the object hit, 2002-2010 | 21 |
| Figure 4.2-3 | Percentage of incidents per energy class | 21 |
| Figure 4.2-4 | Number of incidents by work processes, 2002-2010 | 22 |
| Figure 4.2-5 | K_LL and K_LOE 2002-2010, all cause categories | 24 |
| Figure 4.2-6 | F: External events | 25 |
| Figure 4.2-7 | B: Human activity, introducing latent hazard | 26 |
| Figure 4.3-1 | Barent Sea Buoy | 31 |
| Figure 4.3-2 | Polar low over the Barents Sea | 32 |
| Figure 4.3-3 | Current Pattern | 32 |
| Figure 4.3-4 | Sub-areas with uniform ice conditions | 33 |

Figure 4.3-5 Breaking ice in Canada (O'Morchoe, 2009)..... 34

Figure 5.1-1 Location in the North Sea..... 36

Figure 5.1-2 Location in the Barents Sea..... 37

Figure 5.2-1 Lift operations in arctic regions (Polartrec, 2010)..... 38

Figure 5.3-1 Risk Model..... 48

Figure 5.4-1 Risk indicator model with factors..... 64

Figure 5.4-2 Risk indicator model using MARIT (MARI Tool)..... 65

Figure 5.4-3 Calculation example 66

Figure 5.4-4 Risk Indicator model North Sea..... 69

Figure 5.4-5 Risk Indicator model Barents Sea..... 70

Figure 5.4-6 North Sea model detail 71

Figure 5.4-7 Barents Sea model detail early phases 72

Figure 5.4-8 Barents Sea model later phases 73

Tables

Table 6.4-1 Quantification of risk indicators 66

Appendices

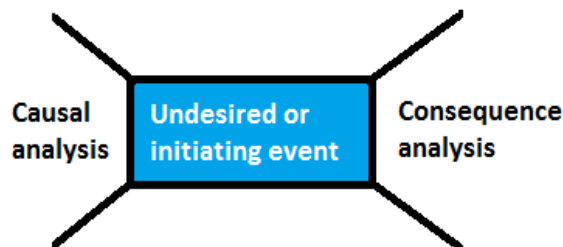
Appendix A: Accidents from 2005 till today A

Terminology

Accidental Event Event or chain of events that may cause loss of life and damage to health, assets, or the environment

Barrier Measure that reduce the probability of realising a hazard’s potential for harm and of reducing its consequence. Barriers may be physical (materials, protective devices, shields, segregation, etc.), or non-physical (procedures, inspection, training, drills). (International Organization for Standardization, 2000)

Bow Tie Bow Tie Model (Vatn, 2006)



There exist several models for the “causal analysis” and the “consequence analysis”. The most common has a “Fault tree analysis” on the left side and an “Event tree analysis” on the right. But it can also be an influence diagram for frequency on the left side and an influence diagram for consequence on the right.

DFU Defined Hazard and Accident situation

Error A generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency (Reason, 2000)

KPI Key Performance Indicator

Major Accident acute occurrence of an event such as a major emission, fire, or explosion, which immediately or delayed, leads to serious consequences to human health and/or fatalities and/or environmental damage and/or larger economical losses (NORSOK Z-013, 2010)

MARI model Major Accident Risk Indicator model. Newly developed risk indicator model by Safetec Nordic AS

Personal Safety Affect individuals. Typically incidents such as falls, trips, crushings,

| | |
|-----------------------|--|
| Hazard | electrocutions and vehicle accidents (Hopkins, 2009). |
| Polar lows | Polar lows are small and intense low pressures formed in the cold Arctic air over the northern seas in winter. |
| Process Safety Hazard | Arise from processing activity. Typical process safety incidents involve the escape of toxic substances and the release of flammable material that may or may not result in fires or explosions. Many process safety incidents either damage the plant or have the potential to damage the plant. Potential to generate multiple fatalities (Hopkins, 2009). |
| PSA | The Norwegian Petroleum Safety Authority |
| PTW | Permit To Work |
| RIF | Risk influencing factors. In this context defined as an aspect of a system or an activity, of which status/condition directly or indirectly might influence the probability of an event to occur, and/or the consequences of the event if it occurs. |
| Risk | Risk is a combination of the probability of occurrence of harm and the severity of that harm. (NORSOK Z-013, 2010) |
| Risk description | Risk is described by (A, C, C*, U, P, K), where A is the initiating event or activity, C equals the consequences of the activity, C* is a prediction of C, U is the uncertainty about what value C will take, and P is the probability of specific events and consequences, given the background information K" (Aven, 2008, p.21). |
| Risk indicator | A risk indicator is a measurable quantity that provides risk relevant information (Vinnem et al., 2003) |
| RNNP | Trends in Risk Level. Annual report from the PSA that aims to measure and improve health, safety and environmental conditions in the petroleum activities offshore and at the petroleum facilities on land. |
| Uncertainty | Lack of knowledge, about observable quantities in particular (Aven, 2008) |

1.0 Introduction

1.1 Background

Safetec Nordic AS is currently developing a method for monitoring major accident risk combining traditional risk modelling and key performance indicators of safety critical elements. The risk modelling is based on causal chains to illustrate the relationship between risk influencing factors and how these affect a specific major accident event. Experience from risk based research projects like the SINTEF indicator project (Øien & Sklet, 2001) and BORA (Haugen et al., 2007) is used as basis.

Indicators have been used to improve safety and support decision-making in other offshore fields, such as for hydrocarbon releases in processing plants. For indicators to be useful they need to have certain qualities. The indicators should be sensitive to change, show the relationship between other indicators, and be pro-active. It is a point to develop indicators that are relevant for the day-to-day operation, both routine and critical, so that it is possible to reduce the risk of an operation before it takes place.

In the Norwegian sector there is an average of two lifts per minute carried out by offshore cranes alone (North Sea Offshore Authorities Forum, Multi-National Theme Audit, 2008). Lifting operations are considered critical operations, as there is a high frequency of lifts and potential high risk involved. They are responsible for 14% of accidents with severe personnel injuries in the oil and gas sector and have a large number of fatalities in relation to unwanted events (PSA, 2008).

Nine out of ten fatal accidents that have occurred during petroleum activities on Norwegian shelf since 1994 have occurred in connection with lifting operations (PSA, 2011). Experiences gained in the petroleum industry up to the present have amply demonstrated the risk inherent in these activities.

The last decade the focus on crane and lifting operations has increased (PSA, 2008) (PSA, 2005), but there is still a way to go in controlling the risk. There has been recent development in triggering causes for falling loads, this years RNNP report has re-categorized the causes for dropped objects due to crane related operations and there is a need to test models which monitors the risk due to these new causes. One element in monitoring is by measuring a set of risk indicators.

1.2 Objective

The purpose of the Thesis is to develop and test a risk indicator model for dropped loads due to crane related operations.

To help solve the main thesis problem the project will establish a set of adequate factors and indicators for dropped objects due to crane related operations.

A case study will be performed to test the sensitivity of the indicator set and see if there is a change in risk of dropped objects during offshore operations in different geographical locations, and that this can be measured with the selected indicators. The locations are the North Sea about 320 km southwest of Stavanger in the Ekofisk area with well-known conditions and in the Barents Sea close to Bjørnøya. An area with high wind speeds, that is susceptible to polar lows, icing and usually have sea ice every winter.

1.3 Limitations

Dropped objects is a rather large topic as defined in RNNP under DFU 21 (PSA, 2010, p.212); *“incidents in which an object falls more than zero yards in the facility's safety zone, either on deck or in the sea with the potential to develop into an accident [...] Assessment of the DFU 21 includes the assessment of staffing, work processes involved, energy (weight and height of fall) and barrier failure”*. This thesis will only deal with dropped objects due to work processes related to internal lift on the installation and loading and off-loading between installations or between a vessel and an installation. The reason for selecting these two categories of lift is that they are found to be similar in initiating events and causes for dropped loads. Other types of lift operations from the RNNP classification not included in the thesis are work processes related to passive structure and maintenance of crane.

1.4 Structure

The second chapter will go into basic theory and use of risk indicators.

The third chapter presents the risk indicator model, the Major Accident Risk Indicator (MARI) model developed by Safetec Nordic AS and the adaption for use in a new field.

Chapter four looks into the background knowledge available for crane operations and falling loads and environmental conditions in the North Sea and the Barents Sea.

In chapter six the case study uses the risk indicator model and looks into the cause side of dropped loads from crane related operations.

Results from the case study are presented in chapter 6

Chapter 7 is a discussion on risk indicators, contribution to risk model and dropped loads due to crane operations.

The conclusions from the report are in chapter 8.

2.0 Theory on Risk Indicators

This chapter presents the basic theory used in this thesis and is divided into three sections. Section 2.1 reviews definitions of risk indicators. The second chapter looks into the discussion on leading/lagging indicators and finally the third chapter will define and analyse requirements for indicators.

2.1 Definitions of risk indicators

A risk indicator can be defined in general terms as *"a measurable/operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality"* (Øien, 2001). This embraces widely and the main point is that indicators tell us something about a phenomenon that is not measurable in it self. Another definition is *"an observable phenomenon that shows the state of another, not directly observable phenomenon"* (Kise, 2008). It is supposed to clarify and establish insight when the phenomenon itself is too complicated to measure directly. Competence of the lift crew for example, is an important factor in an operation, but a person's capability can be difficult to measure. However, the number of years with relevant experience a crane operator has is easier to note and gives some insight to personnel's competence. The establishment of factors and risk indicators for crane related work processes are more thoroughly investigated in chapter 5.3 and 5.4.

The definition that will be used throughout the Thesis is that a risk indicator is a measurable quantity that provides risk relevant information (Vinnem et al., 2003). The reason for selecting this definition is that not only must the phenomenon be measurable but also be relevant for the context and present important information in a clear and understandable manner.

The issues in question are then; what information are we looking for? And what information can we hope to find? On a general basis risk indicators can be used to identify some areas of difficulty for operations. Vinnem et al. (2003, p.8) mentions some points:

- Problem areas
- Basis for trend analysis
- Basis for predicting future accident exposure
- Evaluation of risk reducing measures
- Long-term risk management strategies

Problem areas

Risk indicators can identify problem areas by, among other things; injury rates, technical errors or areas experiencing a lot of delays. Monitoring of risk indicators will focus attention on crucial risk factors, and provide a tool for identifying and rectifying deviations from the assumptions made in the risk analysis. The information can be used for different groups on all levels concerned with the day-to-day operations. Increasing the knowledge and understanding of the hazards around personnel is a good basis for improvement of their own work. More specific, risk indicators should identify problem areas related to the operation that can cause injury/fatalities to personnel as well as near accidents with potential to harm personnel (Vinnem et al., 2003). In addition, the status of safety barriers should be monitored.

Basis for trend analysis

The main reason for measuring process safety performance is to provide ongoing assurance that risks are being adequately controlled. By saying that the starting point is having risk indicators with a certain value, then changes in these values will imply change in the risk level. The intention is to get an early warning of any trends that finally may result in inability to meet risk acceptance criteria as presumed or established in a risk analysis (Vinnem, 2007).

Periodic monitoring will give the organization opportunity to compare results and reveal the developing trend (Rausand & Utne, 2009). Key Performance Indicators (KPIs) are already in use by operating companies for a variety of purposes (Popova & Sharpanskykh, 2010). Some examples are production rates, maintenance backlogs, production downtime, etc. Using risk indicators for process safety performance could easily be part of the day-to-day operations of any oil and gas company as an addition to KPIs.

Basis for predicting future accident exposure

Hindsight shows that if early warnings had been revealed and managed in advance, the undesired incident could have been prevented (Øien et al., 2011). According to HSE (2006) many organisations does not gather the information needed to show how well they are managing major hazard risks. They limit measurements to failure data like incidents or near misses to monitor performance. This leads to changes or improvements being implemented after a procedure have gone wrong. By using risk indicators to discover weaknesses or deteriorations in safety critical systems early on will reduce cost and consequences.

Evaluation of risk reducing measures

Management can be helped to make informed decisions about risk reducing measures and the effect of these through risk indicators. A proactive use of the indicator makes it possible to include risk impact in activity planning, in particular when deciding where to implement risk-reducing measures (Vinnem et al., 2004)

Vinnem et al. (2004) explains further that the use of risk indicators is an effective way to follow up QRA studies during the operations phase. By monitoring the changes in risk level it should be possible to identify parameters or indicators that have a strong impact and what effect risk reducing measures have on the risk level.

Long-term risk management strategies

Managing risk is an important property of risk indicators. Use of indicators assists a proper distribution of resources by addressing the largest safety hazards first (Rausand & Utne, 2009). The risk managers can test their activity plans and combinations, before finalizing their strategies. Unwanted high-risk periods may be avoided through risk indicators, and they could serve as a tool to boost involvement in and understanding of important safety issues. (Vinnem et al., 2004).

Reports from companies who have implemented process safety performance indicators are positive. They have increased assurance on risk management and a better protected reputation. The suitability of their risk control systems has been demonstrated and discovery of weaknesses through costly incidents have been avoided. Companies have saved cost by stopping collection and reporting performance, which was no longer relevant and made better use of information already collected for other purposes (HSE, 2006).

2.2 Leading and lagging risk indicators

A leading risk indicator is a measurable quantity that provides information about risk, explicitly addressing future “performance of key work processes, operating discipline, or protective barriers that prevent incidents” (American Petroleum Institute, 2010). These are designed to indicate problems or weaknesses in barriers before an accident or unwanted event and are an important part in proactive monitoring and safety performance (Ruud, 2010).

Lagging risk indicators is a measurable quantity based on outcomes of accidents and incidents. According to HSE (2006) the previous focus has been on failure data to monitor performance. They are retrospective in the sense that they require reporting and investigation of specific

incidents and events to discover weaknesses in that system before changes or improvements are determined.

To get a visual understanding of leading and lagging risk indicators see the Swiss Cheese Model (Reason, 1997) in Figure 2.2-1 below. In this figure incidents are described by series of weaknesses (holes) in the layers of defenses, barriers and safeguards.

The leading indicator identifies weaknesses or “holes” in aspects of the risk control system discovered during routine checks system (HSE, 2006). Key actions or activities are systematically checked to see if the critical activity within the risk control is undertaken as intended. They can be considered as measures of process or inputs essential to deliver the desired safety outcome.

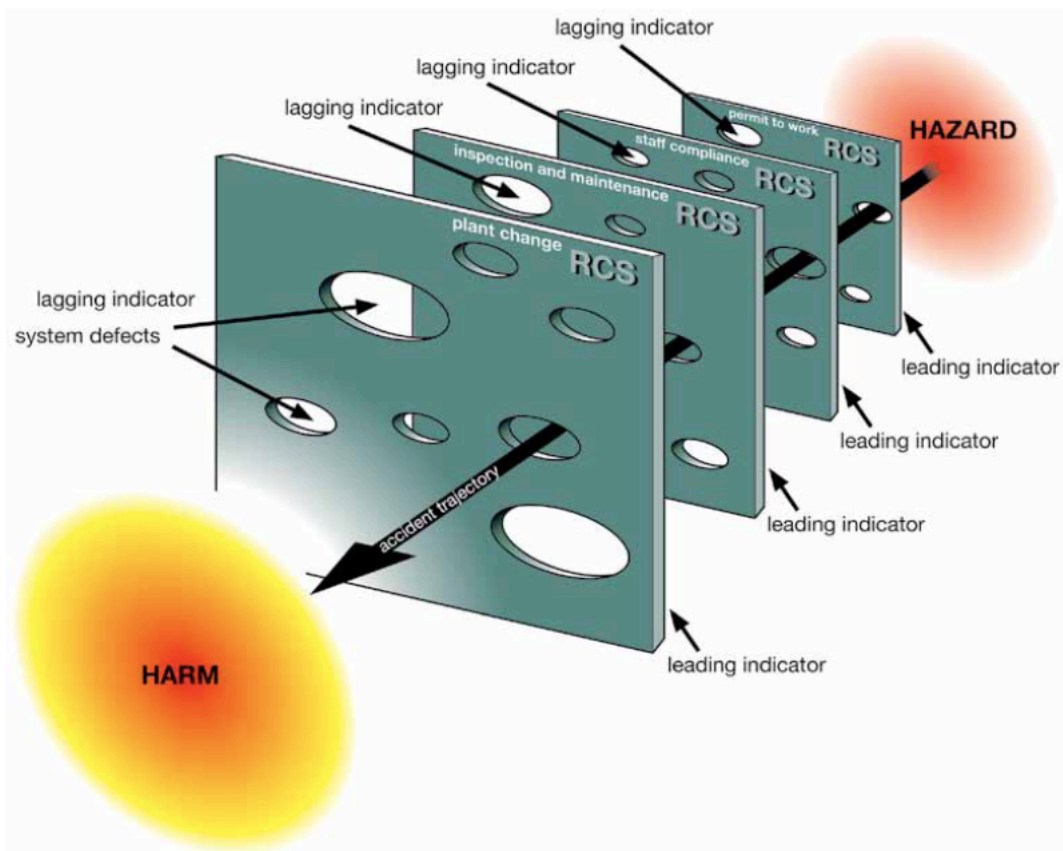


Figure 2.2-1 Leading and lagging indicators

The lagging indicator reveals weaknesses or “holes” when a desired safety outcome has failed, or has not been achieved. (HSE, 2006). These incidents do not have to result in major damage or injury and can be a near accident, precursor event or undesired outcome providing that they represent a failure of a significant control system which guards against or limits the consequences of a major incident.

Lead/lag debate

There is an on-going debate on the use and development of major hazard indicators in the industry.

Dyreborg takes the relativistic view of using lead and lag indicators. He argues that a lag performance indicator measured at a point in the Risk Control System (RCS) in the HSE guide could be a lead performance indicator for the next point. The measure of the performance of the risk control system could be *“perceived as a leading or a lagging indicator, depending on whether the focus is prospective or retrospective”* (Dyreborg, 2009, p.475).

Hopkins criticises Dyreborg’s example that an injury rate is a lag indicator from a company point of view, but a lead indicator from the perspective of a regulatory authority because it can be used to decide which industries to target. He argues that this is problematic for two reasons. Firstly, that injury rates could be considered as a leading indicator is contrary to all usages and will lead to confusion. Secondly, he criticises Dyrborg for making the assumption that companies cannot use injury rates to determine intervention strategies. He states that *“provided injuries are occurring relatively frequently, the data can certainly be analysed at company level to identify the hazards or accident mechanisms involved and thus to determine intervention strategies”* (Hopkins, 2009, p.509).

Another view is the absolutist, or bow tie, explaining that the distinction is absolute (Hale, 2009) (Hudson, 2009) (Webb, 2009). All indicators to the left of the top event are leading indicators, while all on the right side are lagging. The top event is a state of which control of the process has been lost. Hopkins disputes this position saying that incidents involving flaring and unplanned shutdowns to prevent a loss of containment are still a few barriers away from disaster (Hopkins, 2009). According to the bow tie perspective these are lead, not lag indicators as the process remains under control.

The American Petroleum Institute has taken another approach and uses Heinrich’s model to present a predictive relationship exists between lower and higher consequence events that relate to process safety. Heinrich introduced the accident pyramid in 1931. This represents two key concepts. The first is that safety accidents can be placed on a scale representing the level of consequence, and the second is that many precursor incidents occurred with lesser consequences for each accident that occurred with greater consequences (American Petroleum Institute, 2010).

Indicators that are predictive are considered leading indicators and may be used to identify a weakness that can be corrected before a higher consequence event occurs. Figure 2.2-2 depicts a process safety pyramid with four classifications or tiers. Tier 1 is the most lagging with consequences like loss of primary containment and Tier 4 is the most leading, measuring precursor events and barrier system weaknesses.

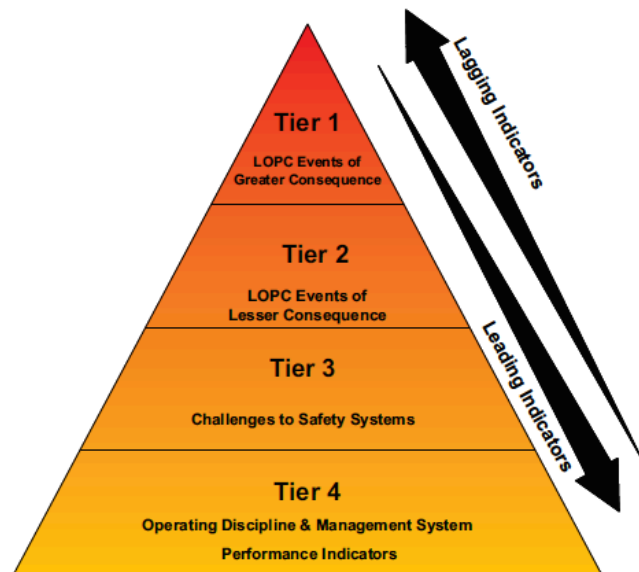


Figure 2.2-2 Process safety indicator model

Vinnem (2010) states that leading risk indicators are preferred over lagging risk indicators. This is consistent with PSA's focus in the industry (PSA, 2010). This suggests that there is more motivation in reporting indicators that say something about the robustness in terms of withstanding incidents, compared to performance in the sense of occurrence of near misses and incidents. For major hazard risk indicators in high reliability industries where even precursor events may be rare events this is particularly crucial.

However, if the risk control measures suggested that the safety management system was improving, but the accident rate increased, the conclusion would be that the state of the safety management system was deteriorating. (Hopkins, 2009)

Conclusion for this thesis

This debate demonstrates the need for a unified theoretical foundation and good knowledge of past developments (Øien et al., 2011).

It is believed that major hazards require a proactive approach to ensure effective management of risk. Switching the importance in favour of leading indicators is thought to be an important step forward in the management of major hazard risks (HSE, 2006).

There needs to be a balance in developing risk indicators between concentrating on direct indicators that have enough data to be meaningful, and focusing on indirect indicators having enough data and providing early warnings, but with less direct safety relevance. Information to confirm that critical systems are operating as intended is essential whether leading or lagging risk indicators are used. One approach specified by Øien et al. (2011) is to focus on indirect

indicators only to the extent necessary, e.g. where there is either lack of data or specific need for early warning information.

The view that will be used throughout the Thesis is that the risk indicator will be lagging or leading according to the factor it measures. Leading indicators try to show if the system is working as intended, the lagging indicators seek to answer whether the unwanted outcomes occur (Ruud, 2010). This statement is up for debate as one can argue that something must happen to be able to measure it. In this context barrier events or deviations discovered during maintenance, and not specifically happening during operations are leading indicators. Thus, discovered before it had made any significance for the operation. While lagging indicators are errors leading to delays in operations or incidents.

