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Development of a New Total Risk Indicator for the Trends in Risk Level Project (RNNP)

By utilizing DFU, Barrier Performance and Survey Results Data and incorporating Uncertainty

Elisabeth Andreassen

Marine Technology
Submission date: June 2016
Supervisor: Jan Erik Vinnem, IMT

Norwegian University of Science and Technology
Department of Marine Technology

Preface

This master's thesis marks the end of my studies in marine technology at the Norwegian University of science and technology (NTNU). The thesis is concerned with the further development of the "Trends in Risk Level Project" (RNNP) by the Norwegian Petroleum Safety Authority (PSA). Writing this thesis has been a challenging and rewarding experience where I have learned extensively about RNNP and further developed my interest for offshore risk assessment.

I would like to thank Bjørnar Heide, Elisabeth Lootz and Bente Hallan from the Norwegian Petroleum Safety Authority (PSA) for their help and valuable guidance. I would also like to thank Roger Flage from the University of Stavanger (UiS) for giving me a better understanding of uncertainty and its role in RNNP. I would like to express my sincerest gratitude to Professor II Trond Kongsvik from NTNU who has helped me establish the safety climate indicator and has taken the time to meet with me and introduce me to important literature on this topic. Additionally, I would like to thank Terje Dammen from Safetec along with Torleif Husebø and Øyvind Lauridsen from PSA for giving me access to necessary RNNP data.

A special thanks goes to "The Baron of Risk", my supervisor Jan Erik Vinnem, Professor II at NTNU, for his invaluable help, availability and guidance throughout the entire process.

I want to thank all my friends and office crew for a memorable time here at NTNU. Furthermore, I wish to thank my boyfriend, Sigbjørn, for his patience and support these last months. Finally, I wish to express my sincerest gratitude to Milly Andreassen, who has been a world-class supporter, not only through this thesis, but through my entire studies. Thank you.

Trondheim, 09.06.2016

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Summary

The “Trends in Risk Level” Project (RNNP) is conducted annually by the Norwegian Petroleum Safety Authority (PSA). The purpose of RNNP is to objectively present offshore risk levels and risk trends on the Norwegian continental shelf (NCS). Major accidents and even near-misses have been few or non-existent in the time period RNNP has been conducted, and the decline in incident reports has reduced the data basis for quantitative risk assessment (QRA) considerably. RNNP presents risk levels and risk trends by establishing a total indicator which is established by evaluating major accident precursor event (DFUs) statistics. The objective of this thesis has been to develop a New Total Indicator which is able to give a more holistic risk level and risk trend presentation than the current total indicator. After developing a New Total Indicator, a case study was executed to test the quality and applicability of the methodology.

The development of the New Total Indicator is based on former and newly developed methodology, utilizing existing and newly established RNNP data. The concept behind the New Total Indicator is to represent a broader risk image than its predecessor. The New Total Indicator addresses uncertainty and survey results in addition to the traditional DFU and barrier performance data, which are already a part of the RNNP risk level presentation.

The New Total Indicator consists of the contribution of four individual indicators; I) DFU Indicator II) Barrier Indicator III) Survey results Indicator IV) Uncertainty Indicator. I-III are individually established, expressed as relative values. IV is a corrective factor, individually established and incorporated in indicators I-III. The New Total Indicator is presented as two relative indicators; leading (The Barrier Indicator and Survey Results Indicator) and lagging (The DFU Indicator), where the relative uncertainty contributions are incorporated in both indicators.

The case study established New Total Indicator Results for years 2008-2014 by evaluating RNNP data from fixed production installations only. The New Total Indicator results are presented in Figure 1.

The results are considered satisfactory from a case study perspective, indicating a positive (decreasing) risk level trend for the leading indicator in the chosen time period. The lagging indicator shows a variable trend with a negative (increase) trend in risk levels from 2012-2014. Compared with published total indicator results; the New Total Indicator results differ considerably. This is due to their differences in structure and design, but also due to a different

data basis for establishing results. The case study demonstrates the ability of the developed New Total Indicator to produce satisfactory results.