2.3 Formal requirements for risk indicators

The requirement for use of risk indicators in a company may be a bit different in a regulatory context. The objectives are somewhat different, but the overall objectives can be broken down into more refined specifications. All types of risk indicators should comply with the following proposed requirements (Vinnem et al., 2003, p.9):

- Observable and quantifiable
- Sensitive to change
- Transparent and easily understood
- Robust against manipulation
- Valid

It must be possible to observe or measure the proposed risk indicator in some form. The lagging risk indicators should address a range of incidents, from the insignificant near misses up to the most severe and complex accident sequences. Aspects that are thought to have an impact on future risk exposure, leading risk indicators, must also be measurable. Usually, the indicators are expressed on a ratio scale of measurement, *such as the number of hydrocarbon leaks (>0.1 kg/s) per installation year, or per 1 million manhours* (Vinnem, 2010, p.777).

The trends for the risk indicators must be monitored relatively continuously, which requires that the risk indicators are suitable to identify changes within a relatively short time span. Indicators reflecting individual systems are required along with a limited set of overall indicators that present an aggregated picture.

The risk indicators must be adapted to the users theoretical background so the meaning is clear for all personnel. Also, it is desirable that the risk indicators do not require complex calculations, but are more closely related to intuitiveness. Decreasing number of observations

should correspond to an improvement. If very complex calculations are required, the confidence may be lost (Vinnem, 2010).

The point is that the risk indicator cannot allow the organization to “look good” by for example changing reporting behaviour, rather than making the necessary basic changes that reduce accident risk. (Vinnem, 2010) Dale and Beyeler (2001, p.6) observe, “*lack of robust procedures for selecting indicators makes it difficult to validate the information provided by those indicators*”.

There is no point in establishing indicators if there is no connection to the possibility of an unwanted incident. The usefulness and relevance for the measurements must be considered. For risk indicators to be valid they need to cover human, organizational, and technical aspects, not just the latter as is often the case.

Measuring the condition of one aspect of reality using risk indicators can be problematic. There will with very few exceptions be possible to measure all aspects of a factor. This means that the indicator(s) identified to measure the variation in performance for a given factor will only cover a fraction of the “real” variation and leave the rest to uncertainty, see figure 2.3-1

There will also always be room for discussion around whether the selected indicators represent the intended objective. This uncertainty could be partially compensated for by weighting the influence that the different indicators have on each factor, based on the fraction of reality they are supposed to cover.

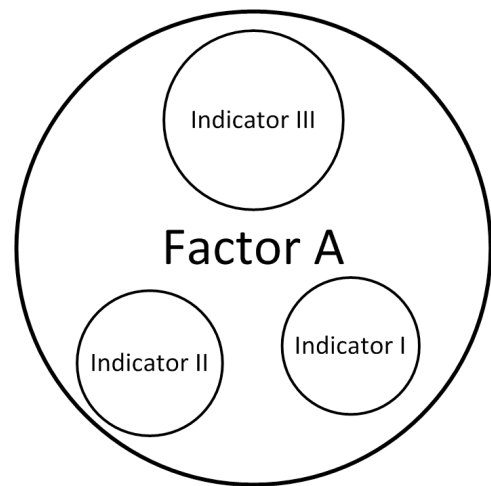


Figure 2.3-1 Indicators measuring parts of a factor

3.0 Risk indicator model

This chapter will go into the risk model used in this Thesis. Section 3.1 introduces the Major Accident Risk Indicator (MARI) model developed by Safetec Nordic AS. Section 3.2 looks into the adaption of the MARI model to dropped loads from crane operations.

3.1 The MARI model

This section will explain the MARI model and the area of use. The model is under continuous development and has been made available for this Thesis in close cooperation with Safetec. It is based on Haugen et al. (2011) and other internal sources in Safetec Nordic AS.

The Major Accident Risk Indicators (MARI) model combines traditional risk modelling and key performance indicators of safety critical elements. The risk modelling is based on causal chains to illustrate the relationship between risk influencing factors and how these affect a specific major accident event. Experience from risk based research projects like the SINTEF indicator project (Øien & Sklet, 2001) and BORA (Haugen et al., 2007) is used as basis.

Structure

Figure 3.1-1 below shows the structure of the model. There are several factors influencing the probability of an accidental event to occur. Each of the factors is associated with a set of indicators, measuring the state of each risk-influencing factor. This helps monitoring the risk associated with the certain event.

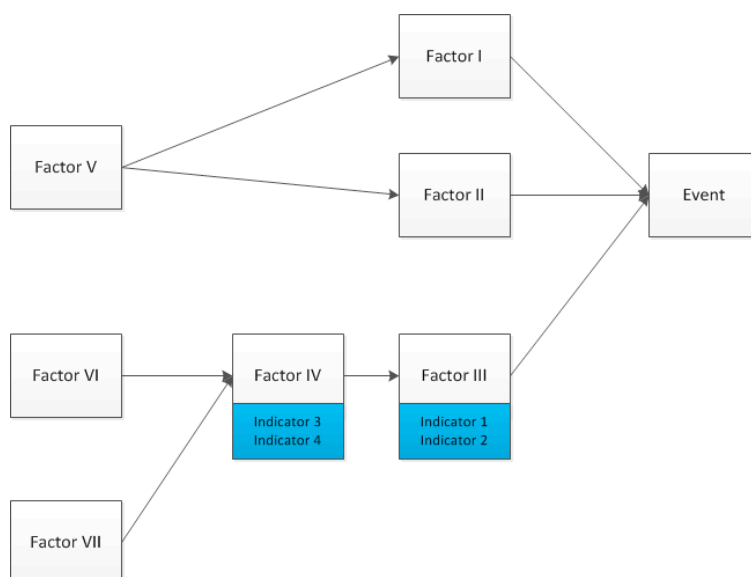


Figure 3.1-1 Illustration of the MARI model

An event is in this context defined as an incident that either involves actual or potential devastating consequences to a system/facility. The main focus in the process of method development has been on major accident scenarios or incidents with major accident potential.

A risk influencing factor (RIF) could in this context be defined as an aspect of a system or an activity, of which status/condition directly

or indirectly might influence the probability of an event to occur, and/or the consequences of the event if it occurs.

A given factor (e.g. competence) might not be directly measurable. Therefore it is necessary to establish a set of indicators to measure the “real” condition of the “immeasurable” factors; in other words create operational variables that represents the theoretical variable of each factor.

Identification of all relevant factors that influence the event has to be performed. This is done using the principles of a classic risk model, with causal chains that result in an accident and subsequent consequences when an accident occurs. This approach gives a systematic identification of how a wide diversity of factors influences the development of a major accident. These factors may be identified from a wide range of categories, from management systems, technical systems/barriers, and operational parameters, as well as organisational factors like competence, communication, and working environment.

Layers

When all key factors of a certain major accident scenario are identified, these factors will have to be arranged and ordered in a suitable manner, to allow influences (links) between different factors to be established. In the MARI model the factors are arranged according to their distance in time from the operations and accidents.

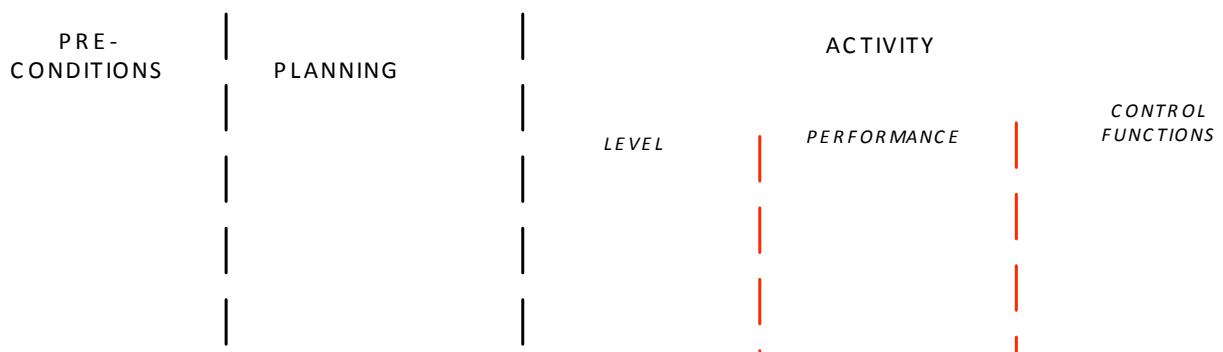


Figure 3.1-2 Layers of factors

Based on this ordering, the factors may be categorised into the following layers:

- **Preconditions;** contains factors whose conditions are pre-determined and/or changed infrequently, e.g. environmental conditions, design basis, regulations, company policy.
- **Planning;** contains factors whose conditions are determined during pre-operational planning, e.g. operational plans/procedures, maintenance plans/procedures, competence plans.
- **Activity;** contains factors whose conditions are influenced through daily operation, e.g. activity level, work performance.

All factors located within each of these “layers” share the same characteristics when it comes to determining the risk status of the event. The risk of an event is not only dependent on the “activity factors”, but also other factors whose conditions are determined prior to daily operations.

In order to make the model a useful tool for risk management in daily operations, the Activity-layer is further differentiated into three sub-layers, as listed below:

- **Level:** contains factors that describe the activity level for the different operations, e.g. how often is maintenance on HC-containing equipment performed
- **Performance:** contains factors that describe the performance of the different activities in accordance with specific procedures, e.g. best practice
- **Control functions:** contains factors that describe control of the different work operations, e.g. verifications, inspections

An example will illustrate this; the activity levels are dependent on the operation plan, the performance of the work is dependent on the procedures describing the work and the personnel performing the work etc.

Qualitative and quantitative

When the qualitative framework has been established, this is used as a basis for developing indicators. This is performed based on the identified risk models for each event. In some cases, the identified factors may be more or less directly transformed into indicators, while in other cases it is necessary to specify measurable indicators. When a feasible set of indicators is selected, each indicator has to be specified by its properties. Further, evaluation criteria of each indicator are determined and sources for data collection are suggested.

The indicators may now be used qualitatively in order to monitor the trend in the major accident risk level. However, a quantification of the model will further improve the opportunities for monitoring how the trend of a single or a few indicators could influence the total risk level. The quantification may be done in several ways, but a simple and useful method is based on assigning each indicator an initial score based on its observed status. This gives the associated factor a calculated value.

However this score will in many cases be influenced by the status of other factors. The final score of an indicator could be described as a function of a) the initial score of the indicator(s), b) the value (calculated score) of influencing factor(s), c) the weight expressing the importance of influencing factors, and d) the distribution in strength between values of the influencing factors.

Risk model

The phases influence each other from left to right towards the event.

First, there are many factors that influence the risk. It is not feasible to monitor all, but it is important to have an understanding of the whole picture, in order to be able to monitor the important factors.

Second, many factors influence risk only indirectly through others. However, they may still be important for the end result.

Third, decisions made early in the design process or in the operations planning may have a significant impact on major accident risk.

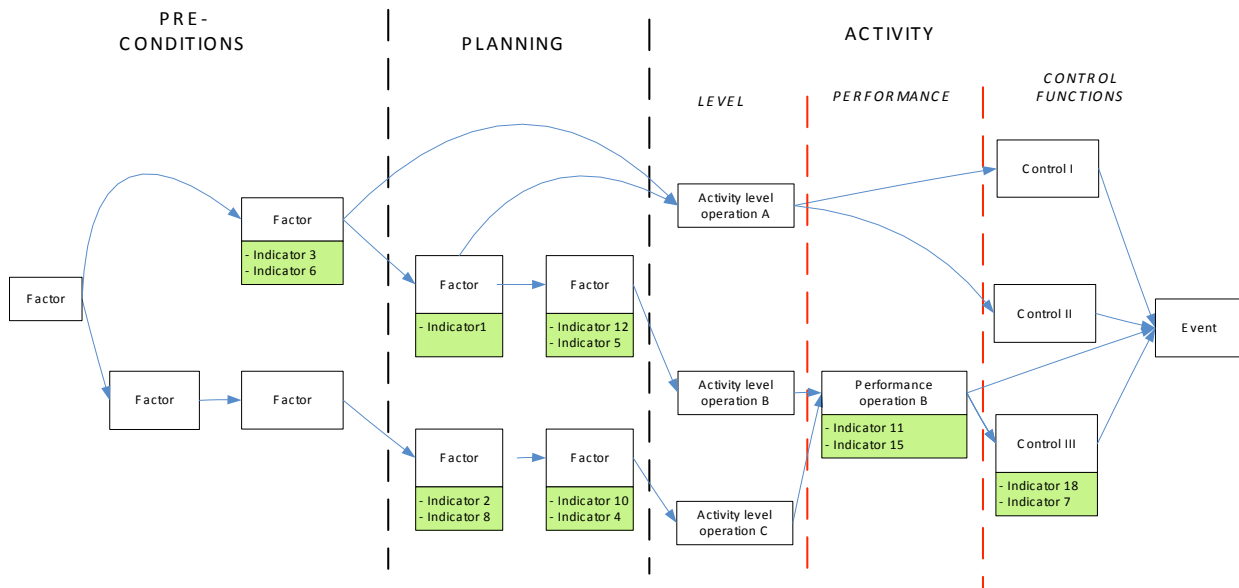


Figure 3.1-3 Risk model

3.2 Adaption of risk indicator model to new field

This section will investigate the changes needed to use the MARI model for dropped load due to crane related operations.

The MARI model was developed for major accident risk and dropped objects are normally not considered as major accidents, but rather as occupational accidents. However, MARI can be more than a tool for major accidents. The method has a generic value and the model for establishing a performance measurement system could also apply to lift operations, as they require a high level of assurance that systems and procedures continue to operate as intended.

Risk indicators in the form of process safety indicators are relevant for major accident incidents. Most of the previous research on risk indicators is tied to process safety indicators and is not necessarily directly transferable to the dropped loads. Monitoring major accident risk is difficult because accidents are rare and monitoring therefore requires use of indirect measures rather than statistics (Haugen et al., 2011)

According to Vinnem (2007) there are three different hazard mechanisms that have to be considered when approaching dropped loads: Loss of containment events due to loads dropped on process equipment. The other hazard mechanism is loads dropped on buoyancy compartment of floating platforms which can lead to critical loss of buoyancy, in the worst case even leading to capsize or sinking of the platform. The last mechanism to be considered is loads

dropped on subsea structure and equipment. This could result in damage and possible loss of containment from subsea equipment, including pipelines.

As mentioned in chapter 1.1 crane and lifting accidents are a major issue in the oil and gas sector today. Crane and lifting operations contribute significantly to the risks in the petroleum industry. They are responsible for only a small percentage of serious injuries, but have a large number of fatalities in relation to events. As much as nine out of ten fatal accidents that have occurred during petroleum activities on Norwegian shelf since 1994 have occurred in connection with lifting operations (PSA, 2011).

Considering the definition in NORSOK Z-013 Risk and emergency preparedness analysis of a major accident *“an acute incident, such as a major discharge/emission or a fire/explosion, which immediately or subsequently causes several serious injuries and/or loss of human life, serious harm to the environment and/or loss of substantial material assets.* (2010), then dropping loads from crane could be considered to fall into that category.

There have been analyses for correlations between leak occurrences and falling objects, but the results were inconclusive. Some models show significant correlation while others do not.

As the cargo handled weighs several tonnes, dropped loads could easily cause fatalities. Falling objects are one of the most common causes of serious occupational injury and use of personal protective equipment is not sufficient to avoid serious injury (Vinnem et al., 2010).

Dropped objects from crane can be seen as a precursor to major accident and consist of both personal and process safety hazards. The consequences of dropped loads from crane have major accident potential which is the area of use for the MARI model.

4.0 New field – Background information

The chapter is divided into three parts. The first part is a presentation of crane operations and goes into details around the lift crew's job responsibilities. The second part outlines the experience gained by the petroleum industry on the Norwegian shelf in connection with falling objects caused by crane-related work processes. The third part introduces environmental conditions in the North Sea and the Barents Sea.

4.1 Characteristics of crane operations

This section presents crane operations and planning of a lift and the lift crew's job according to NORSOK R-003 (2004).

An offshore crane is a lifting device where the load can be lifted vertically and horizontally in several directions. Offshore cranes are installed for general use in the oil and gas industry on



Figure 4.1-1 Offshore crane

offshore installations to lift cargo between supply vessels, barges or semi-submersibles. Lifting of containers, pipes and other cargo are common tasks for offshore cranes.

The lifting operation consists of all administrative and operational activities before, during and after moving the load and the lifting equipment is ready for a new cargo. Each lifting operation shall be planned in order to ensure safe execution and that all predictable risks are taken into consideration. Personnel

who have the relevant competence shall carry out the planning.

The crane team comprise primarily of crane operator, slinger and signaler. The crane operator is responsible for maintaining the safety of each lift and is central in planning the lift operation in accordance with NORSOK R-003N § 4.4 (2004). The crane operator has the overall safety responsibility in the job. It is a requirement that crane operators have the knowledge and competence to assess risk and prevent accidents. During operations there is ongoing communication through the headset and microphone with the crew on the ground. Crane operators must also lead inspection of equipment used.

The slinger's main objective is to perform the hooking and unhooking of the lifting equipment used for the current load, and ensure that the equipment selected is controlled and suited for the load. He will also participate in planning the lifting operation.

The signaler's tasks is to be in radio contact with the crane operators and slinger at the beginning and end of a lift. The signaler then uses previously agreed hand and arm signals or messages over the radio.

The planning of lifting operations has several points to ensure safety, among others; making sure all personnel involved are familiar and competent for the task at hand; getting work permits for critical lifting operations; having barriers in place to prevent personnel from walking or standing under suspended load and restrict other personnel from entering the lift zone.

For repeated or routine operations, such planning is only necessary the first time, provided that an operating procedure is in place or documented in another way. Periodic revisions shall be carried out to ensure that no critical factors have changed.

For complex lifting operations like lifts in a blind spot, where the crane operator does not have direct visibility of the cargo or landing area, it requires careful planning and good communication between all involved.

When loading and unloading of supply vessels the risk of squeeze is higher for the slinger and other personnel due of movement due to waves and wind. The storage on oil and gas installations is often limited so slinger and signaler must plan the placement of cargo carefully.

Operations with an offshore crane shall be halted when one of three things occur. Firstly, if the crane operator considers further operation unsafe; secondly, if wind speed or wave height exceeds 80 % of the crane's design limit, and lastly if any movements on the mobile installation make it difficult to carry out the operation in a safe and controlled manner. This is installation specific and limit values for movements must be pre-determined before use of any offshore crane. If the operation is stopped, it can only be resumed after reviewing the "Checklist for lifting operations under marginal weather conditions" in Annex K of the NORSOK R-003.

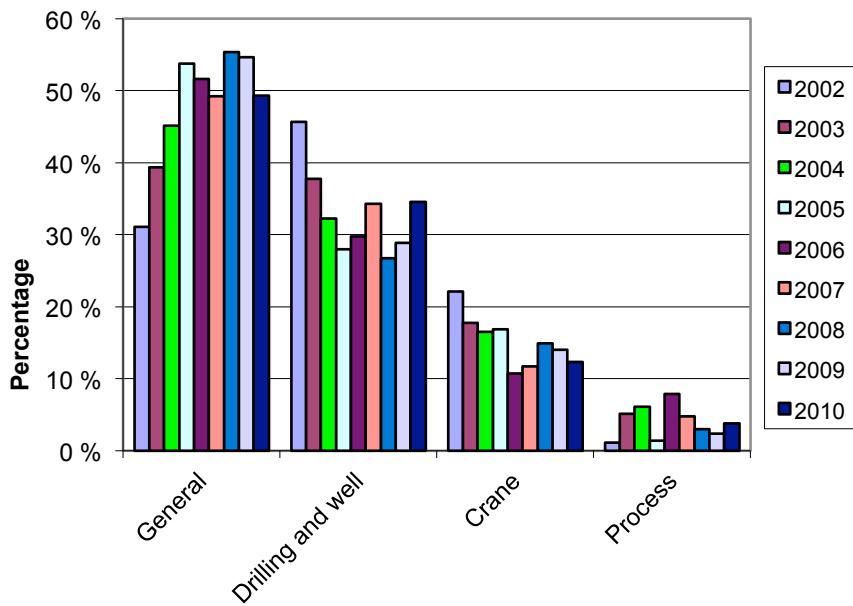
4.2 Accident statistics

The number of serious incidents associated with lifting operations with offshore cranes on the Norwegian shelf has been greatly reduced in recent years. However, it seems like the causal relationships when incidents do occur have been the same the last 16 years. This is consistent with historical statistics from the years 1994-2004 (Ptil, 2005).

Despite the positive trend, there have been seven fatalities on installations throughout the 16-year period, three involving offshore cranes, four in connection with other lifting operations (Scandpower, 2005) (PSA, 2007). In addition, there have been two fatal accidents on supply boats with offshore cranes directly involved. Also, there have been several incidents involving serious injury. The last fatal accident was in 2007, but several of the incidents in later years could have led to fatalities under slightly different circumstances.

Statistics on dropped objects is one of the topics in the RNNP (Trends in risk level) project governed by the PSA (Petroleum Safety Authority). The project attempts to express the risk level from occupational accidents and major hazard risks on installations both offshore and onshore on the Norwegian Continental Shelf. A variety of data related to major accident risks, barriers, serious injuries and selected work environment factors are collected and analysed. The presentation of these indicators has emphasis on relative trends and contributions and the results are presented in annual reports.

The RNNP defines DFU (Defined Hazard and Accident situation) 21 as *“incidents in which an object falls more than zero yards in the facility's safety zone, either on deck or in the sea with*



the potential to develop into an accident [..]

Assessment of the DFU 21 includes the assessment of staffing, work processes involved, energy (weight and height of fall) and barrier failure” (PSA, 2010, p.212).

As can be seen from figure 4.2-1 crane operations stand for a little over 10% of the number of incidents for dropped objects in 2010.

During previous years

Figure 4.2-1 Percentage of incidents per work process, 2002-2010

crane-related work processes, has been responsible for more than 20% of the incidents (2002), but has shown a declining trend during the last nine years.

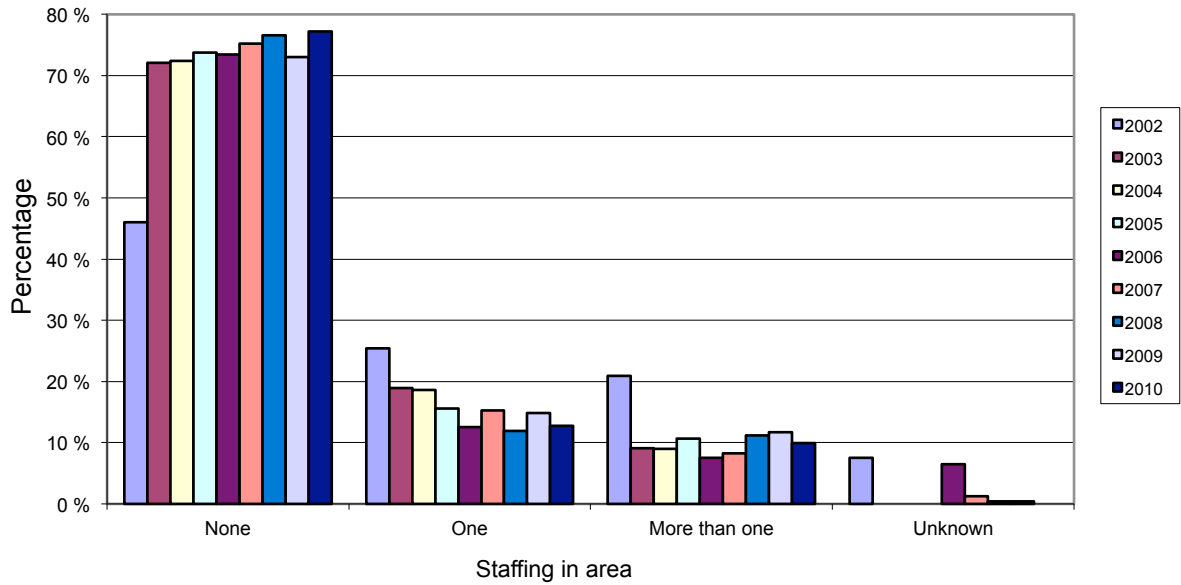


Figure 4.2-2 Staffing in the area where the object hit, 2002-2010

Most incidents have no personnel in the area according to figure 4.2-2. The trend is stable and slightly inclining towards 80 %. This still means that one in five accidents have the potential to immediately harm personnel.

Crane related work processes stands out from drilling, process and other work processes as they have the highest concentration of incidents in the two highest energy classes. For the other work processes the two middle energy classes dominate the picture (PSA, 2010, p.190)

Figure 4.2-3 shows the percentage of incidents per energy class for crane related work processes. Around 47 % of the events in 2010 are in energy class C (J 100-1000). There is a large variation in the events in this category, both in terms of weight and height of fall. In addition to damage to

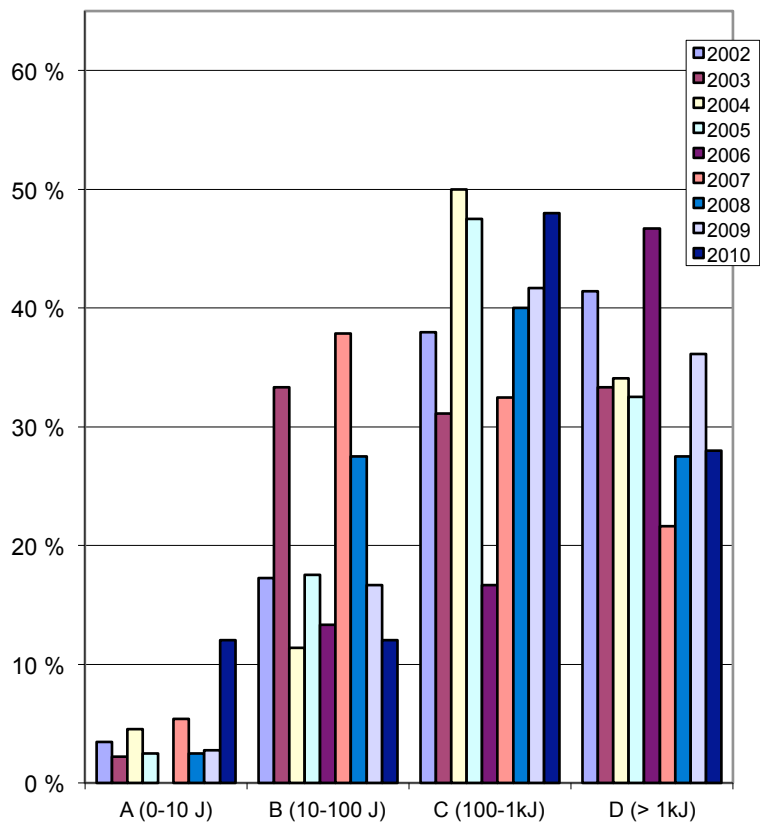


Figure 4.2-3 Percentage of incidents per energy class

personnel, such events could cause material damage, but rarely penetrate the decks or roofs.

Energy Class D includes falling objects with energy exceeding 1 kJ. These constitute 28 % of the events in 2010. This category has events such as "container fell 4 feet onto the deck. " These events can cause significant damage, depending on location, and will lead to downtime in addition to being potentially harmful for multiple personnel.

RNNP has defined four different crane related work processes. The work processes relevant for this Thesis are:

- K_LL, which includes work processes related to loading and off-loading between installations or between a vessel and an installation.
- K_LOE, which includes work processes related to internal lift on the installation

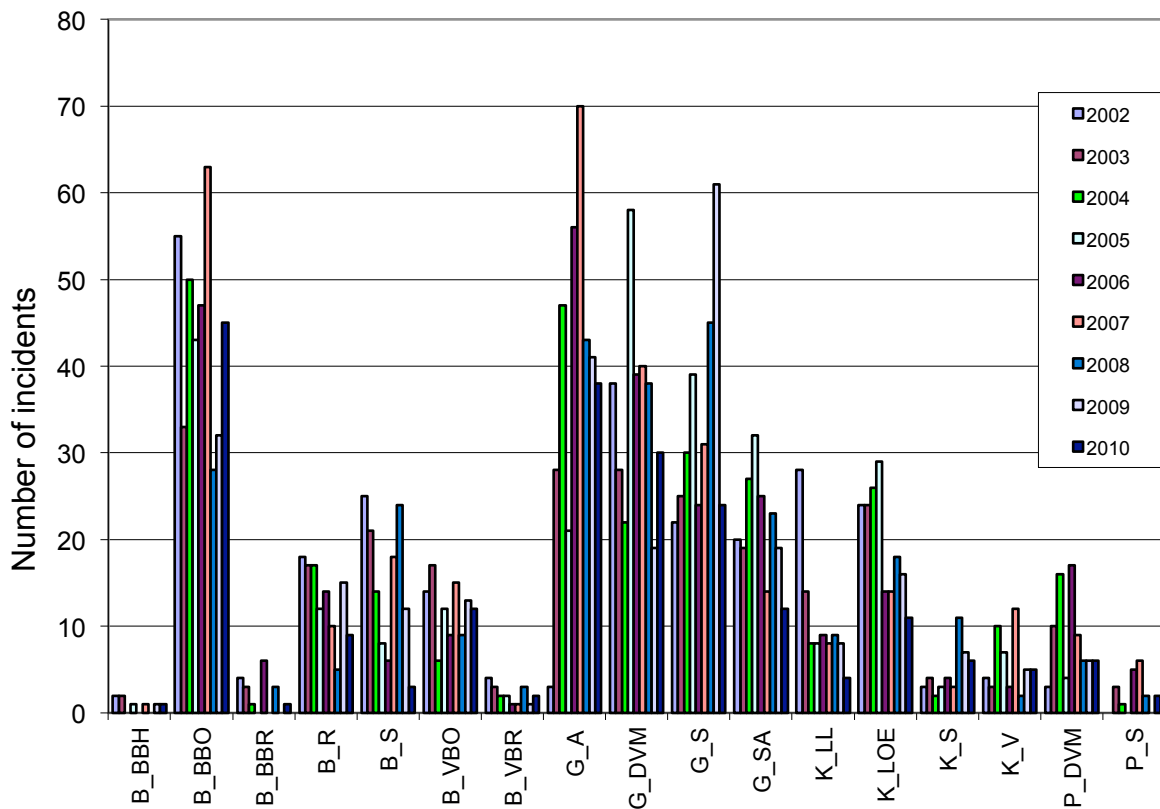


Figure 4.2-4 Number of incidents by work processes, 2002-2010

Internal lifts (K_LOE) on the installation have the overall largest proportion of incidents with a yearly average of 20 incidents since 2002. Internal lifts had an inclining trend in 2002-2005, and then plummeted in 2006, before starting another climb.

Loading and off-loading (K_LL) gave the highest contribution to incidents to crane related work processes in 2002 with nearly 30 incidents, but has since been stable on around 6-7 yearly incidents.

Still, it is difficult to spot any clear trends. The PSA believes this may be due to several factors: The first being that there is no development on the continental shelf related to the reduction and improvement of work processes that can lead to falling objects, or if the development means that one takes more risk in operations. Or it could be that improvement efforts and the effect of this are not measured. Another reason may be that the risk indicators are not normalized, meaning that they are not optimal for the purpose (PSA, 2010).

This years RNNP report has established the accident categories from generic BORA-categories (Seljelid et al., 2011). Six generic categories were developed to cover initiating causes of all incidents:

- A. **Technical degradation or failure** – Deviations characterized by (slow) degradation of the system until a failure eventually occurs. An example of this type of deviation is corrosion.
- B. **Human activity introducing latent hazard** – Deviations characterized by human performance of an activity that introduces a hazard into the system that at some later point in time could cause a failure if it is not detected
- C. **Human activity immediately triggering an incident** – Deviations characterized by human performance of an activity that immediately causes an incident. What is special in this case is that there are no barriers between the deviation and the accidental event, although there are barriers to prevent the initial deviation from happening.
- D. **Unexpected deviations from planned operation** – Deviations which are “internal” to the well or process system, whether this is caused by the production flow by a process operator error in these cases, it is the operation of the process system itself that causes the release. An example of such an initiating event would be overpressure in a well or in a tank.
- E. **Design** – Deviations related to errors in design that are not known, and/or not meaningful or possible to introduce specific barriers to protect against.
- F. **External events** – Deviations caused by impact from external activities or the natural environment. e.g. impact from a dropped load that is causing a process release.

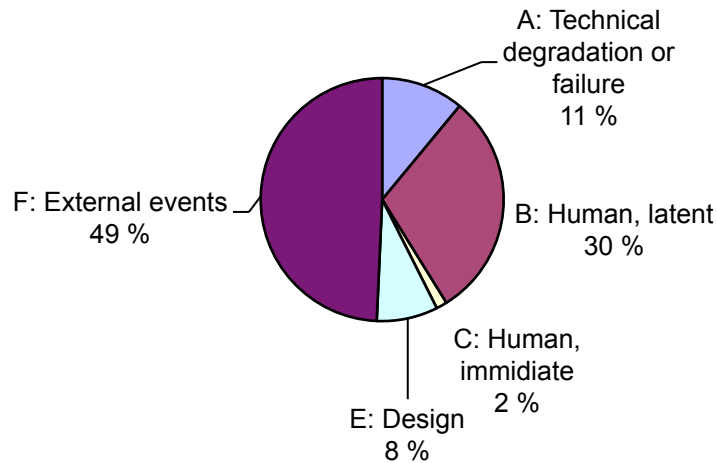


Figure 4.2-5 K_LL and K_LOE 2002-2010, all cause categories

The incidents are categorised based on initiating event. Taking a closer look on the statistics from 2002-2010 the causes for incidents in internal lifts and loading and off-loading are mostly latent human error and from external events. These make up for 79 % of all incidents.

Technical degradation or failure is the third largest cause with 11 % of all incidents. The incident types in this category are degradation or fatigue in the material, corrosion due to harsh environment or overload of equipment or structure resulting in sudden fracture.

Design is the cause of 8 % of accidents. Incidents in this category are ergonomics or workplace design that complicates safe execution. Layout is another contributor to this category, meaning that workspace design complicates safe execution of work tasks. There could be incidents due to error or weaknesses in design or malfunction of equipment that is difficult to know before execution of an activity/work task.

The Thesis takes a closer look at the main cause categories F, external events and B, human activity introducing latent hazard for K_LL and K_LOE in for K_LL and K_LOE on the following pages.

From category F in figure 4.2-6 more than 90 % of the causes are from F3: Impact from hooking/bumping, making this the most important factor due to external events. Hooking situations often cause overload on lifting equipment. Two examples from incidents caused by hooking / bumping are presented below. Hooking: *“During lifting of a pipe (50kg), from G 22 to*

G33, the hoisting arrangement got hooked in structure on G33 causing the lifting strap to fail, resulting in a 30m drop.” Bumping: “In connection with a lift of scaffolding material, the tip of the crane boom rail on crane 2 bumped into the ball arrangement on crane 1, causing the rail to fall down to weather deck” (Seljelid et al., 2011).

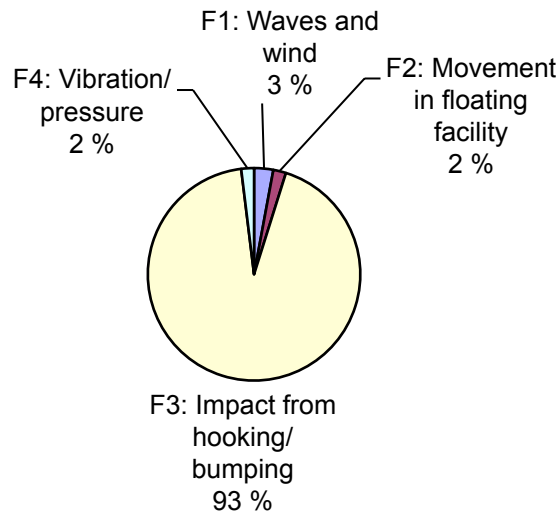


Figure 4.2-6 F: External events

The other categories; F1: Waves and wind, F2: Movement in floating facility, and F4: Vibration/pressure are only responsible for a few percent each. This is interpreted as accidents that are due to waves and wind, movement or vibration on their own. However, harsh weather conditions may be a contributing factor to hooking or bumping. Movement in a vessel or floating facility or marginal weather conditions can lead to difficult operational working conditions leading the crane operator to incidents like bumping the cargo into other containers or getting hooked on a vessel.

The high number of incidents caused by hooking/bumping during internal and loading/unloading crane operations can most likely be further categorised in some kind of broad category of human error, like wrong execution of operations, lack of concentration or lack of competence (Seljelid et al., 2011) (Scandpower, 2005)

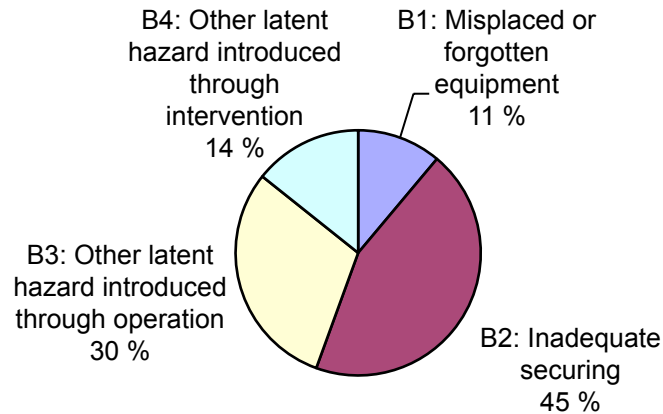


Figure 4.2-7 B: Human activity, introducing latent hazard

In Figure 4.2-7 it is seen that B2: Inadequate securing is the main reason for human activity introducing latent hazards with 45 % of all incidents. An example of incident categorized as B2, is given below. *“During loading of backload using a basket, a lever fell out before landing. ...”* (Seljelid et al., 2011) This is a typical example for the incidents caused by inadequate securing at an earlier stage. The load in the basket should be secured properly to ensure that it won't fall out during crane operations.

B3: Other latent error introduced during operation is the second largest contributor to category B, with 30 % of all incidents. This is followed by B4: Other latent error introduced during intervention, e.g. during installation, inspection, maintenance or dismantling of equipment containing 14 %, and B1: Misplaced or forgotten equipment / materials with 10 % of incidents.

Some lift accidents have had investigations performed by the PSA. To get a better impression of the situation today all accidents/incidents since 2005 has been studied. The cases considered are in Appendix A: Accidents from 2005 till today. Similarities were found between the accidents. These could be divided into human, technical and organisational causes.

Human:

- Insufficient risk identification
- Communication
- Work procedures and explanations
- Personnel under suspended load
- Supervision and inspection of the system
- Unwanted behaviour

Technical:

- Technical weaknesses
- Lack of maintenance
- Failures from crane manufacturer
- Absence of safety function
- Insufficient design
- Weakness in the control system

Organisational:

- Lack of management and follow-up
- Insufficient knowledge of procedures
- Insufficient planning
- Insufficient distribution of responsibility and communication lines
- Insufficient compliance of controlling documents for lifting operations
- Lack of danger and safety specification

From the accident analysis and the statistic from the RNNP report from 1994-2010 the greatest triggering causes found can be summed up to:

- Unwanted behaviour
- Lack of considerations and regard to risk
- Lack of comprehensive assessments and facilitation in the planning and execution of lifting operations
- Lack of compliance with procedures
- Inadequate maintenance
- Technical failure or weakness in component/system/construction
- Weaknesses in incident analysis and lessons learned

This is also consistent with conclusions about the causal factors in reported incidents related to crane lift from the Petroleum Safety Authority review of investigation reports from incidents in drilling operations (PSA, 2008).

4.3 Environmental conditions in the North Sea and Barents Sea

This following section is based on a previously written report (Røsnes & Prøsch, 2010)

Several factors create challenges for the petroleum industry in the Barents Sea. One of them is the cold. There are lower temperatures here than the industry is used to from the North Sea. Other challenges are winds, icing, polar lows, uncertain weather forecasts, long distance to infrastructure, and months of darkness. Climate differences are also large from the southern and western areas to the north and eastern Barents Sea. When more of these factors are combined they provide significant challenges to work on installations in the area (Thelma, 2010).

Experience has shown that the weather conditions are more stable throughout the year in the Barents Sea than in the North Sea. Today there are three oceanographic buoys in the Barents Sea. They measure metrological and ocean surface parameters such as air and sea temperatures, air pressure and humidity, wind speed, directions, gust, sea current speed and direction, buoy position and battery status.

Monitoring of the oceans require a combination of observations and models. In emergency situations direct observations provide the immediate results, but models provide refinement of observations for short and long-term forecasts. (Fjørtoft & Kvamstad, 2010)

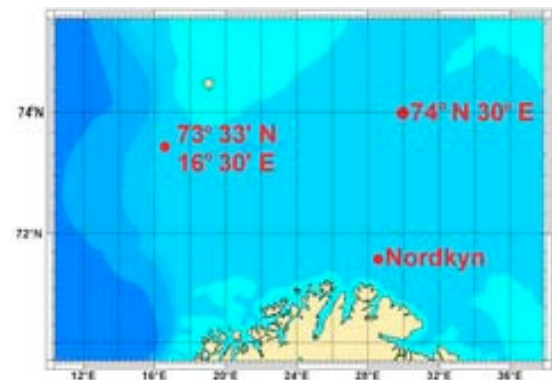


Figure 4.3-1 Barent Sea Buoy

4.3.1 Wind condition

Metrological conditions in the Barents Sea are dominated by the storms that occur in the North Atlantic. The winter wind is usually from the southwest, except near the coast where the wind is most commonly from the northeast (Thelma, 2010)

There is no significant difference in wind strength when comparing the conditions in the Barents Sea and the North Sea. The proportion of wind speeds above 6 on the Beaufort scale (near gale) is highest for the Halten light house. However, Bjørnøya has the highest measured wind speeds. The wind speed decreases towards the east and north. The iceberg drift is only dependent on wind speeds higher than approximately 10 m/s, which is a 6 on the Beaufort scale. Atmospheric lows and highs can change the wind speeds and affect the iceberg drift (Løset et al., 2006)

4.3.2 Polar lows

Polar lows are small cyclones that form over open sea during the cold season within polar or arctic air masses. The Norwegian Sea and the Barents Sea are particularly favourable formation areas. They are typically several hundred kilometres in diameter and can develop rapidly, reaching maximum strength within 12 to 24 hours of the time of formation. They often dissipate just as quickly, especially upon making landfall. Polar lows are characterized by rapidly changing wind direction, maximum wind speed of 70 knots, heavy snowfall and icing. They are most prevalent between Bjørnøya and Northern Norway, but it is common all the way down to Trøndelag (Thelma, 2010).

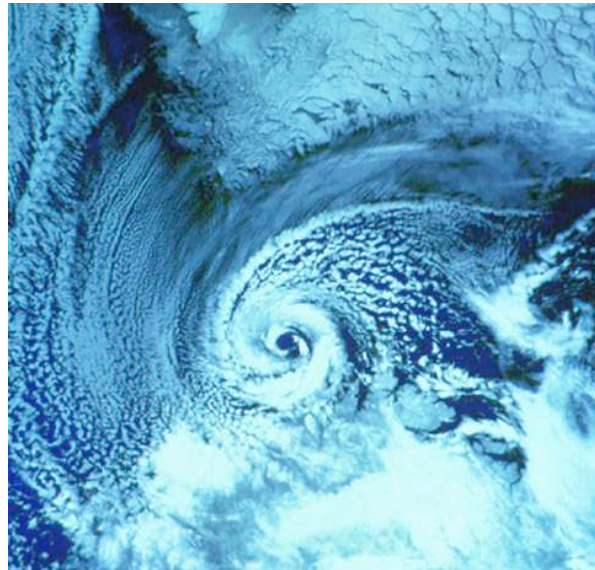


Figure 4.3-2 Polar low over the Barents Sea

Polar lows are hard to detect and difficult to forecast and weather history is limited. Therefore weather forecasting of local conditions can be challenging.

Figure 4.3-2 shows a polar low over the Barents Sea on 27 February 1987. The southern tip of Spitsbergen is visible at the top of the image. The polar low is centred just north of the Norwegian coast. (Arctic Climatology and Meteorology, 2009)

4.3.3 Currents

Currents are very local and their pattern is quite decisive for the location of the ice edge. In the Barents Sea there are two main current directions. In the southern part the currents move towards east, and in the northern part it moves westward and southward. The Barents Sea is inflexed by Arctic water along the route between Spitzbergen and Frank Josef Land, and through the channel between Franz Josef Land and Novaya Zemlya.