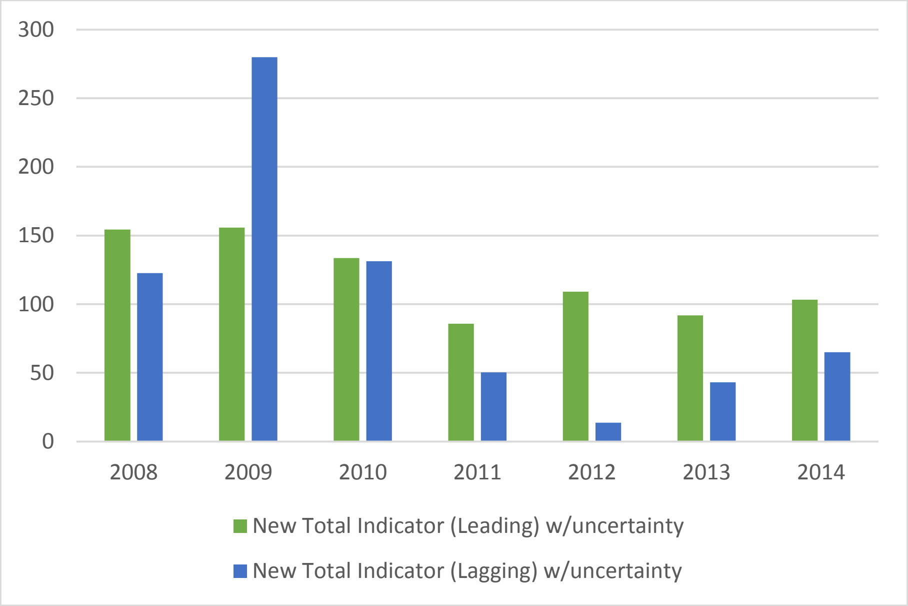

Figure 1: New Total Indicator results (leading and lagging indicators w/uncertainty)

The numerous data and method assumptions in this thesis question the applicability of the New Total Indicator and the quality of results. The New Total Indicator is, in its present state, not considered recommendable for implementation in RNNP. The results are satisfactory from a case study perspective, but the methodology itself needs to be developed further to reduce method uncertainty and improve the method quality.

Despite the method shortcomings, it is recommended to evaluate whether the developed DFU Indicator could replace the current total indicator in RNNP. The DFU Indicator is similarly established as the current total indicator, but includes DFU 12 (helicopter incidents). In light of the tragic helicopter accident at Turøy in April this year, the suggested DFU 12 weights may be a solution for incorporating helicopter risk in the RNNP total indicator.

The developed New Total Indicator methodology is an exciting contribution to the discussion on the role of overall vs. individual indicators in risk level presentation. In conclusion this thesis contributes more to the discussion on the future risk level presentation of RNNP, rather than producing a methodology ready for embodiment in RNNP.

Sammendrag

Prosjektet "Risikonivå i Norsk Petroleumsvirksomhet" (RNNP) blir årlig utført av Petroleumstilsynet (Ptil). Målet med RNNP er å gi en objektiv presentasjon av offshore risikonivå og risikotrender på sokkelen. Storulykker og initierende hendelser har vært praktisk ikke-eksisterende i tidsperioden RNNP har blitt utført, og reduksjonen i antall hendelsesrapporter har redusert datagrunnlaget for kvantitativ risikoanalyse betraktelig. RNNP presenterer risikonivå og risikotrender ved å etablere en totalindikator. Denne totalindikatoren blir bestemt ved å evaluere storulykkespotensial-hendelsesstatistikk (DFU'er). Formålet til denne masteroppgaven har vært å utvikle en ny totalindikator som er i stand til å gi en mer helhetlig presentasjon av risikonivå og risikotrender enn dagens totalindikator. Etter at den nye totalindikator-metodologien ble utarbeidet, ble en case-studie gjennomført for å teste kvaliteten og anvendeligheten til den nye metodologien

Utviklingen av den nye totalindikatoren er basert på eksisterende- og ny metodologi på grunnlag av eksisterende og egenvalgte RNNP data. Konseptet bak den nye totalindikatoren er å representere et bredere risikobilde ved å etablere risikoindikatorer som adresserer usikkerhet og spørreskjemaresultater i tillegg til de tradisjonelle DFU- og barriereytelsesdata som allerede er en integrert del av RNNPs risikonivå-presentasjon.

Den nye totalindikatoren består av bidragene til fire individuelle indikatorer; I) DFU-indikator II) Barriereindikator III) Spørreskjemaresultat-indikator IV) Usikkerhetsindikator. Indikatorene I-III er gitt på en relativ skala, mens usikkerhetsindikatoren er en korrektiv faktor som blir individuelt bestemt og inkorporert i indikatorene I-III. Den nye totalindikatoren presenteres som to indikatorer; ledende (Barriere- og Spørreskjemaresultat-indikatorer) og laggende (DFU-indikatoren).

Case-studien etablerte ny totalindikator-resultater for 2008-2014 ved å bruke RNNP data for faste produksjonsenheter. Resultatene er presentert i Figure 2 og vurderes som tilfredsstillende fra et case-perspektiv, hvor den ledende indikatoren viser en positiv (synkende) trend i risikonivå for den ledende indikatoren innenfor den valgte tidsrammen. Den laggende indikatoren viser en til dels variabel trend, med en negativ (økende) trend i risikonivå mellom 2012 og 2014. Sammenlignet med publiserte totalindikatorresultater skiller resultatene for den nye totalindikatoren seg betydelig. Dette skyldes ulikheter i design og struktur, men også fordi datagrunnlaget er noe ulikt for de presenterte resultatene. Case-studien tydeliggjør den nye totalindikatorens evne til å produsere fornuftige og tilfredsstillende resultater.