The main part of the Persey Current goes southwestwards along the eastern slope of

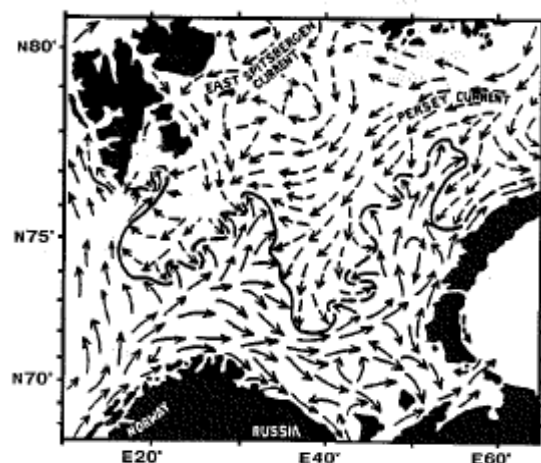


Figure 4.3-3 Current Pattern

Spitzbergbanken as the Bjørnøya Current. For the station west of Kvitøya there has only been one long-term measurement of currents reported (Løset et al., 2006, p.210).

Influx of cold seawater from the polar region to the east side of Bjørnøya gives noticeable lower temperatures near the eastern parts of the island compared with the sea temperature on the west. The lowest sea and air temperatures usually occur during late winter/early spring.

4.3.4 Ice condition and icing

The biggest difference in the Barents Sea from the North Sea is sea ice and icing. The ice condition varies in the Barents Sea, but is uniform in each area. The Northern Barents Sea is part of the seasonal ice zone in the Arctic. During summertime some years the sea ice melts or withdraws entirely from these waters, in other years it remains in the north-western and north-eastern parts of the Barents Sea.

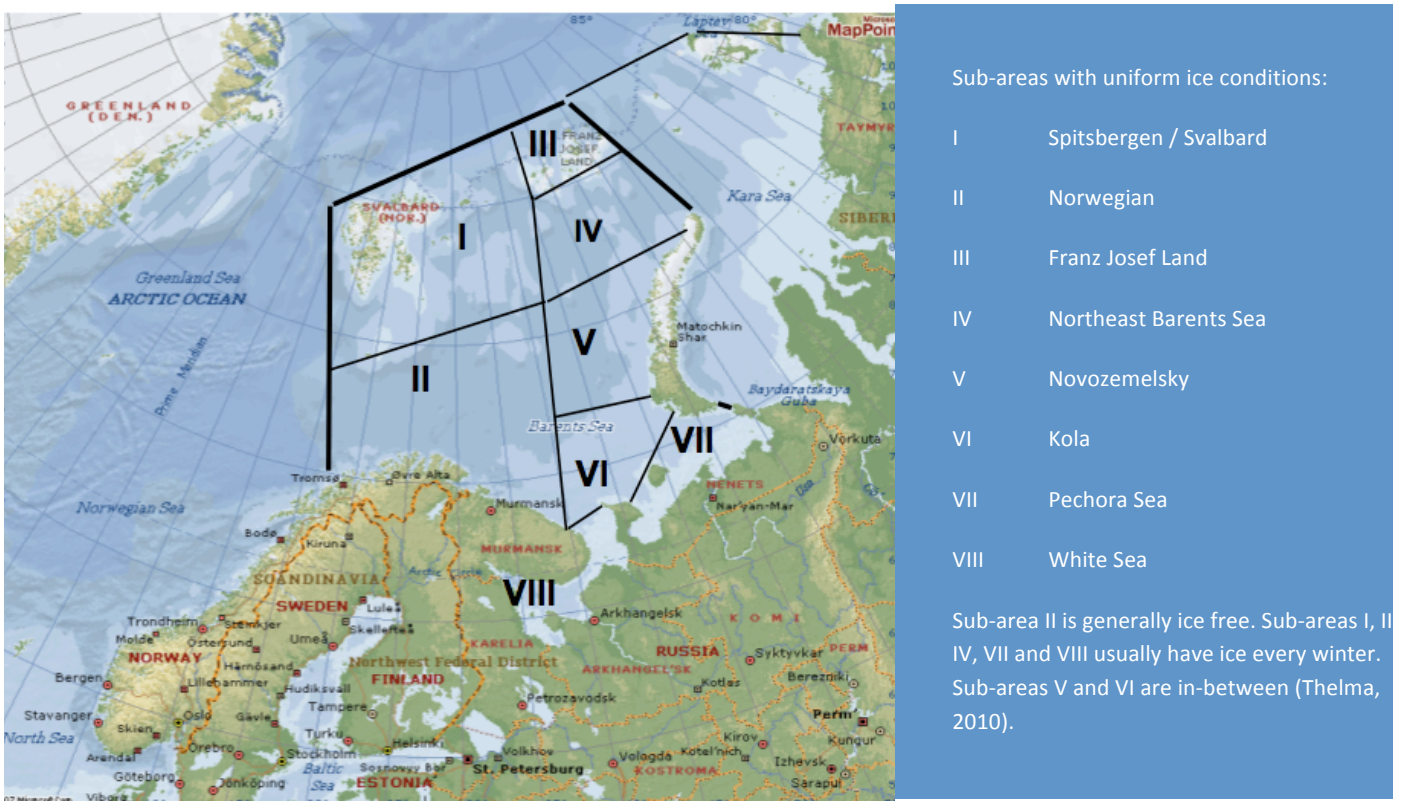


Figure 4.3-4 Sub-areas with uniform ice conditions

The most common ice here is first-year ice and 3-5 m multi-year ice. The variation of sea ice extension is very high, the maximum southern extension is in March and minimum in September. The most typical ice fields have at thickness of 1 m. In the central parts of the sea,

local origin ice may appear once every 3-4 years, while pack ice from the northern part can be seen more often. (Løset et al., 2006)

“Icing is a phenomenon where water or moisture at subfreezing temperatures freezes onto surfaces above sea level” (Løset et al., 2006, p.193)

The causes of icing are sea spray, freezing rain, rain and fog in combination with cold. Icing in the ocean can be divided into two main categories; Sea spray icing and Atmospheric icing. Ice and snow accumulation on structure will increase the gravity load; atmospheric icing is harmless compared to sea spray icing. Spray is the most common cause of icing and gives the greatest amount of ice on vessels.

Ice formation due to spray is a phenomenon that can occur at low temperatures in combination with strong winds from the south and southeast that brings cold air masses from the east. The data for icing is sparse. According to Meteorological Department the icing could occur when the air temperature is below -2°C and wind speed is greater than 11 m/s (Thelma, 2010).

The relative frequency of sources of ice accretion on ships in:

- Non-arctic environments:
 - 90% spray icing
 - 7% spray + atmospheric icing
 - 3% atmospheric icing
- Arctic environments:
 - 50% spray icing
 - 41% spray + atmospheric icing
 - 9% atmospheric



Figure 4.3-5 Breaking ice in Canada (O'Morchoe, 2009)

Three important factors need to be present for spray icing to occur; water droplets, relative movement between the surfaces and the droplets and removal of heat from the liquid.

Atmospheric icing is possible because of negative air temperatures. In the Kara Sea it has been observed 30-50 times per year, Laptev, East Siberian and Chukchi Seas 80-90 times per year. It occurs through fresh water precipitation, like snow, rain or super cooled droplets, when the air temperature is between zero and -20°C and the wind speed is less than 10 m/s.

Icing rates is affected by air temperature, wind speed/direction, wave height and sea surface temperature. The maximum accretion zone is when the atmosphere removes enough heat

from the water at a sufficient rate so that all the spray delivered freezes. The geometry and the height above sea level of the object exposed to ice are also dependencies. But sea spray icing is usually limited to 15-20 m above the sea level. From analysis it is found that high icing rates occur by the simultaneous occurrence of high wind speeds, and low air and seawater temperatures.

Observations of air temperature at the Norwegian coastal stations indicate that the icing will primarily be a problem related to the Barents Sea. In the part of the Barents Sea that has been opened for petroleum activity, this type of icing is a phenomenon that mainly occurs in coastal areas, at low temperatures and when there are strong winds from the south and southeast. North in the Barents Sea the icing problem could be extreme. At its worst, spray and mist build up to four inches of ice per hour on the surface of a facility.

For the areas around Bjørnøya the icing rates are above zero in 22% of the days in January. East of Bjørnøya there is an area with very low icing rate comparable to those in the south of the region. In addition the sea ice regularly covers the whole of the northern area around to the east of Bjørnøya from November through to May. High wind speeds generates high water flux, low air temperature gives high icing rates when the wind speed is high. But be aware of that high wind speeds will not necessarily increase the icing rate, this because the icing rate is dependent on wet or dry icing. (Løset et al., 2006)

5.0 Case Study

The case study presented in this chapter is based on the adapted version of the MARI model discussed in the previous chapter. Section 5.1 will lay the basis for the sites that were chosen for the case study. In section 5.2 the effect of the arctic conditions in the Barents Sea is examined and possible problems identified. The third section identifies the factors on the preventive phase of the event and ties these up to findings in the accident statistics in chapter 4.2. Section 5.4 develops risk indicators according to requirements found in chapter 2.3 with the systematic approach explained in the MARI model in chapter 3.1.

5.1 The sites in the North Sea and the Barents Sea

Location in the North Sea: About 320 km southwest of Stavanger in the Ekofisk area. Discovered in 1969, it remains one of the most important oil fields in the North Sea. There have been operations here for more than four decades and the conditions are well known with sufficient historical data to base future assumptions on influencing factors and risk indicators. Figure 5.1-1 shows the location with a red circle.

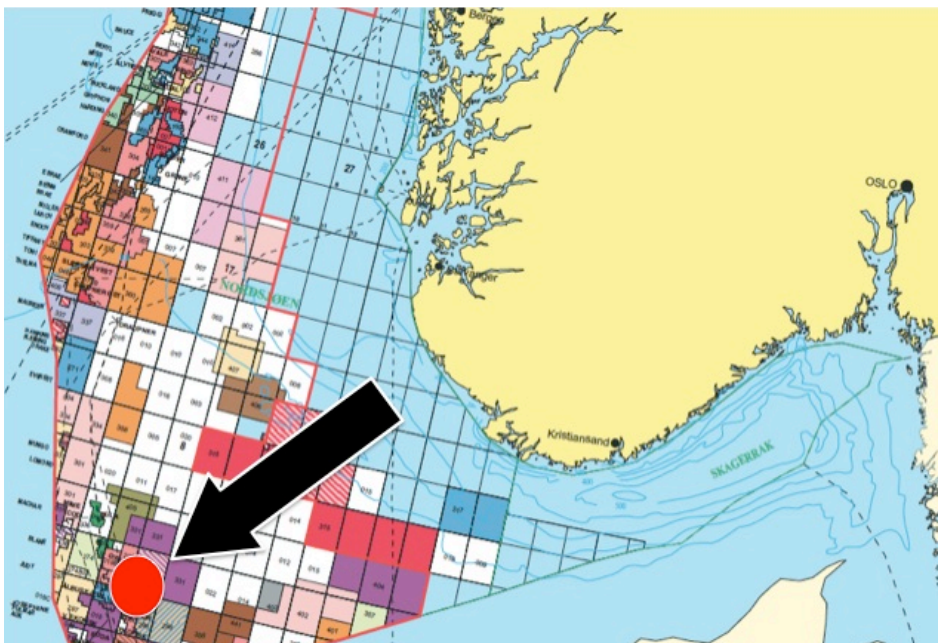


Figure 5.1-1 Location in the North Sea

The Norwegian Oil Industry is moving farther north and east to the arctic region. Operating in these areas will be a challenge, with extreme climate elements. There is little experience of working further north and east in the Barents Sea on the Norwegian side. In addition, there is sparse data on icing and climate conditions in the Barents Sea in relation to the rest of the Norwegian shelf (PSA, 2010).

There are only two fields that have an approved plan for development and operation, Snøhvit and Goliat (PetroNord, 2011). Both of these are relatively close to shore in sub area II (defined in section 4.3.4) that are generally ice free. For the case study it is more interesting to move further north, to the east side of Bjørnøya. Figure 5.1-2 shows the location in the Barents Sea marked with a red circle. As mentioned in chapter 4.3 the east side of Bjørnøya has high wind speeds, is susceptible to polar lows, icing and usually have sea ice every winter.

Location in the Barents Sea: Sub area I, close to Bjørnøya.

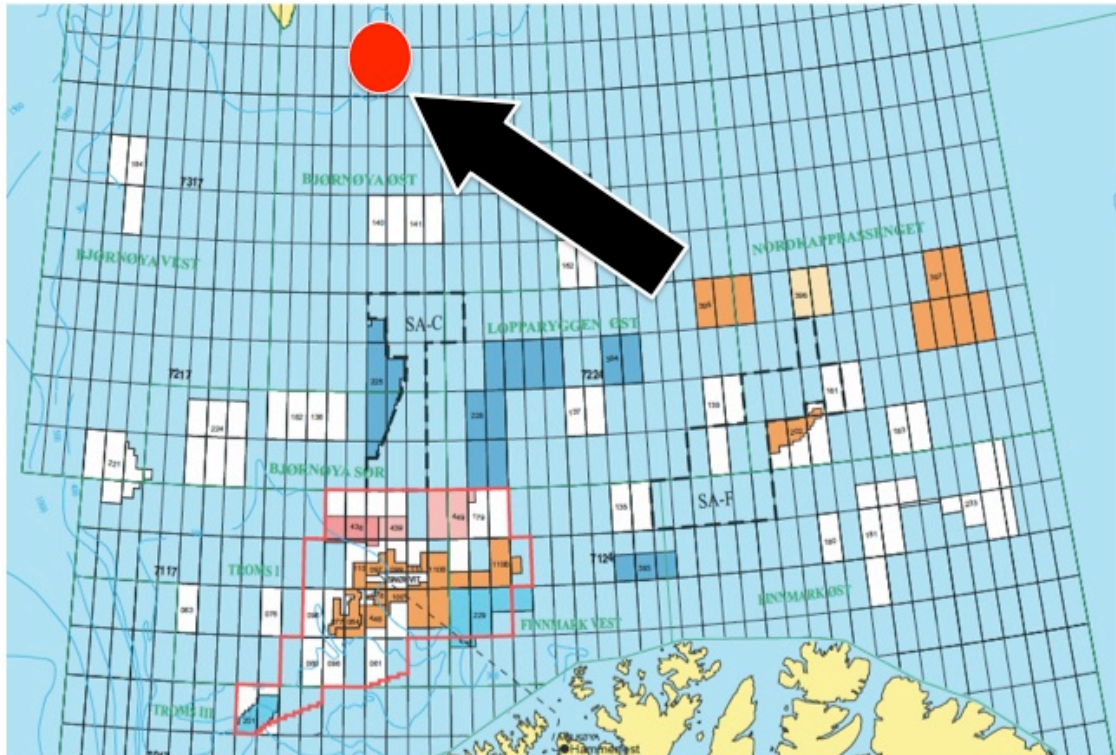


Figure 5.1-2 Location in the Barents Sea

5.2 Effect on lift operations in the Barents Sea

Personnel on deck who loads and unloads are those who on a daily basis are most exposed to wind and cold problems. There are distinct restrictions on acceptable exposure for personnel who work on such exposed areas on a rig (Thelma, 2010).

Identifying cold related challenges during the design phase of the rig would be important, as well as risk identification and evaluation of adjustment to work tasks, personal protective clothing, personal safety equipment and other equipment. Beneficial routines, information and training, winterization and sufficient numbers of personnel to alternate outside work, is important to secure appropriate working environment in cold surroundings.

Removal of ice from exposed areas is more likely to be a larger task in the future than the oil industry is used to. There are still no recognized standards that cover ice loads sufficiently (PSA, 2010). Due to lack of knowledge this leads to large deviations in calculations of ice loads on offshore devices.

On offshore structures in the arctic, ice accretion is a major concern for operations and can lead to a variety of problems:

- Slippery decks, ladders and handrails
- Equipment; winches, derricks and valves must be checked before use, or else it can lead to delays.
- The engine driven equipment needs heat before starting. The crane is engine driven and in cold days under normal conditions it needs preheating.
- Ice on radar antennas can interfere with operation creating a safety hazard.
- Ground based structures will have higher structural members which can lead to higher lateral wave and wind forces.
- On floating structures and vessels the draught and the centre of gravity can be increased, while the freeboard will decrease which can in worst case lead to loss of stability. Supply vessels going into that are very exposed to these phenomena and can lead to problems for crane and lifting operations. (Fjørtoft & Kvamstad, 2010)
- Wind driven surface waves are a major source of dynamic environmental forces on crane vessels and other ships. These waves are irregular in shape, can vary in length and height, and can approach the vessel from more directions simultaneously. (Karunarkaran, 2010)
- The distances between ports and infrastructures are enormous in the north. This is a major challenge because accidents can happen out of reach for the available helicopters and the SAR vessel will need several hours to reach the emergency site.
- Life saving and fire fighting equipment can be unusable, e.g. deluge system can freeze without heat tracing.



Figure 5.2-1 Lift operations in arctic regions (Polartrec, 2010)

5.3 Factors influencing falling loads related to crane operations

This chapter will use the method in the MARI model described in section 3.1 to establish a qualitative framework for the consideration of crane operations. Accident statistics in chapter 4.2 is used as basis for selection of factors. This chapter is divided into the different phases of activity. Experts at Rogaland Crane School have been consulted after the selection of factors.

5.3.1 Pre-conditions

This phase contains pre-determined factors that reflect laws and regulations, design basis, and environmental conditions. These are not possible or at best difficult to change and affect later phases.

Economy

The company's economy could be considered to influence almost every other factor, but it has been established a higher correlation between design of crane in the pre-conditions phase and risk assessment and maintenance plan and procedures. Design of crane is influenced because the budget will be important for deciding crane type and capacity. Short cuts are sometimes taken to reduce cost and only fulfill the minimal requirements to maintenance. Also, it is possible to be allowed deviations from planned maintenance from the PSA if asked according to experts at Rogaland Crane School. There are less costly risk assessments to be done.

Regulations

Laws and regulations is the authorities way of controlling lift operations so they are uniform. It influences all factors in the planning phase, like lift crew competence, risk assessment, operation procedures and support, and maintenance plan and procedures through requirements in NORSOK R-003 (2004).

Design of crane

The design delivered from the manufacturer should have a functionality, quality and reliability that give the necessary safety level for the intended purpose. The crane design in the Norwegian oil and gas industry is usually of good quality. However, many old installations did not consider the layout of the deck, leading to blind zones for the crane operator. This demands more in training of the crane operator. The crane operator's blind zone is one of the most dangerous parts of an operation, and a camera can be a helpful tool. Technical deviations in the accident statistic revealed failures from crane manufacturer, absence of safety function,

insufficient design and weaknesses in the control system as important triggering causes. Therefore, design of crane is a significant factor for dropped loads.

It influences lift crew competence, operation procedures and support and maintenance plan and procedures in the planning phase.

Environmental conditions

Coldness, sea temperatures, waves and wind in combination can make operations on deck on vessels and open offshore installations very dangerous. In the Barents Sea icing can be challenging. Structures can be destabilized, equipment can have decreased performance and areas can be slippery. The weather forecasts are often of low quality; this is challenging for all types of critical maritime operations that is dependent on good weather. If the weather forecasts had been more accurate the safety in the arctic would have increased. Forecasting more than 3 days ahead is difficult at best.

Annex K in the NORSOK R-003 (2004) has a checklist for lift operations under marginal weather conditions. Usually in real life, the crane operator or the captain of the vessel are the one demanding operations to shut down. The significant wave height might be too high. Continuing operations in marginal operations is up to the crane operator's experience. He might deem the operation to work and they can continue. The signaler might also stop the operations if he sees it fit. He might have a better grip on the situation in some situations. Say the container is lowered down somewhere in a wind tunnel that creates speeds higher than expected.

Take-off or landing of cargo at vessel/installation is a critical part of a lifting operation. On a crane vessel it can be very dangerous because waves can move the vessel in another frequency than the platform. Not all weather conditions are worse in the Barents Sea, when there is sea ice the wave motion is dampened.

External events are responsible for almost half of the causes for internal lifts and loading and off-loading. Impact from hooking or bumping is the triggering cause for more than 90 % of these events. And marginal weather conditions make it more likely to hook onto a vessel or bumping into other cargo.

Examples of influencing weather can be: wind, snow, ice, waves, rain, lightning, darkness, fog, temperature changes, and polar lows. For example the waves can be too high for a lifting operation from the supply vessel to the Installation. Low temperature can lead to the need of heating the hydraulic oil before activation of the crane.

It influences operations procedures and support as well as maintenance plan and procedures in the planning phase.

5.3.2 Planning

Contains factors that describe the performance of the different activities in accordance with specific procedures or best practice. From the accident statistics in chapter 4.2 one of the greatest triggering causes are lack of comprehensive assessments and facilitation in the planning and execution of lifting operations. Planning is the number one focus in the industry according to experts at Rogaland Crane School.

Lift crew competence

Human error, both latent and immediate is responsible for one third of the causes for internal lifts and loading and off-loading and unwanted behaviour is one of the greatest triggering causes in the accident analysis.

Lift crew must have the required knowledge and skills to enable effective lift operations internally, from vessel to installation, from vessel to vessel, and between installations such that the safety is preserved and unwanted incidents do not occur.

The co-workers performance is affected by certain factors: Personnel competence, licensing of engineering staff, recurrent training, and certificate of apprenticeship, individual psychological and physiological factors. If the operator is under pressure from superiors he might rush an operation and that might make it less safe. Physical factors can be hunger, illness, etc.

The crane operator has the overall responsibility for the logistic on deck and safety. It is very important that the crane operator and the deck personnel communicate well during lifts.

Simulation is a great way to learn about risks and how to tackle critical situations. Simulations and practice will help the workers on the installation to handle emergency situations in a routine way. By training to go "blind" if the camera fails under controlled conditions make crane operators more confident and competent if they fall into a similar situation.

Organisational working conditions that influences the ability to perform assignments and the attention of the workers, like working schedules, access to necessary equipment, health and safety regulations, hotel facilities, food, resting shelters, clothing, etc.

Information and training covering job-specific knowledge and relevant experience of: work processes, hazards, and emergency actions. The company will determine the type of training

and experience necessary to achieve competence. Practical experience is worth more than theoretical knowledge.

New crane operators know the laws and regulations are more focused on the lift at hand is less willing to take chances. Experienced crane operators that have been in the game for more than 20 years are usually more up for cutting corners and working in marginal conditions. They've done this "forever" and nothing has gone wrong yet. For planning operations it's the other way around, more experience is key.

It influences simultaneous operations and day-to-day operations on the activity level.

Operation procedures and support

Procedures should cover all aspects of lifting operations. Often it is a fact that had the procedure been followed then the accident would not have happened, the problem is when the procedures not are followed.

One of the greatest triggering causes from the accident analysis and statistics are lack of compliance with procedures. Procedures are supposed to be in place to restrict access, so unauthorized personnel do not go into the area during a lift operation.

Personnel have commented on their use of procedures with "It may occur that I violate the safety rules in order to get the job done quickly" and "I think it is easy to find the right steering document and HES procedures are adequate for my tasks" (Vinnem et al., 2010, p.1152).

Procedures for lifts with crane are often described at a relatively detailed level. Still, the procedures are rarely developed together with the personnel involved. Another issue is that they are often not evaluated from a human factors perspective (ease of use) (Scandpower, 2005).

Unclear procedures are noted and commented on, and reviewed continuously and changed if necessary. Procedures are easier to access than standards. However, there are a lot of procedures (everything needs to be certified). This means that one usually have access to thick folders with information that is impractical for the day-to-day operations. The main concern is just to know if the lifting equipment is certified and able to do the job.

It influences day-to-day operations on the activity level.

Risk assessment

One of the greatest triggering causes from the accident analysis and statistics are lack of considerations and regard to risk as well as weaknesses in incident analysis and lessons learned.

Risk assessment should be up to date, stimulate thinking and improve collective and individual decision-making. Rather than driven by regulatory concern, it should be an integral part of planning. Inspectors should assess the quality of the risk assessment by attending shift change toolbox talks or comparing written risk assessments for actual activity and thereby increasing the competence and depth of the assessment.

Informal talk with drilling leader on platform X (anonymized for this purpose), both day and night shift, say they have enough time to plan the operation and perform risk assessment. They never felt rushed by management regarding time spent on toolbox talks and risk assessment. It did not matter whether they spent half hour, whole hour. This might be different for hired contractors, or personnel that are less experienced.

Risk assessment sheets like SJA must be gone through and signed for critical lifts. There is some form of risk assessment for nearly every task. All involved personnel must be informed and understand the task at hand, and there should always be room for comments.

It influences day-to-day operations on the activity level.

Maintenance plan and procedures

One of the greatest triggering causes from the accident analysis and statistics are inadequate maintenance and it is therefore an important factor. The maintenance is set by the design organisation and by the company's maintenance organisation.

It is a fact that maintenance is necessary for safe operations. A good maintenance program will decrease down time and prevent equipment failure. Most importantly it will ease the planning process. The focus on maintenance and safety must be of high priority to signal to personnel on all levels how they affect the system.

The specification of scope and frequency of the inspection and maintenance system is based on how safety critical the item is, and on the degree of challenge presented to the system integrity, or to comply with the manufacturer or supplier's instructions.

Faults must be fixed within specified timescales and repairs and improvements must meet installation design standards and a log of findings enabling trending.

It influences maintenance on the activity level.

5.3.3 Activity – level

Contains factors whose conditions are influenced through daily operation, e.g. activity level, work performance. All factors located within each of these “layers” share the same characteristics when it comes to determining the risk status of the event. The risk of an event is not only dependent on the “activity factors”, but also other factors whose conditions are determined prior to daily operations.

Activity – level contains factors that describe the activity level for the different operations

Simultaneous operations

Simultaneous operations are areas that require extra considerations to risk.

The permit to work system is designed to have control of certain operations with potential hazards. In this system the work permit is a formal written statement of where and what the job involves, and what safety procedures should be followed. This must be approved by both the platform management and site manager, and checked in the control room before the work starts. Safety aspects apply equally to the work to be performed, but also with regard to those who may be affected by the job. That means nearby areas or equipment that are affected. The works area should be checked before and after the work starts and ends, and if there is other work in the same area the work permit can be revoked. It is also to have control of all hot work, which may cause sparks and smoke. In a situation where a gas leak is detected, for example, all hot work permits will be withdrawn to prevent ignition.

For a system to act as a barrier, it must also be followed. The use of checklists has become very widespread, and in theory a good tool. In most cases this works well, but that assumes that the users follow it. The work permit system is one such system, which can fail if staff chooses to sign before the action is performed. A classic example is the area controller checks of work before and after starting work / is done. To save time, many choose to write that this is done before they have physically checked the area. Yet this is primarily a cultural problem as it is allowed to be used this way. The Area Manager is not blamed before something goes wrong, as he/she should have foreseen it.

It influences lifting restrictions in control functions.

Day-to-day operations

Most of the crane lifts offshore are routine lifts. These lifts lack detailed planning or comprehensive risk assessment. According to (Eikeland, 2007, p.73) these are considered more critical than others by the interviewed and observed crane operators.

Blind spots are an issue. The design of an installation prevents the crane operator from seeing where loads are picked up or placed. Even newer facilities have still not been configured to eliminate such problems in routine lifting operations (PSA, 2009). Other factors that may affect visibility are fog, blowing snow and daylight hours (Trbojevic & Gudmestad, 2009). Rescue capacity is dependent on visibility and daylight conditions in addition to wind and wave condition and may prove challenging if the visibility is low.

Critical lifts may be loading and offloading. There is more stress for the lift crew in connection with offloading of vessels, as there is high demand for doing the job quickly and it is a more complex and difficult operation compared to internal lifts.

It influences operational working conditions and crane operational and technical dependability in the performance phase of activity.

Maintenance

The way the crane operator's organisation or maintenance-approved organisations plan and carry out the maintenance, to the extent that this has a direct or indirect influence on crane safety.

It influences crane operational and technical dependability in the performance phase of activity.

5.3.4 Activity – performance

Contains factors that describe the performance of the different activities in accordance with specific procedures or best practice

Operational working conditions

The crew's ability to perform its assigned assignment requires good working conditions

The location plan is very important, especially with regards to the blind zone of the crane operator and pinch accidents. Different installation types have different design; therefore the decks will be placed in different ways and the cargo will be stored in different ways. The supply vessels will have to approach the installation in the best possible way, also with regards to weather. The way the supply vessel is loaded is also a factor regarding the unloading process. The shape of the cargo can be a container or another lifting object.

Blind spots are an issue. The design of an installation prevents the crane operator from seeing where loads are picked up or placed. Even newer facilities have still not been configured to eliminate such problems in routine lifting operations (PSA, 2009). Other factors that may affect visibility are fog, blowing snow and daylight hours (Trbojevic & Gudmestad, 2009). Rescue capacity is dependent on visibility and daylight conditions in addition to wind and wave condition and may prove challenging if the visibility is low.

It influences lifting restrictions under control functions in the activity phase.

Crane operational reliability and technical dependability

Crane operational reliability depend on a number of factors like reliability of lift equipment and processes, which require high-quality procedures and support, and a good understanding of these. A superior maintenance strategy will lead to efficient maintenance, which must be built into the design phase and the crane operator's organisation. Low operational reliability could lead to mistakes, low production and dangerous situations (Duran, 2010).

Technical dependability is also an important factor to a good operational crane. It is dependent on the crane design and the maintenance done so that the crane is continuous operational.

A power failure on the installation could be a problem if the crane does not have its own aggregate. This can be very critical if the cargo is just loaded of the supply vessel and hanging in the air.

It influences technical safety system in the control functions phase of activity.

5.3.5 Activity – control functions

Contains factors that describe control of the different work operations, e.g. verifications, inspections

Lifting restrictions

Insufficient compliance of controlling document for lifting operations is an important cause found in the accident analysis and is therefore an important factor.

It influences the event dropped load due to crane operation

Technical Safety System

There are two categories of causes that fit in this factor, weakness in the control system and absence of safety function. This is good reason for having a factor on the technical safety system.

It influences the event dropped load due to crane operation

Figure 5.3-1 on the following page shows the connection and influences between the factors identified in this chapter. The weighting will be explained in the results in chapter 6.0.

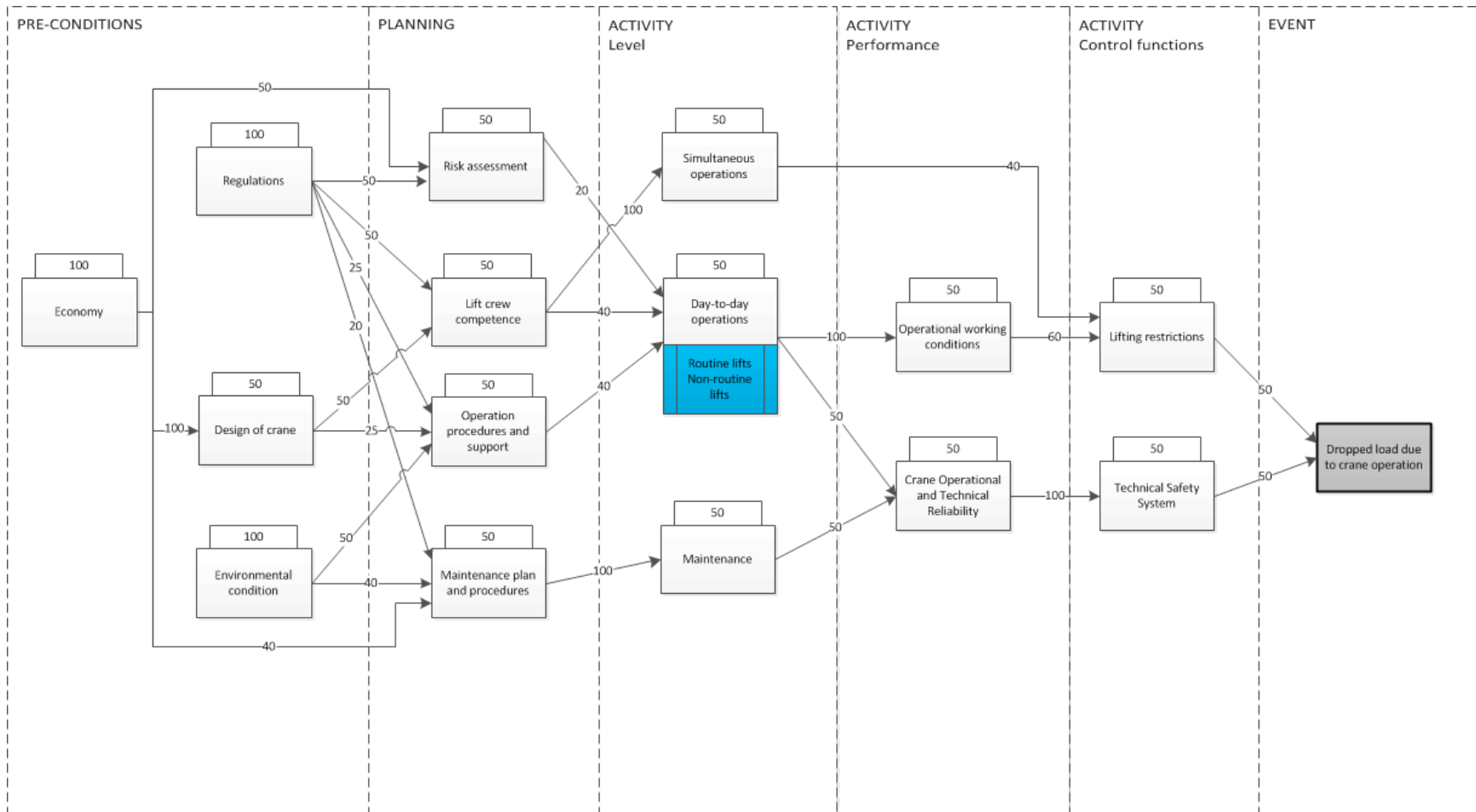


Figure 5.3-1 Risk Model

5.4 Developing Potential Risk Indicators

In order to develop indicators for lift operations that are considered to have major accident risk, it is helpful to use the qualitative framework in the previous chapter to identify risk indicators. This chapter is divided into the different phases of activity and is tied up to risk indicator requirements described in chapter 2.3.

Indicators can be developed through the identified risk influencing factors (Haugen et al., 2011). By constructing a causal network for a particular problem, it is possible to identify relevant indicators in a structured, yet flexible manner. At the same time the approach brings out the structural relation between indicators making this relation one of the key selection criteria (Niemeijer & de Groot, 2008).

The indicators must fit the requirements described in chapter 2.3:

- Observable and quantifiable
- Sensitive to change
- Transparent and easily understood
- Robust against manipulation
- Valid

In some cases, the factors may be used more or less directly, but most likely, it will be difficult to find suitable indicators for all factors.

It is not necessary to measure every aspect or element of a risk management system. Busy management teams will quickly lose interest if there are too many indicators, so it is essential to avoid KPI overload. Data collection and analysis is resource intensive, so arrangements for monitoring performance should be cost effective (HSE, 2006).

Selection of indicators is important since some indicators may not provide the needed insights to ensure desired performance (American Petroleum Institute, 2010). Poorly developed risk indicators may lead to knowledge gaps or result in unwarranted confidence. More than one risk indicator and both leading and lagging risk indicator should be developed to monitor the different dimensions of process safety operating discipline and management system performance.

5.4.1 Pre-conditions

Risk indicators in the pre-condition phase are not as sensitive to change as later phases of an operation.

Economy

Potential leading indicators

- Budget available

Installations in the Barents Sea will be more expensive than in the North Sea. They would require a bigger budget, as they would need to be more robust in terms of standard of steel and winterization of rig. The indicator could be measured by the budget available in terms of NPV (Net present value), which is the sum of the present values (PVs) of the individual cash flows. In terms of being quantifiable and sensitive to change it passes the requirements. Net present value is in general a term that is generally well understood, at least in the finance department. It is valid in the way that it measures the most important and most used economical aspect, the net present value.

The risk indicator is leading, as it is known before the execution of any operation.

Regulations

Potential leading indicators

- Regulations

Regulations for the North Sea have been developed for four decades and cover all operations and procedures. However, there has not been as much activity in the Barents Sea and not all regulations are fully developed. Among others, there is ongoing work on an ISO standard ment to cover the petroleum and natural gas industries — Arctic offshore structures. Quantifying regulations could be done by monitor the way they are used in the industry.

Design of crane

Potential leading indicators

- Technical standard of crane / lift equipment to be used in operation
- Remaining design life time of crane / lifting equipment

Technical standard of crane and lift equipment used in the operation. It must be customized for the operations with equipment like a heave compensator. It is difficult to set an appropriate measurement for the standard, but choosing of technical generation crane could cover a part of the factor. Remaining design life could easily be measured through a ratio between remaining lifetime and total lifetime. It is difficult to manipulate the indicators, however new design life calculations may be done if operations are continuing longer than originally expected. This will not be looked into any further, but the calculations need to fulfill rigorous requirements and would hopefully meet the safety requirements of any offshore installation.

The risk indicators are leading, as they are known before the execution of any operation.

Environmental conditions

Potential leading indicators

- Vulnerability
- Ice condition

Loss of containment events due to loads dropped on process equipment could lead to major oil spills that affect marine life. There is general consensus that the marine life in the Barents Sea is more vulnerable than the marine life in the coastal areas in the North Sea (Bellona, 2002).

It is observable in a way through research papers on marine life, but difficult to quantify. How can one put a price tag on marine life? It is not truly sensitive to change, however, if the operating oil company can prove they are readily available to control any oil spill through improved oil spill mitigation it can be categorized as less vulnerable. The ice condition is decided through geographical location and is robust against manipulation as there are established ice zones in the Barents Sea.

The risk indicators are leading, as they are known before the execution of any operation.

Potential lagging indicators

- Exceeding the weather criteria (e.g. wind speed more than 20 m/s, wave height higher than 4.5 m)
- Number of delays of operations due to weather forecast
- Icing

Exceeding weather criteria is quantifiable as it is defined to be wind speed or wave height exceeding 80 % of the crane's design limit as mentioned in chapter 4.1. This would be site specific. Both of the potential lagging indicators are quantifiable and easily understandable. A

good reporting culture should prevent manipulation of data and they are sensitive to change. They are transparent as the number of observations goes down so does the risk.

Risk indicators are lagging as they would lead to delay or more hazardous operations.

5.4.2 Planning

Lift crew competence

Potential leading indicators

- Lift crew experience
- Experience in working together

Average number of years relevant lift crew experience and percentage of turnover are suitable risk indicators

Potential lagging indicators

- Errors made by staff

Number of times lift does not proceed as planned due to errors made by staff without the necessary understanding, knowledge or experience to take correct actions.

Operation procedures and support

Potential leading indicators

- Review of procedures

Percentage of procedures that are reviewed and revised within the designated period.

Potential lagging indicators

- Incorrect/unclear operational procedures.

Number of times lift does not occur as planned due to incorrect/unclear operational procedures.

Risk assessment

Potential leading indicators

- Pre job risk analyses

Percentage of operations performing a risk analyses before the job

Maintenance plan and procedures

Potential leading indicators

- Availability of external resources (distance to shore)
- Coverage and review of critical systems

The distances to infrastructure and ports in the north are huge. Therefore an indicator on the availability of extra personnel to perform any type of critical maintenance or spare parts is useful. Coverage of critical systems are most relevant for new installations and review of critical systems is easily quantifiable as they must satisfy time requirements.

Potential lagging indicators

- Backlog

If the backlog is increasing on safety critical maintenance the crane operator have the right to shut down the crane and not reassume work before maintenance is complete. This would again lead to the installation being forced to shut down and personnel being sent to shore, and no company wants that.

5.4.3 Activity - level***Simultaneous operations***

Potential lagging indicators

- Number of simultaneous operations
- Violations

Number of simultaneous operations can be measured.

Extent the work permit system is followed (*e.g.*, number of violations of the system). (OECD Environment, Health and Safety Publications, 2008), however PTW should prohibit conflict with other operations.

Day-to-day operations

Potential leading indicators

- Stress/Communication
- SJA (Safe Job Analysis)

This is an important indicator, responsible for many accidents according to experts at Rogaland Crane School, but difficult to measure.

Potential lagging indicators

- Delays in operations

Number of delays in operation.

Maintenance

Potential leading indicators

- Time since last planned maintenance

Is quantifiable, but it is a point to specify what type of maintenance that are considered. In this case, safety critical systems is the planned maintenance.

Potential lagging indicators

- Trend deviations

Trend in number of deviations in inspection of crane and lift equipment with a high risk level if there is more than 20% increase or increase in more than two consecutive inspections.

5.4.4 Activity - performance

Operational working conditions

Potential leading indicators

- Time since last training
- Shift work

Simulation is a great way to learn about risks and how to tackle certain situations. Simulations and practice will increase the level of awareness and the level of the crane operator's

competence. It can also contribute to make co-workers more aware of what that is happening during a lifting operation and what dangers there are. Crane operators as well as slinger and signaller are sent to simulation and practice every 3rd year.

Shift work is hazardous, especially when workers turn the day around going one week on day shift, and the other on night shift

Crane operational and technical reliability

Potential lagging indicators

- Wrong signals
- Lift incidents

In a sense it will not be possible to get a wrong signal (red instead of green). The meaning of this is that it will not give a full feedback. Sort of half and half, and the equipment will not be able to operate. Stop and reassess.

Lift incidents can be number of hooking/bumping, which is a major cause for internal lifts and loading and offloading.

5.4.5 Activity – control functions

Lifting restrictions

Potential lagging indicators

- Lifting restrictions violated

There are several areas that are out of reach for the crane leading the operator to switching crane. Objects may be in the way. Need to get a PTW. Also, Not certain areas, like helideck, is not allowed to lift cargo over.

Technical Safety System

Potential leading indicators

- Emergency system functions on testing

Emergency break system /aggregate or MOPS functions on testing

Potential lagging indicators

- Number of alarms

Number of loading bolt alarm or for sea lifts: Work area exceedance alarm.

5.4.6 List of factors, indicators and properties

In the following page the indicators developed in chapter 5.4 have been placed according to phase and factor. A short description and /or how to measure them will be discussed.

RISK INDICATOR MODEL

| No | Category | Factor | Leading Indicator | Lagging indicator | Description | Evaluation Criteria | Weight % |
|----|----------------|-------------------------|--|-------------------|---|-----------------------------------|----------|
| 1 | Pre-conditions | Economy | Budget available | | The budget available | | 100 |
| 2 | Pre-conditions | Regulations | Regulations | | Authorities regulations | | 100 |
| 3 | Pre-conditions | Design of crane | Remaining design life time of crane / lifting equipment | | Ratio between remaining lifetime and total lifetime of crane / lifting equipment | R: > 0.9 Y: 0.5-0.9 G: <0.5 | 50 |
| 4 | Pre-conditions | Design of crane | Technical standard of crane / lift equipment to be used in operation | | Technical Standard of crane / lift equipment to be used in operation. Is it adapted for the operations? Does it have a compensator for heave? | | 50 |
| 5 | Pre-conditions | Environmental condition | Vulnerability | | Vulnerability of marine life | | 30 |
| 6 | Pre- | Environmental | | Exceeding | Exceeding weather criteria or using Annex K | | 20 |

RISK INDICATOR MODEL

| | conditions | condition | | weather criteria | for marginal weather conditions | |
|----|----------------|-------------------------|--------------------------------|--|---|----|
| 7 | Pre-conditions | Environmental condition | | Number of delays of operations due to weather forecast | Number of delays of operations due to weather forecast | 20 |
| 8 | Pre-conditions | Environmental condition | | Icing | Geographical location, wind speeds | 20 |
| 9 | Pre-conditions | Environmental condition | Ice condition | | Geographical location R: Sub-areas I, III, IV, VII and VIII (usually ice every winter) Y: Sub-areas V and VI (in-between) G: Sub-area II and the rest of the North Sea | 10 |
| 10 | Planning | Lift crew competence | Lift crew experience | | Average number of years relevant lift crew experience R: < 3 years Y: 3-10 years G: > 10 years | 30 |
| 11 | Planning | Lift crew competence | Experience in working together | | Percentage of turnover among drilling crew R: > 30 % Y: 10-30 % G: < 10 % | 10 |

RISK INDICATOR MODEL

| | | | | | | |
|----|-----------|-----------------------------------|---|--|---|-----|
| 12 | Planning | Lift crew competence | | Errors made by staff | Number of times lift does not proceed as planned due to errors made by staff | 60 |
| 13 | Planning | Operations procedures and support | Review of procedures | | Percentage of procedures that are reviewed and revised within the designated period. | 50 |
| 14 | Planning | Operations procedures and support | | Incorrect/unclear operational procedures | Number of times lift does not occur as planned due to incorrect/unclear operational procedures Incorrect apply mainly for new installations. Old ones have had several reviews and would not be incorrect. | 50 |
| 15 | Planning | Risk Assessment | Pre job risk analysis | | Percentage of operations performing a risk analyses before the job | 100 |
| 16 | Planning | Maintenance plan and procedures | | Backlog | | 60 |
| 17 | Planning | Maintenance plan and procedures | Availability of external resources | | Availability of external resources (distance to shore) | 20 |
| 18 | Planning | Maintenance plan and procedures | Coverage and review of critical systems | | Coverage and review of critical systems | 20 |
| 19 | Activity, | Simultaneous | | Simultaneous | Number of simultaneous operations | 30 |

RISK INDICATOR MODEL

| | | | | | | |
|----|--------------------|----------------------------|---|-------------------------|--|----|
| | level | operations | | operations | | |
| 20 | Activity, level | Simultaneous operations | | Violations | Extent the work permit system is followed (<i>e.g.</i> , number of violations of the system) | 70 |
| 21 | Activity, level | Day-to-day operations | Stress / Communication | | This is an important indicator, responsible for many accidents according to experts at Rogaland Crane School, but difficult to measure | 60 |
| 22 | Activity, level | Day-to-day operations | | Delays in operations | Number of delays in operations | 20 |
| 23 | Activity, level | Day-to-day operations | SJA (Safe Job Analysis) | | Percentage of lifts that uses SJA (for critical lifts) | 20 |
| 24 | Activity, level | Maintenance | Time since last planned maintenance | | Time since last planned maintenance | 30 |
| 25 | Activity, level | Maintenance | | Trend in deviations | Trend in number of deviations in inspection of crane and lift equipment R: > 20% increase or increase in more than two consecutive inspections Y < 20% increase or increase in more than two consecutive inspections G: No change or decrease | 70 |

RISK INDICATOR MODEL

| | | | | | | |
|----|-----------------------------|---|--------------------------|-------------------------------|--|-----|
| 26 | Activity, Performance | Operational working conditions | Time since last training | | Can be measured according to simulation practice, which is every 3 rd year, or installation specific training | 50 |
| 27 | Activity, Performance | Operational working conditions | Shift work | | Shift work is hazardous, especially when workers turn the day around going one week on day shift, and the other on night shift | 50 |
| 28 | Activity, Performance | Crane operational and technical reliability | | Lift incidents | Number of lift incidents due to hooking, bumping, failure of couplings, valves or instrumentation. | 60 |
| 29 | Activity, Performance | Crane operational and technical reliability | | Wrong signals | Number of wrong signals | 40 |
| 30 | Activity, Control functions | Lifting Restrictions | | Lifting restrictions violated | Areas out of reach for the crane, must switch crane. Objects in the way. Get PTW. Not allowed to lift over certain areas | 100 |
| 31 | Activity, Control functions | Technical Safety System | Emergency system | | Emergency break system /aggregate or MOPS functions on testing | 50 |
| 32 | Activity, Control functions | Technical Safety System | | Number of alarms | Number of loading bolt / Sea lifts: work area exceedance alarm (Boom extension) | 50 |

6.0 Results

This chapter presents the finished risk indicator model with weighting of influencing risk factors.

Factors

Factors influenced by their own risk indicators:

- 100 % on pre-conditions (as no factors influence them) except design of crane, which is influenced by the economy of the company.
- 50 % in all other stages, meaning that half of the calculated value are due to the factor's risk indicators and the other half is due to influence from other factors.

The incoming influence to a factor must amount to 100 %. Figure 5.4-1 on the following page shows the weighting of the risk indicators and influence.

As can be seen, risk indicators are the only influence on all factors in the pre-conditions phase, except design of crane.

Risk assessment is influenced equally by economy and regulations. The company's economy could be considered to influence almost every other factor, but it has been established a higher correlation with risk assessment, and regulations affect risk assessment through requirements in NORSOK R-003 (2004).

Lift crew competence is influenced equally by regulations and design of crane. Regulations affect risk assessment through requirements in NORSOK R-003 (2004) and design of crane as blind zones due to the layout of the deck, demands more in training of the crane operator.

Operation procedure and support is mainly influenced by environmental conditions (50 %) and regulations (25 %) and design of crane (25 %).

Maintenance plan and procedures is influenced equally by economy and environmental conditions with 40 % each and 20 % influence from regulations.

Simultaneous operations are influenced by lift crew competence.

Day-to-day operations are influenced equally by operation procedure and support and lift crew competence with 40 % each and 20 % influence from risk assessment.

Maintenance is influenced by maintenance plan and procedures.

Operational working conditions are influenced by day-to-day operations.

Crane operational and technical reliability is influenced equally by maintenance and day-to-day operations.

Lifting restrictions is mainly influenced by operational working conditions (60 %) and 40 % from simultaneous operations.

Technical safety system is influenced by crane operational and technical reliability.

The event dropped load due to crane operations is equally influenced by the control functions lifting restrictions and technical safety system.

Figure 5.4-2 shows the risk indicator model with factors and associated risk indicators in MARIT (MARI Tool), which is the software developed for MARI by Safetec Nordic AS.

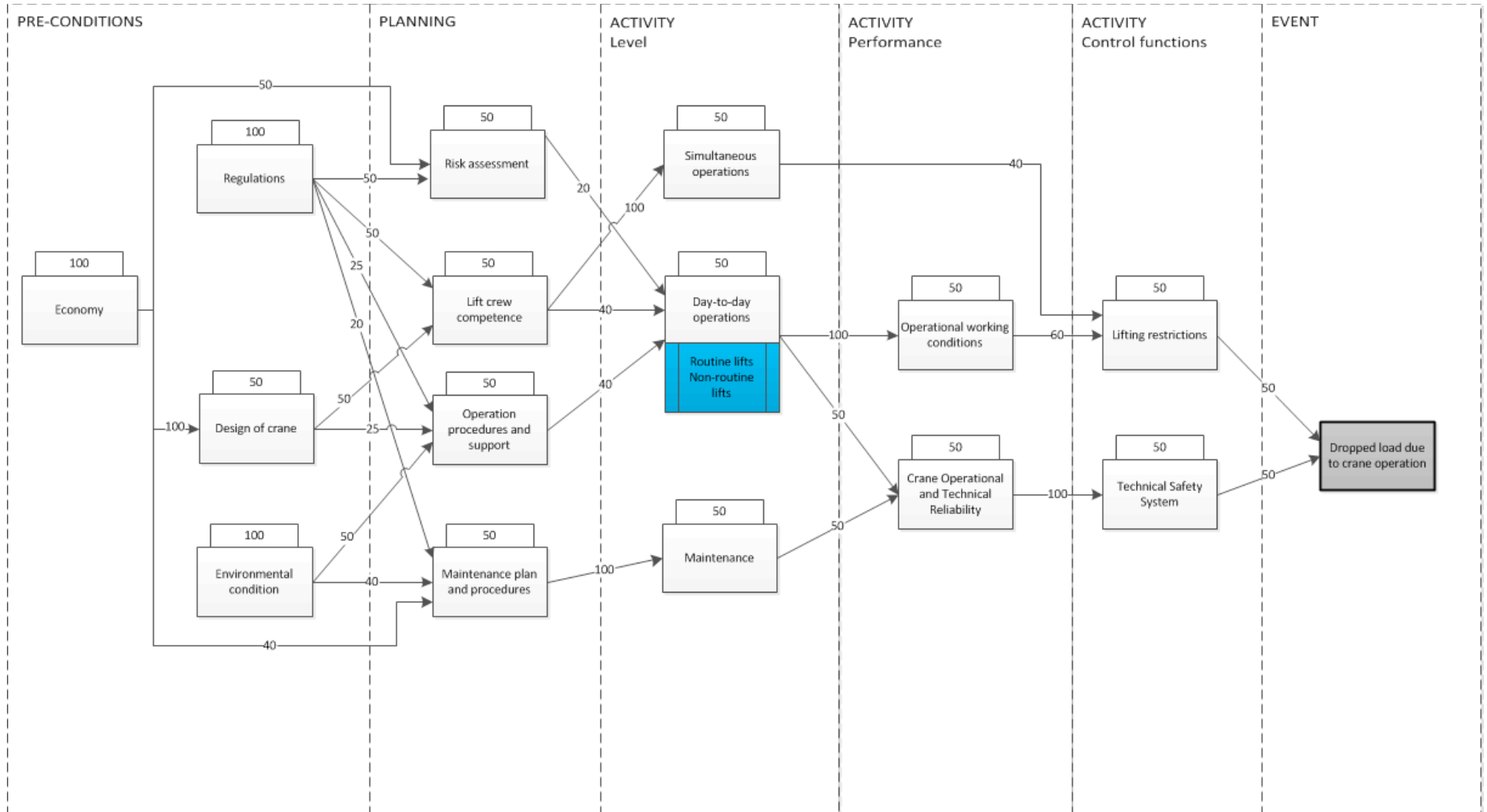


Figure 5.4-1 Risk indicator model with factors

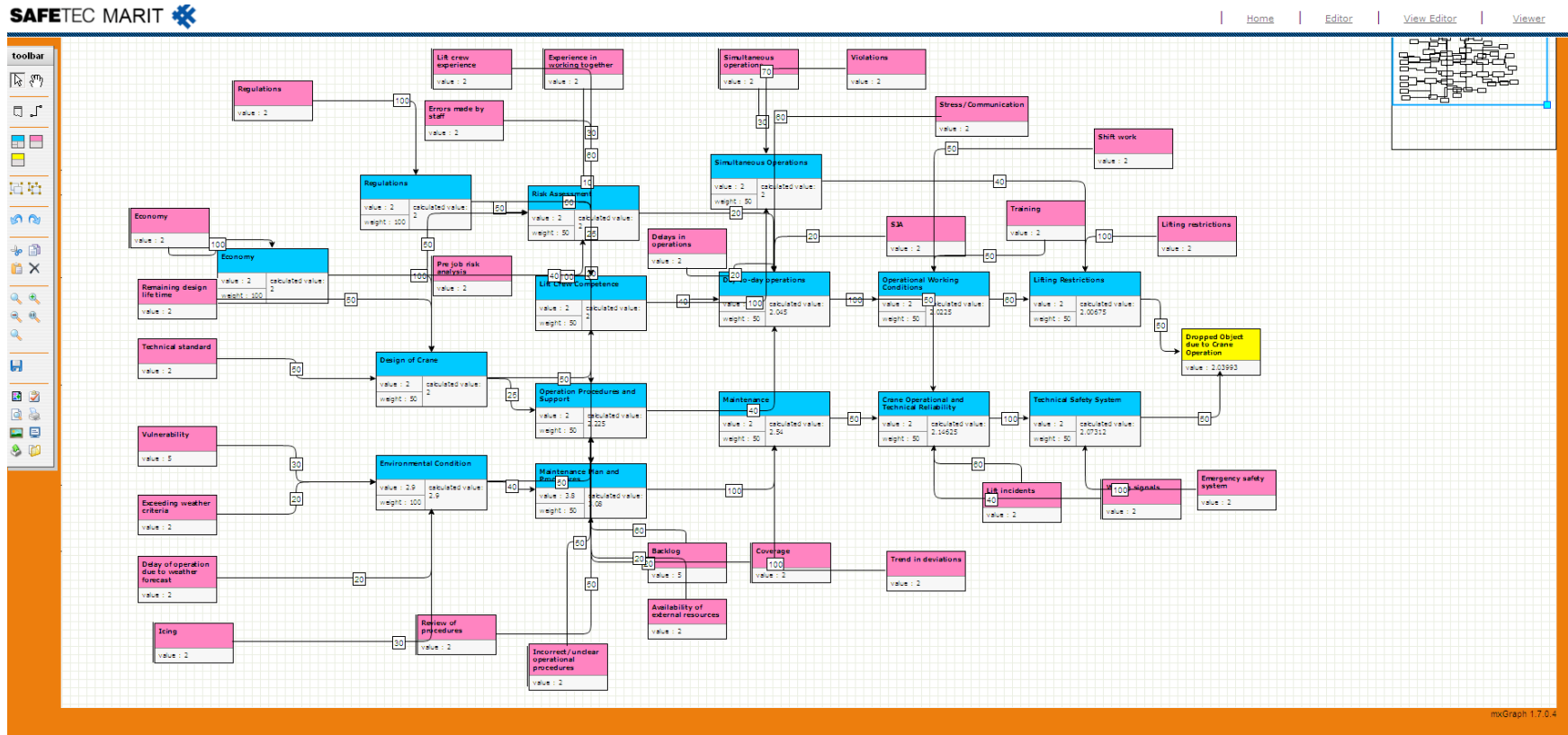


Figure 5.4-2 Risk indicator model using MARIT (MARI Tool)

Quantification

All indicators are given a standard value of 2, 5 or 8 to consequently green, yellow or red risk level.

Table 5.4-1 Quantification of risk indicators

| Color | Green | Yellow | Red |
|----------------------|-------|--------|-----|
| Risk indicator value | 2 | 5 | 8 |
| Range in model | 1-3 | 4-6 | 7-9 |

Figure 5.4-3 shows a simple example of how influence from factors and risk indicators are calculated.

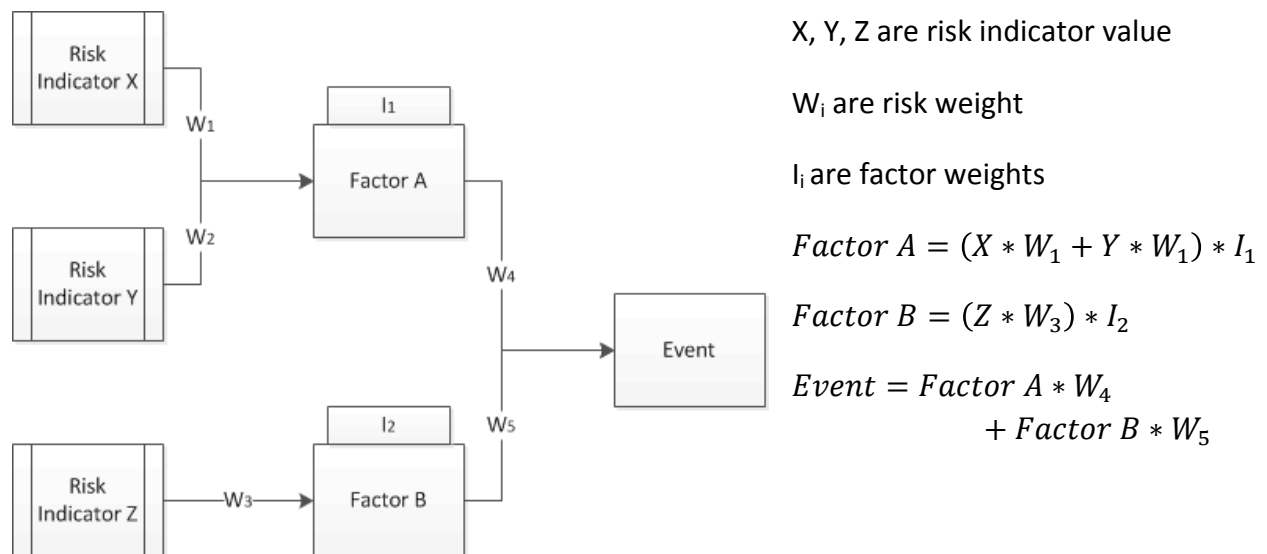


Figure 5.4-3 Calculation example

The altered indicators and associated factors for the North Sea

- Environmental conditions
 - Vulnerability (yellow)
- Maintenance plan and procedures
 - Backlog (yellow)

Conservative values are used.

Loss of containment events due to loads dropped on process equipment could lead to major oil spills that affect marine life. There is general consensus that the marine life in the Barents Sea is more vulnerable than the marine life in the coastal areas in the North Sea (Bellona, 2002). However, the marine life in the North Sea is vulnerable and has been adjusted to a medium level.

If the backlog is increasing on safety critical maintenance the crane operator have the right to shut down the crane and not reassume work before maintenance is complete. This would again lead to the installation being forced to shut down and personnel being sent to shore, and no company wants that. It is possible to get suspension from the PSA to postpone important maintenance work and this is bad habit in the industry according to experts at Rogaland Crane School. The indicator on backlog is set to a medium risk level on both locations.

The altered indicators and associated factors for the Barents Sea

- Economy
 - Budget available (yellow)
- Design of Crane
 - Technical standard (yellow)
- Environmental conditions
 - Vulnerability (red)
 - Exceeding weather criteria (yellow)
 - Delay of operation due to weather forecast (red)
 - Icing (red)
 - Ice condition (red)
- Regulations
 - Regulations (yellow)
- Maintenance plan and procedures
 - Backlog (yellow)

- Availability of external resources (yellow)

Conservative values are used.

Installations in the Barents Sea will be more expensive than in the North Sea. They would require a bigger budget, as they would need to be more robust in terms of standard of steel and winterization of rig. The risk indicator on the budget available is set to a medium risk level for the Barents Sea and unchanged for the North Sea.

Technical standard of crane and lift equipment used in the operation must be customized for the operations with equipment like a heave compensator. It is difficult to set an appropriate measurement for the standard, but setting the measurements to the technical generation of a crane could cover a part of the factor. An offshore crane used in the North Sea may not be usable in the Barents Sea and the indicator is therefore set at a medium risk level.

As mentioned for the North Sea, vulnerability of marine life in the Barents Sea is deemed high risk.

The threshold for writing deviations has become lower. The reason for this is to be proactive, but this can lead to misuse. Example: Some think that filling in Annex K will make it OK to operate under marginal weather conditions. They've filled out a form, so they're in the clear. Usually in real life, the crane operator or the captain of the vessel are the one demanding operations to shut down. The significant wave height might be too high. The signaler might also stop the operations if he sees it fit. He might have a better grip on the situation in some situations. Say the container is lowered down somewhere in a wind tunnel that creates speeds higher than expected.

In the Barents Sea icing can be challenging. Structures can be destabilized, equipment can have decreased performance and areas can be slippery. The ice condition is decided through geographical location as there are established ice zones in the Barents Sea and the case study location in the Barents Sea is in Sub area I, close to Bjørnøya. Bjørnøya has high wind speeds, is susceptible to polar lows, icing and usually have sea ice every winter.

In addition to the backlog risk indicator being in the medium risk level, the distances to infrastructure and ports in the north are huge. Therefore an indicator on the availability of extra personnel to perform any type of critical maintenance or spare parts is useful. Coverage of critical systems are most relevant for new installations and review of critical systems is easily quantifiable as they must satisfy time requirements.

The risk indicator models for the North Sea and the Barents Sea can be seen in figure 5.4-4 and figure 5.4-5 on the following pages.

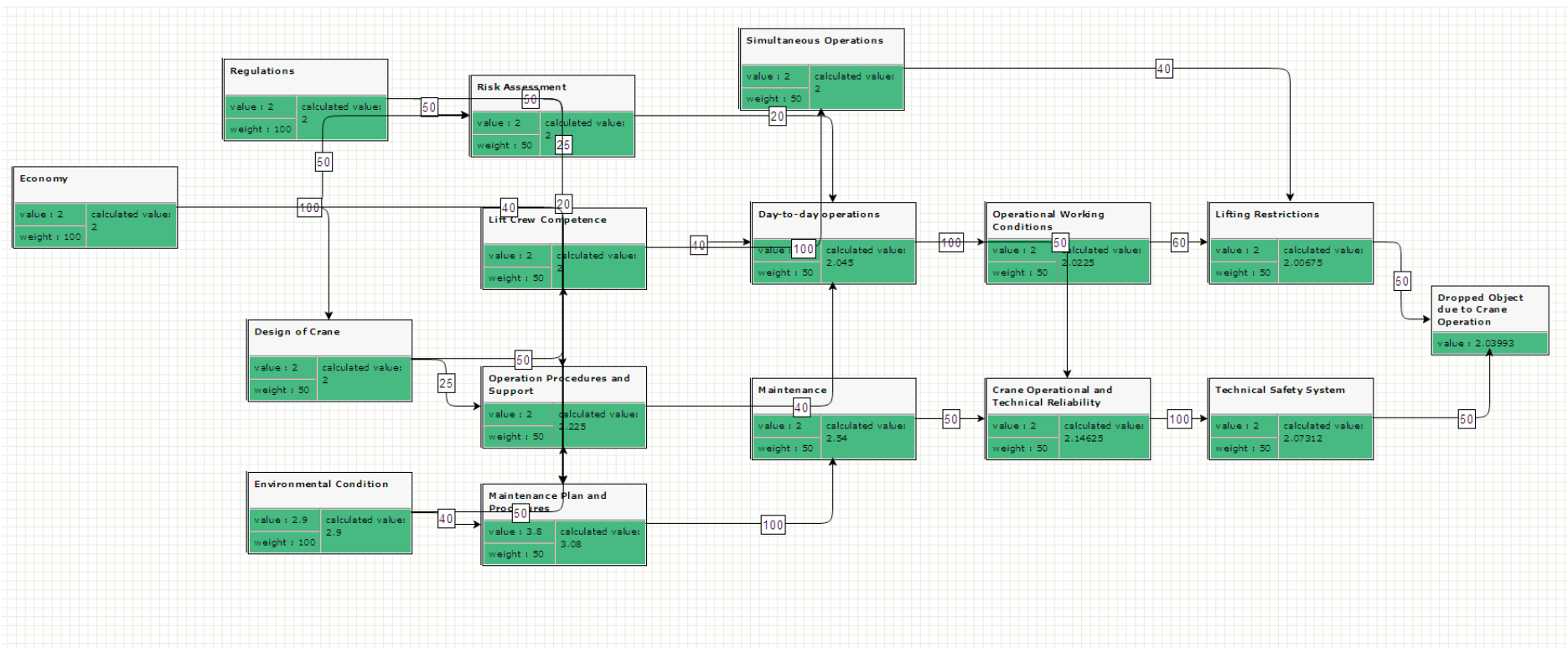


Figure 5.4-4 Risk Indicator model North Sea

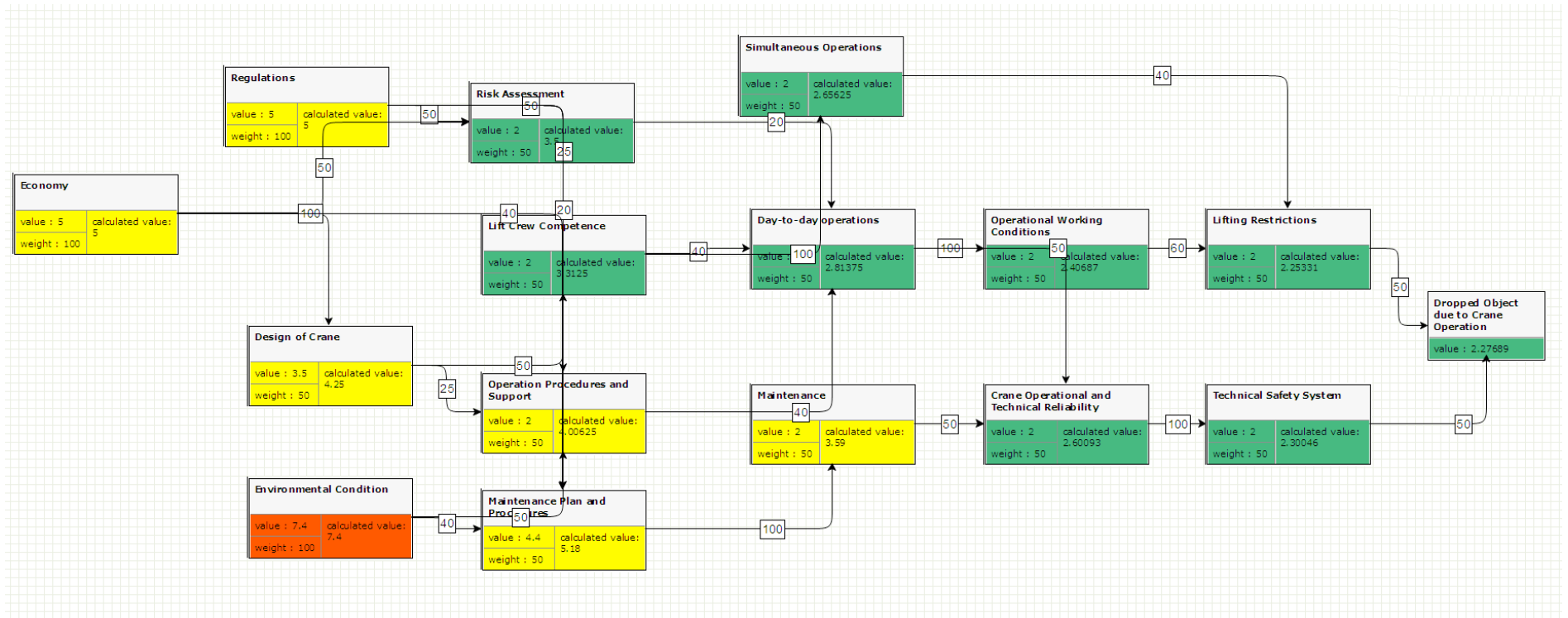


Figure 5.4-5 Risk Indicator model Barents Sea

Going more into details for the North Sea model, it is seen that the end result in the MARI model in the figure below has a value slightly over 2. Thereby being green, or low risk, with good margins. Can see how the highest value of 2.56 in maintenance is reduced in the following phases that have risk indicators deemed as low risk and well functioning barriers in place.

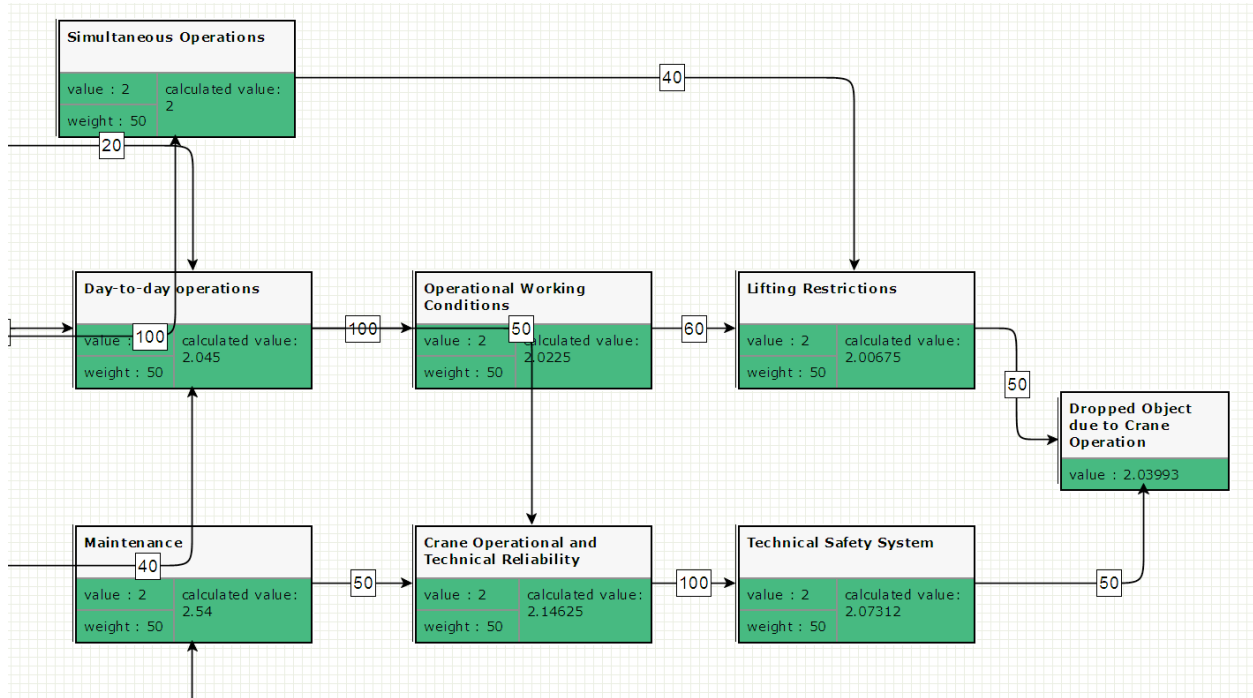


Figure 5.4-6 North Sea model detail

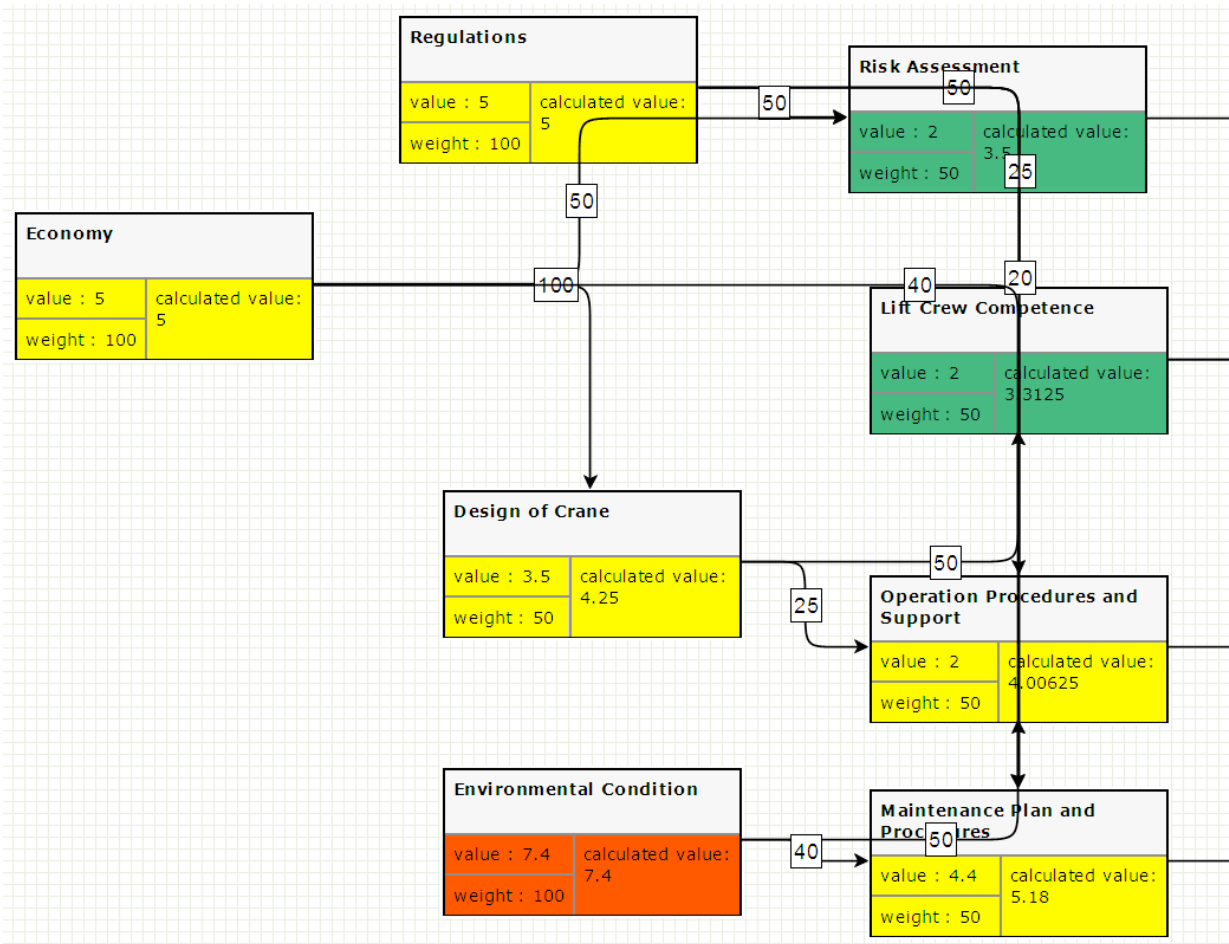


Figure 5.4-7 Barents Sea model detail early phases

Environmental conditions are considered to be high risk in the Barents Sea. The other factors in the pre-conditions and maintenance plan and procedures in the planning phase are considered to be in a medium risk level. Operational procedures and support however, had low risk level for their own indicators, but the influence from environmental conditions and design of crane was high enough to affect the risk level.

Event is green due to good barriers. The point is that if factors in pre-conditions and planning phase are considered to have a medium or high risk level, then factors in the following phases need to be in good shape to “pick up the slack” and turn the operation into low risk.

In figure 5.4-8 it is seen how maintenance is in the medium risk level. This is due to the influence from maintenance plan and procedures. Again it can be seen that the value of 3.59 in maintenance is reduced in the following phases that have risk indicators deemed as low risk and

well functioning barriers in place.

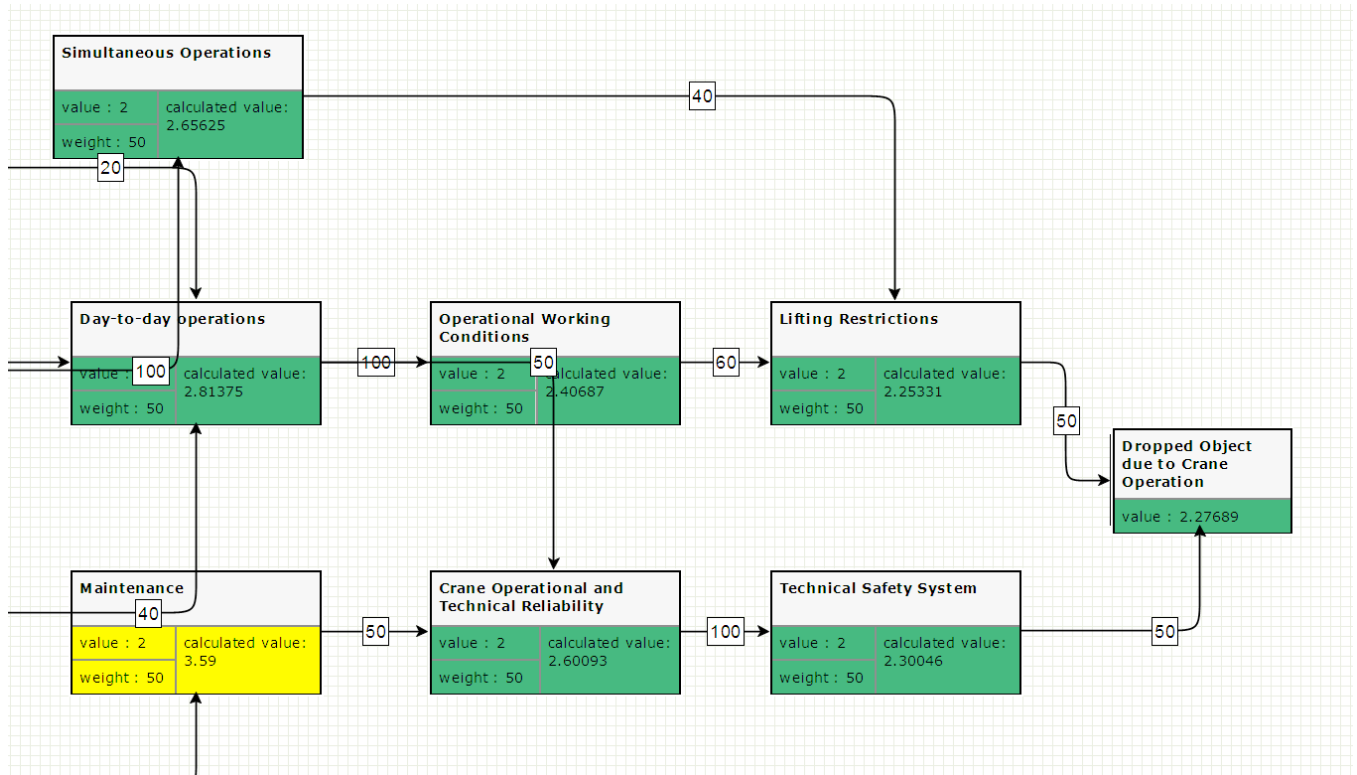


Figure 5.4-8 Barents Sea model later phases

7.0 Discussion

The discussion will revolve around two subjects. The first is a discussion on the conception and use of risk indicators. The second chapter discusses the contribution from the use of the MARI to risk understanding in dropped loads from offshore cranes.

7.1 Generally on risk indicators

There is a misconception that it is possible to express risk truly objective through risk indicators (Vinnem, 2010). This means that the only thing needed is to find the correct risk indicators. But this is not true; there are no single indicators that can express all risk relevant aspects of safety. Different indicators measure different aspects of performance and that's the reason it is advantageous to develop indicators as a set.

The purpose of risk indicators is to identify events or states that leads to higher-level consequences. Risk indicators provide a method to measure activity, status, or performance against the companies' requirements and goals (American Petroleum Institute, 2010, p.18). Monitoring and analyzing performance enables risk managers to take corrective action when needed. Properly defined and easily understood risk indicators can provide the operating company confidence that the right things are managed.

Bigger risk indicator sets are costly to monitor, maintain and follow up with action. On the other hand, major accident risk is a complex topic with several factors influencing the risk level. This could be used as an argument for developing large indicator sets.

Risk indicator set can also combine indicators that are measured frequently (monthly) with indicators that are measured less frequently (quarterly, annually or even more seldom). However, there need to be sufficient data on the level where the indicator is used to give meaningful information about the status of the risk level.

In connection with lagging indicators based on accident data; near-accidents are not always registered or reported, and may be lacking in empirical data. They give important information of what has happened in the past, but historical data does not predict the future. It is therefore not certain that the statistics of reported incidents provide a true risk picture. For example, it is possible that staff fails to report incidents such as falling objects if they do not do damage, because they do not see the purpose of it. Indicators based on reported events may thus be misleading in terms of real numbers. Therefore, it will always be some uncertainty associated with these probabilities. Events where things "almost" went wrong, and that due to the

circumstances did not develop into an undesirable event, are not always included in these statistics.

A good reporting culture may be a solution. It is important to encourage personnel to report unwanted incidents, but only to a certain degree. Setting a standard for the type of incident that we want to measure could help. There are horror stories with personnel winning all expenses paid vacation trips for having found the most errors in a year. This is not promoting a good safety culture.

The problem with leading indicators is that they are more difficult to develop and there will be more uncertainty in knowing if you are measuring the right things. They require good assumptions and expert judgement.

Risk indicators should be used more as pointers of what might be expected but is neither comprehensive nor absolute. New technologies may also affect the risk picture so annual expert reviews could be a good way to examine the risks in offshore lift operations today to make sure all new risks are examined.

In both cases it is important to have regular reviews to make sure that the indicators are saying something about the risk picture. Indicators do not tell the absolute truth. It is a tool - not an end in itself. Indicators must be interpreted in light of the context.

Some say that the differentiation or classification of indicators as lagging or leading is not important. That the important part is to capture information that can be acted upon to correct a situation, to identify lessons learned, and communicate this knowledge (American Petroleum Institute, 2010).

The discussion on leading/lagging indicators is far from over, but this thesis is agreeing with Hopkins' view (2009) in that there is a need to establish some common ground on the use of leading and lagging risk indicators.

The view that was used throughout the Thesis is that the risk indicator will be lagging or leading according to the factor it measures. Leading indicators try to show if the system is working as intended, the lagging indicators seek to answer whether the unwanted outcomes occur. In this context barrier events or deviations discovered during maintenance, and not specifically happening during operations are leading indicators. Thus, discovered before it had made any significance for the operation. While lagging indicators are errors leading to delays in operations or incidents. This worked out perfectly in the case study.

7.2 Contribution to risk indicator model and area of application

Development of indicator models

Methods for development and application of safety factors have changed since its early beginning. Going back to the SINTEF's indicator project starting in 1994 with the intention of developing technical indicators. Later in 2003 the BORA project started where the main target was an analysis of hydrocarbon leaks. HSE published a guide for developing process safety indicators in 2006 with dual assurance, meaning both leading and lagging indicators.

The RNNP-project put focus on the Norwegian petroleum industry as a whole and gives a picture of the overall condition, while OTS, TTS and BORA put effort on one separate installation/plant for each review (Ruud, 2010). Compared to the traditional QRA-model, all models above are more detailed. They include considerable more risk influencing factors i.e. they give a more detailed risk picture. Additionally, the RNNP-project (and BORA) focus on all parts of the safety concept, in contrast to the OTS and TTS-project focusing exclusively on respectively organizational and technical safety.

RNNP has collected major hazards precursor data for almost ten years and is a valuable assistance, especially when developing lagging indicators. PSA director Magne Ognedal wants to have continuous improvement of the risk picture in connection with the major hazard indicator (PSA, 2011). However, the last four years there have been 70 of these incidents on the Norwegian shelf. This gives reasons for concern. The hope is that the major hazard indicator shows an improvement in today's situation, but it does not do that. The indicator is level. It is worth mentioning that development of indicators with basis in RNNP data will give general indicators, which is not necessarily the objective.

MARI

This section investigates the goodness of MARI as a model to develop indicators for dropped loads due to crane operations.

MARI considers human, organizational and technical aspects and in that way can go into the same group as the RNNP project and BORA. The Major Accident Risk Indicators (MARI) model combines traditional risk modelling and key performance indicators of safety critical elements. The risk modelling is based on causal chains to illustrate the relationship between risk influencing factors and how these affect a specific major accident event. The difference from BORA lies here in the way that BORA considers a whole installation, while MARI considers one major accident event and sorts the factors according to phases.

There are usually complex reasons for major accidents not one single error. The indicators are supposed to pick up on subtle changes in risk level and give a better risk picture. There could be a single error in the maintenance plan and another with the operating procedure. On their own they might not cause any damage, but combined might be a different story. It is the influence between factors that make MARI a good model for dropped loads due to crane operations. How the earlier phases might cause the factor in the next phase to have an increased risk level. However, it is equally important to make improvements in later phases to pay off. Meaning that later indicators can “pick up the slack” and reduce risk level again so that operations remain safe.

The MARI model has several areas of use. Among others it can be used as a monitoring tool, aimed at continuously following the development of the risk level. This gives opportunities to correct negative trends early and thereby increasing the possibility to take action. MARI can also be used as a benchmarking tool, to compare with other companies, industries, or installations (Haugen et al., 2011).

It is important to keep focus and attention high on crane and lift operation even if there haven't been an accident or near-accident in many years on an installation. This is difficult as motivation to continue with safety procedures can be reduced over time (Vinnem et al., 2004). However, this should be the other way around. No accidents should be motivation for employees as this is a signal that you are doing something right. Measuring may be a way of motivating the employees to improve the status of indicators which have a negative trend or a poor result. A requirement is that the risk indicators measure parameters that the employees have a form of control over and can improve.

There are some negative aspects of the risk indicator set and the largest one is probably the number of risk indicators that are required. The heavy workload can be lessened if risk indicators are defined in a way that input data is readily available. All risk indicators are in addition, not necessarily monitored each month. Some risk indicators are relevant to check only once per operation, some are related to the rig design and will change very seldom while others maybe need to be checked every three or six months (Haugen et al., 2011, p.9).

Seeing the development in methods for risk indicators it is understood that it is difficult to develop industry wide risk indicators, which can also be applied for a specific offshore installation. A comprehensive set of risk indicators need to take into account the particular circumstances of the operation, the equipment and the organization and there is no guarantee that a generic set will give the answers needed.

8.0 Conclusions

The newly developed MARI model is suitable for use on dropped loads due to crane operations. This is a new area of application for this risk indicator model that should be further explored.

The case study showed a change in risk of dropped objects during offshore operations in different geographical locations, and that this could be measured with the selected indicators.

Leading and lagging risk indicators are useful in an indicator set and the case study had good results using leading indicators to show if the system was working as intended, and the lagging indicators to answer whether the unwanted outcomes occur. In this context barrier events or deviations discovered during maintenance, and not specifically happening during operations are leading indicators. Thus, discovered before it had made any significance for the operation. While lagging indicators are errors leading to delays in operations or incidents.

Changing the risk level in factors and associated risk indicators in an early phase, pre-condition and planning phase does not necessarily end in an unacceptable high-risk level for the event. If the indicators in the later phases are good and low risk, they reduce the risk transferred on to the event.

These factors were adjusted to have the highest risk through the case study in the Barents Sea:

- Environmental conditions
- Maintenance plan and procedures
- Economy
- Design of Crane
- Regulations

For the North Sea this only applies for environmental conditions and maintenance plan and procedures. Environmental conditions are thought to have the largest contribution to the risk level in the Barent Sea.

8.1 Further studies

This case study looked into factors and risk indicators for dropped objects due to crane operations. Only the probability side of the event was analysed. This means that there is not enough data as basis for a general model. One cannot state that the results from this case study are true for all dropped objects from crane operations on the Norwegian shelf.

To be able to generalize from the results it is recommended to continue the study on the consequence side of the event. Analyzing more site/installation specific model should create a risk indicator model for practical use and yield a larger database to be used as source for a general model. The installations analyzed should be placed on several locations in the North Sea and Barents Sea where oil activities are ongoing or will be developed in the future.

9.0 Bibliografi

American Petroleum Institute, 2010. *Process Safety Performance Indicators for the Refining and Petrochemical Industries*. Recommended Practice.

Arctic Climatology and Meteorology, 2009. *Polar lows and arctic weather patterns*. [Online] Available at: http://nsidc.org/arcticmet/patterns/polar_low.html [Accessed 27 November 2010].

Aven, T., 2008. *Risk Analysis, Assessing Uncertainties beyond Expected Values and Probabilities*. Wiley.

Bellona, 2002. *Snøhvit: Reasons for Bellona's opposition*. [Online] Available at: http://www.bellona.org/english_import_area/energy/fossil/barents/snohvit/24419 [Accessed 15 May 2011].

Dale, V.H. & Beyeler, S.C., 2001. Challenges in the development and use of ecological indicators. *Ecological Indicators*, (1), pp.3-10.

Duran, J., 2010. *TPMonline*. [Online] Available at: http://www.tpmonline.com/articles_on_total_productive_maintenance/reliability/operational_reliability.htm.

Dyreborg, J., 2009. The causal relation between lead and lag indicators. *Safety Science*, 47, pp.474-75.

Eikeland, L.Ø., 2007. *Indikatorer på svakheter i menneskelige og organisatoriske barrierer i forbindelse med kran- og løfteoperasjoner på norsk sokkel*. Masteroppgave. Stavanger: Universitetet i Stavanger.

Fjørtoft, K. & Kvamstad, B., 2010. *Analysis of Maritime safety in the high north*. Trondheim: Marintek.

Hale, A., 2009. Why safety performance indicators. *Safety Science*, (47), pp.479-80.

Haugen, S., Seljelid, J., Mo, K. & Nyheim, O.M., 2011. Major accident indicators for monitoring and predicting risk levels. In *Society of Petroleum Engineers*. Vienna, 2011. SPE International.

Haugen, S. et al., 2007. *Operational risk analysis: total analysis of physical and non-physical barriers*. H3.1 Generalisation Report, Rev. 1.

Hopkins, A., 2009. Reply to comments. *Safety Science*, (47), pp.508-10.

Hopkins, 2009. Thinking about process safety indicators. *Safety Science*, (47), pp.460-65.

HSE, 2006. *Developing process safety indicators. A step-by-step guide for chemical and major hazard industries.*

Hudson, P.T.W., 2009. Process indicators: Managing safety by numbers. *Safety Science*, (47), pp.483-85.

International Organization for Standardization, 2000. *ISO Standard 17776.*

Karunakaran, D., 2010. *Marine Operation Tools.*, 2010. Subsea 7.

Kise, M., 2008. *Indikatorer - hva, hvorfor og hvordan?* [Online] Available at: http://www.universell-utforming.milj.no/file_upload/marit_kise_indikatorer.ppt [Accessed 29 January 2011].

Løset, S., Shkhinek, K.N., Gudmestad, O.T. & Høyland, K.V., 2006. *Actions fom ice on arctic offshore and coastal structures.*

Niemeijer, D. & de Groot, R.S., 2008. A conceptual framework for selecting environmental indicator sets. *Ecological Indicators*, 8(6), pp.14-25.

Niemeijer, D. & de Groot, R.S., 2008. A conceptual framework for selecting environmental indicator sets. *Ecological indicators* 8, pp.14-25.

NORSOK R-003, 2004. *Safe use of lifting equipment.* Standard Norge.

NORSOK R-003, 2004. *Safe use of lifting equipment.* Standard.

NORSOK Z-013, 2010. *Risk and emergency preparedness analysis.* NTS.

North Sea Offshore Authorities Forum, Multi-National Theme Audit, 2008. *Lifting equipment and lifting operations.*

OECD Environment, Health and Safety Publications, 2008. Guidance on developing safety performance indicators related to Chemical Accident Prevention, Preparedness and Response for industry. *Series on Chemical Accidents*, 19.

O'Morchoe, M., 2009. [Online] Available at: <http://www.flickr.com/photos/omorcmi/3263857725/in/photostream/> [Accessed 15 May 2011].

Petroleumstilsynet, 2010, n.d. *Petroleumstilsynet.* [Online] Available at: http://ptil.no/granskinger/category26.html?ptil_md_art_list-select_group=Category-202 [Accessed 20 September 2010].

- PetroNord, 2011. *Funn i Barentshavet*. [Online] Available at: http://www.petro.no/nord/modules/module_123/proxy.asp?C=254&I=13088&D=2&mid=174 [Accessed 20 May 2011].
- Polartrec, 2010. [Online] Available at: www.polartrec.com [Accessed 15 May 2011].
- Popova, V. & Sharpanskykh, A., 2010. *Modelling organizational performance indicators*.
- PSA, 2002. *HSE and culture*. [Online] Available at: <http://www.ptil.no/getfile.php/z%20Konvertert/Products%20and%20services/Publications/Dokumenter/hescultureny.pdf>.
- PSA, 2005. *Færre alvorlige hendelser med offshorekraner*. [Online] Available at: <http://www.ptil.no/nyheter/faerre-alvorlige-hendelser-med-offshorekraner-article2128-24.html> [Accessed 30 January 2011].
- PSA, 2005. *VARSEL OM PÅLEGG TIL NORSK HYDRO OG PROSAFE ETTER ALVORLIG HENDELSE MED PERSONSKADE PÅ OSEBERG B*. [Online] Available at: <http://www.ptil.no/nyheter/varsel-om-paalegg-til-norsk-hydro-og-prosafe-etter-alvorlig-hendelse-med-personskade-paa-oseberg-b-article2122-24.html> [Accessed 30 January 2011].
- PSA, 2006. *Rapport etter gransking av hendelse på Ekofisk 2/4X*. [Online] Available at: <http://www.ptil.no/nyheter/rapport-etter-gransking-av-hendelse-paa-ekofisk-2-4x-article2547-24.html> [Accessed 30 January 2011].
- PSA, 2007. *Alvorlig personskaade ifm. løftehendelse med catwalk sylinder ved Scarabeo 5, 11. Mai 2007*. Investigation report.
- PSA, 2007. *Gransking av hendelse med dødelig utfall på Saipem 7000*. [Online] Available at: <http://www.ptil.no/nyheter/gransking-av-hendelse-med-doedelig-utfall-paa-saipem-7000-article3532-24.html> [Accessed 20 March 2011].
- PSA, 2007. *Gransking av hendelse med utstyr som falt ned på boredekk – Stena Don 30.5.2007*. Investigation report.
- PSA, 2007. *Gransking av hendelse på Kvitebjørn 4.7.2006 – revidert rapport*. Investigation report. Ptil.
- PSA, 2007. *Gransking av hendelse på Transocean Searcher der BOP falt rundt en meter under klargjøring for kjøring av BOP 2.6.2007*. Investigation report.
- PSA, 2007. *Rapport etter gransking av hendelse hvor 30" foringsrør falt ned på borehytta - West Epsilon - 14.9.2007*. Investigation report.

PSA, 2008. *Personskade ved demontering og løfting av en krankrybbe på Troll A 18.09.08.* Investigation report.

PSA, 2008. *Risiko knyttet til kran/løft.* [Online] [Accessed 30 January 2011].

PSA, 2008. *Risiko knyttet til kran/løft.* [Online] Available at: <http://www.ptil.no/kran-og-loeft/risiko-knyttet-til-kran-loeft-article3778-16.html> [Accessed 30 February 2011].

PSA, 2009. *Deadly blind spots.*

PSA, 2009. *Deadly blind spots.* [Online] Available at: <http://www.ptil.no/news/deadly-blind-spots-article5290-79.html> [Accessed 30 January 2011].

PSA, 2009. *Gransking av Løftehendelse Troll C 9.5.2009.* Investigation report.

PSA, 2010. *Gransking av løftehendelse med personskade på boredekk på Stena Don.* Investigation report.

PSA, 2010. *PTIL gransker hendelse på Njord A.* [Online] Available at: <http://www.ptil.no/nyheter/ptil-gransker-hendelse-paa-njord-a-article7485-24.html> [Accessed 20 May 2011].

PSA, 2010. *Rapport etter gransking av hendelse 10.8.2009 på Deepsea Atlantic hvor 30" foringsrør falt ned på "catwalk"..* Investigation report.

PSA, 2010. *Risikonivå i petroleumsvirksomheten Hovedrapport, utviklingstrekk 2010, norsk sokkel.*

PSA, 2010. *Status Barents 2020 - Harmonisering av HMS standarder.*

PSA, 2011. [Online] Available at: <http://www.nrk.no/nyheter/distrikt/rogaland/nord-jaeren/1.7609418>.

PSA, 2011. *Løftehendelse med personskade GFA 28.2.2011.* Investigation report.

PSA, 2011. *Løfteutstyr på boredekk: Faller i unåde.* [Online] Available at: <http://www.ptil.no/kran-og-loeft/loefteutstyr-paa-boredekk-faller-i-unaade-article7857-16.html> [Accessed 25 May 2011].

PSA, 2011. *Pålegg til Statoil etter løftehendelse på Heidrun.* [Online] Available at: <http://www.ptil.no/nyheter/paalegg-til-statoil-etter-loeftehendelse-paa-heidrun-article6946-24.html> [Accessed 20 May 2011].

- Ptil, 2005. *Færre alvorlige hendelser med offshorekraner*. [Online] Available at: <http://www.ptil.no/nyheter/faerre-alvorlige-hendelser-med-offshorekraner-article2128-24.html> [Accessed 5 March 2011].
- Rausand, M. & Utne, I., 2009. *Risikoanalyse: Teori og metode*. Trondheim: Tapir akademisk forlag.
- Røsnes, S. & Prøsch, K., 2010. *Risk associated with lift operations in arctic conditions*. Unpublished report. Longyearbyen: The University Centre in Svalbard.
- Reason, J., 1997. *Managing the Risks of Organizational Accidents*. Ashgate Publishing Limited.
- Reason, J., 2000. Human error: models and management. *BMJ*, 320.
- Ruud, K., 2010. *Indicators for operational safety*. MSc Thesis. NTNU.
- Safetec Nordic AS, 2010. *Kategorisering av fallende last hendelsene i RNNP*. Internt notat.
- Scandpower, 2005. *Analyse av årsakssammenhenger til uønskede - Fase 2 – Perioden 2000 - 2004*. Petroleumstilsynet.
- Seljelid, J., Kvalheim, S.A., Nyheim, O.M. & Vinnem, J.E., 2011. New approach to analysis of falling objects in the offshore petroleum industry – operational categorization of events. In *Sent to ESREL.*, 2011.
- Thelma, 2010. *Kalde utfordringer - Helse og arbeidsmiljø på innretninger i nordområdene*.
- Trbojevic, V.M. & Gudmestad, O.T., 2009. *Risk analysis of marine operations in arctic waters*.
- Vatn, J., 2006. *Risk analysis and risk influence modelling*. Trondheim: SINTEF.
- Vinnem, J., Aven, T., Sørum, M. & Øien, K., 2003. Risk Indicators for major hazards in the offshore petroleum industry. In *ESREL 2003.*, 2003.
- Vinnem, 2007. *Offshore Risk Assessment*. Springer.
- Vinnem, J.E., 2007. *Offshore Risk Assessment - Principles, Modelling and Applications of QRA Studies*. 2nd ed. London: Springer.
- Vinnem, J.E., 2010. Risk indicators for major hazards on offshore installations. *Safety Science*, 48, pp.770-87.
- Vinnem, J.E., Hestad, J.A., Kvaløy, J.T. & Skogdalen, J.E., 2010. Analysis of root causes of major hazard precursors (hydrocarbon leaks) in the Norwegian offshore petroleum industry. *Reliability Engineering and System Safety*, 95, pp.1142-53.

Vinnem, J.E., Veire, G., Knudsen, B.H. & Aven, T., 2004. *A method for developing and structuring risk activity indicators for major accidents.*

Webb, P., 2009. Process safety performance indicators: A contribution to the debate. *Safety Science*, (47), pp.502-07.

Øien, K., 2001. A framework for the establishment of organizational risk indicators. *Reliability Engineering and System Safety*, 74, pp.147-67.

Øien, K., 2001. *Risk Control of Offshore Installations: a Framework for the Establishment of Risk Indicators.* PhD Thesis. NTNU.

Øien, K. & Sklet, S., 2001. *Risk Analyses during Operation (The Indicator Project) Executive Summary.* Trondheim: SINTEF.

Øien, K., Utne, I.B. & Herrera, I.A., 2011. Building Safety indicators: Part 1 - Theoretical foundation. *Safety Science*, 49(2), pp.148-61.

Øien, K., Utne, I.B., Tinmannsvik, R.K. & Massaiu, S., 2011. Building Safety indicators: Part 2 – Application, practices and results. *Safety Science*, 49, pp.162-71.

Appendices

Appendix A: Accidents from 2005 till today

The accidents below are based on investigation reports from PSA (Petroleum Safety Association).

26.04.2005: Oseberg B

During removal of tubes at Oseberg B (PSA, 2005), a person got struck in the head by an 600 kg drill pipe that fell from the pipe handling crane. The person suffered serious head injuries and the incident could have resulted in loss of life under slightly different circumstances.

The direct cause of the accident is that a drill pipe, which was transported by the pipe handling crane, detached from the magnetic yoke and struck a person in the head. This person was located within the restricted area. The underlying causes of the incident were:

- Inadequate management of operations on the pipe deck
- Lack of compliance with procedures for lifting operations
- Inadequate training
- Inadequate document control
- Technical weaknesses in pipe handling crane

13.01.2006: Ekofisk

During the installation of a new exhaust cooling system on one of the engines in a cementing unit at 2/4X there was an incident in connection with the lifting operation (PSA, 2006). The exhaust cooler (390 kg) fell and hit a person in the left leg. The incident was deemed as having a potential for loss of lives.

Several causes for the incidents are listed:

- Lack of leadership on the structure
- Lack of preparation for maintenance on cementing unit
- Lack of expertise in connection with the assembly and use of temporary lifting equipment
- Inadequate planning of the lifting operation
- Inadequate training in ConocoPhillips procedures

04.07.2006: Kvitebjørn

A 13.6 meter long and 921 kg heavy drill pipe fell 26 meters from the grab-hook on the pipe handling crane and landed on a walkway on the Installation Kvitebjørn (Statoil) (PSA, 2007). No personnel were injured and there was no further material damage, but if the pipe had struck personnel the outcome could have been fatal.

PSA's investigation revealed many weaknesses and breaches of the law. The deviations are related to failures of the crane manufacturer, National Oilwell Varco, and with the drilling contractor, KCA Deutag. The investigation also points out that Statoil has potential for improvement when it comes to their responsibility as operator.

During the operation the conclusion was that the pipe supports were not activated and the communication between the crane operator and the installer was vague.

Technical weaknesses like absence of built in safety functions on the crane and there were other hazard crane was not identified. The user manual was lacking hazard and safety specifications, and the switch indication for activation of the pipe support was inadequate.

Other critical circumstances were among others that the crane operator was given the task without being sufficient qualified for the assignment.

11.05.2007: Scarebeo 5

One person got seriously injured in the shoulder during the installation of a 1300 kg and 6-meter long hydraulic lift cylinder on a catwalk machine on the drilling arrangement Scarebeo 5 (PSA, 2007). The general impression after the investigation was insufficient organisation and risk comprehension.

Deviations:

- Inadequate organisation of work
- Inadequate risk identification
- Inadequate supervision - roles and responsibilities
- People under the suspended load

02.06.2007: Transocean Searcher

A failed connection between the BOP and lifting device during transportation led the BOP (weight around 200 tons) to fall about a meter and was standing on the edge of the transport vehicle (PSA, 2007). The cause of the incident could probably be linked to faulty assembly of

lifting gear to the riser section. No personnel were injured, but it could have been a potential fatal accident under marginally different circumstances.

30.05.2007: Stena Don

During preparation for the start of drilling activity on the Åsgard field a hydraulic tool with a weight of approx. 790 kg fell down to the unsecured area of the drill floor on board the Stena Don (PSA, 2007). The investigation revealed both regulatory gaps and deficiencies in technical equipment and the procedures.

Deviations were found in the following barriers:

- Technical solution (from the supplier)
- Documentation (the supplier)
- Risk assessment of equipment arriving rig
- Work Descriptions and procedures
- Audit, inspection of the equipment.

12.08.2007: Saipem 7000

One person fell over board and died during a lift operation on the lift arrangement Saipem 7000 (StatoilHydro) (PSA, 2007).

The person that fell was a part of a work team of four, which worked together on a winch that was wounded on a hydraulic hose. The hose was connected from the winch to a pulley in the crane beam and down to the module.

The caster had stuck, and there was tension in the hose from the caster down to the module and a slack from caster down to the winch. A part of the hose was left on the winch platform next to the winch after failed attempts to free the hose.

The victim was most likely struck by the hydraulic hose as it was suddenly tightened up. The hose has then turned or pushed the person over the railing. He fell into the sea from the winch platform 30 meters above the sea and drowned.

During the investigation PSA found the following deviations:

- Incorrect design of castor arrangement
- Inadequate planning and risk assessment
- Lack of consideration of the use of technology to reduce risk

- Inadequate risk assessment and risk awareness
- Lack of responsibility and lines of communication
- Inadequate handover / communication
- Inadequate monitoring of the operator

14.09.2007: West Epsilon

During a lifting operation on West Epsilon a 30 " casing with a weight of 8.5 tonnes fell down on the drilling cabin (PSA, 2007). The casing broke the ceiling on the drilling cabin, and the end of the casing landed in the driller's chair. Two people were sent to land with helicopter with smaller injuries.

The direct cause of the accident was that the lifting tether was not properly closed and locked when the casing was lifted.

The underlying deficiencies were found in:

- The design of the drill floor
- Construction of the lift tether
- Manual
- Follow-up of safety reports
- Competence, planning and implementation
- Management and procedural violations

18.09.2008: Troll A

One person was injured in the left hip and thigh and right leg in connection with the removal of a steel beam using the offshore crane (PSA, 2008). The incident happened during the removal of an approximately 335 kg heavy steel beam that was used as a cradle for the crane boom. The cradle was welded onto a steel frame. Because of the design of the structure the weld was not properly removed with an angle grinder. The offshore crane was used to break free the last part of the weld. When the cradle came loose, it fell down and hit a flagman in the left hip and thigh and right leg.

Deviations found:

- Lack of organization and planning
- Inadequate understanding of risk
- Improper use of offshore cranes.

09.05.2009: Troll C

A roughneck was caught between the container hanging in the crane hook and the other containers on the cargo deck during a lifting operation on the Troll C facility (PSA, 2009). The injured had fractures and minor internal bleeding. Under slightly different circumstances the incident could have had fatal consequences.

Investigation of the incident has revealed several deviations from the regulations:

- Inadequate management of crane and lifting activities
- Inadequate planning
- Lack of description and communication of roles and responsibilities for HSE-coordinator/nurse
- Inadequate job description for the operationally responsible for lifting operations
- Inadequate compliance with the governing documents for lifting operations

06.06.2009: Stena Don

During a lifting operation a 11 meter long and 1.24 tones part of a riser detached from the fixture about 12 m above the deck, tilted on a help arm and fell down on the workbench (spider) on the drill floor and hit the head and neck of a service technician (PSA, 2010). The injured lost consciousness for a while and had minor injuries. In addition some equipment on the drill floor had damages, but the consequences could have been much worse.

Investigation shows that the piece of riser was not locked in the fastening tool when it was lifted. Identified root causes of the accident include defects in the construction and maintenance of attachment tools, training, expertise, planning and implementation, supervision and procedural violations.

The following deviations were found:

- Lift when personnel are under suspended loads
- Construction of fastening tools
- Education and training
- Compliance with procedures

10.08.2009: Deepsea Atlantic

A lifting accident occurred at Deepsea Atlantic (StatoilHydro, Odfjell Drilling As and Odfjell Well Services AS) when a seven tonnes heavy riser casing fell approximately six meters down on the catwalk. No one was hurt, but one person was in the sealed off area. There was some material damage, but the consequences could have been much worse under slightly different circumstances. The direct cause for the accident was most likely that some of the equipment was not properly locked during lifting of the riser.

The underlying reasons were (PSA, 2010):

- Defects during construction of the elevators
- Insufficient control and maintenance of the elevators
- No user instruction manual
- Weakness in the control system for HMS
- Insufficient control of the receipt
- Lack of the systems information of the transfer of experience and improvement
- Lack of competence
- Lack of planning, performing and risk assessment
- Insufficient leadership
- Lack of procedure
- Breach of procedure
- Insufficient procurement, control and usage of provisional equipment
- Insufficient follow up of the accident

15.04.2010: Heidrun

During lift of a riser to the drill deck the riser came loose from the lifting gear and the end of the pipe fell about ten meters down on the drill floor. The pipe was about 14 meters long, and weighed approximately 3500 kg (PSA, 2011). Three people were in the area.

The incident has clear similarities with previous serious lifting events in the drilling area, where Statoil has been the operator, as on the 02.06.2007: Transocean Searcher (2007), 14.09.2007: West Epsilon (2007), Heidrun (2008), 06.06.2009: Stena Don (2009) and 10.08.2009: Deepsea Atlantic (2009).

In general, both the events and observations in the audit activities over several years shows the following deviations:

- Specially designed lifting equipment in the drilling area

- Real knowledge of, and use of recommended standards for carrying out lifting operations safely on the drill floor
- Protection of the operator's supervisory responsibility

18.12.2010: Njord A

During a lifting operation on the Statoil-operated Njord A platform the elevator slip joint loosened and fell down on the drill floor. Slip joint weighs about 23 tons (PSA, 2010).

The incident did not cause injury.

PSA considers the incident to be serious, with a great potential for personal injury and loss of life and assets. The results from the investigation are not yet released.

28.02.2011 Gullfaks A

One person was injured during a routine lifting operation. There was an incident where a roughneck was crushed between two containers and sustained fracture in his left collarbone (PSA, 2011).

The direct cause of the incident was that the container lifted had a large momentum and hooked up in another container. The damaged roughneck was standing in a non-secure area and was hit.

The incident had the potential to cause a fatality and there could have been larger material damage under slightly altered circumstances.

The investigation report has shown the following deviations from the regulations:

- The lifting operation was not sufficiently planned and evaluated.
- The lifting operation was not performed with sufficient staffing.
- The lifting operation was not conducted in a prudent manner - procedural violations.
- Inadequate monitoring, control and management follow-up of routine lifting operations.