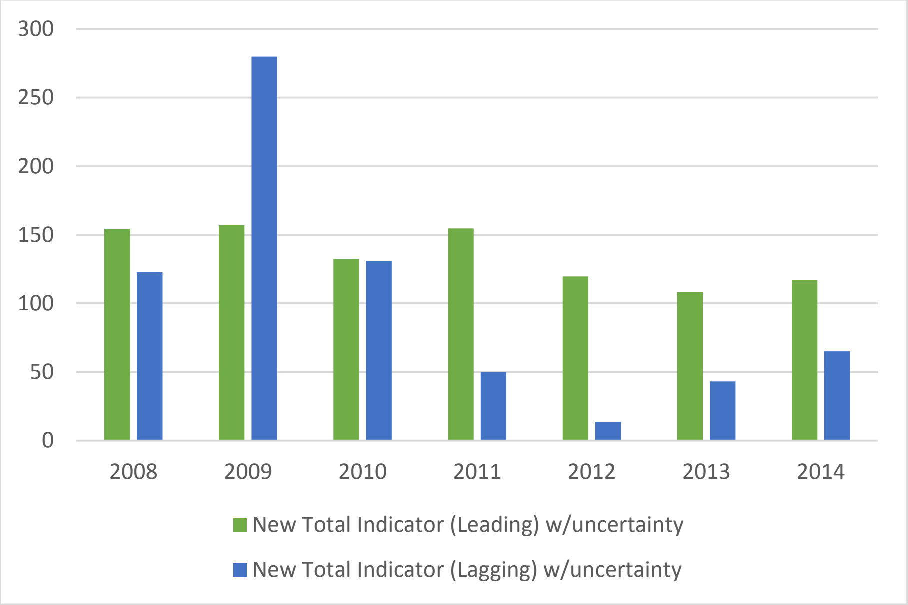

Figure 2: Ny totalindikator-resultater (ledende og laggende indikatorer med usikkerhet)

De mange data- og metodeantagelser som er gjort i denne oppgaven gjør at det kan stilles spørsmålstegn ved anvendeligheten til den nye totalindikatoren og kvaliteten på resultatene. Den nye totalindikatoren anbefales ikke for implementering i RNNP i dens nåværende stand. Case-studien evner å fremstille resultater av den utviklede metoden, men metodologien må videreutvikles for redusere usikkerhet og forbedre kvaliteten.

Til tross for metodens svakheter, er det anbefalt å vurdere om DFU indikatoren potensielt kan erstatte den nåværende totalindikatoren i RNNP. DFU Indikatoren blir bestemt ved tilsvarende metode som totalindikatoren, men inkluderer i tillegg DFU 12 (helikopterhendelser). Sett i lys av den tragiske helikopterulykken på Turøy i april i 2016 kan det være ønskelig å reflektere helikopterrisiko i RNNPs totalindikator for storulykker i fremtiden. De foreslåtte DFU 12 vektene kan være en mulig løsning til å inkludere helikopterrisiko i den totale storulykkes-indikatoren i RNNP.

Den nye totalindikator-metodologien er et spennende bidrag i diskusjonen om individuelle og overordnede indikatorers rolle i RNNP. Som konklusjon bidrar denne rapporten mer til diskusjonen om videre utvikling av RNNP, enn å introdusere en ny metode som kan bli inkorporert i RNNP.

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Abbreviations

CFA	Confirmatory Factor Analysis
CM	Corrective Maintenance
DFU	Defined situations of hazards and accidents
EFA	Exploratory Factor Analysis
FA	Factor Analysis
FAR	Fatal Accident Rate
HC	Hydrocarbons
HSE	Health, Safety & Environment
IO	Integrated Operations
MTO	Man, Technology and Organization
NCS	Norwegian Continental Shelf
NORSCI	Norwegian offshore risk and safety climate inventory
OHS	Occupational Health and Safety
PLL	Potential Loss of Life
PM	Preventive Maintenance
PSA	Norwegian Petroleum Safety Authority
QRA	Quantitative Risk Analysis
RNNP	Trends in Risk Level Project
RRM	Risk Reducing Measures
SPSS	Statistical Package for the Social Sciences
STAMI	The National Institute of Occupational Health

1. Introduction

This chapter provides the reader with background knowledge on the research topic and presents the objectives of the thesis. After reading this chapter, the reader should understand the scope of the thesis, its limitations, its structure and the motivation for the chosen topic.

1.1 Background

The Norwegian Petroleum Safety Authority (PSA) has annually since 1999/2000 collected data from operators on the Norwegian continental shelf (NCS) through the "Trends in Risk Level Project" (RNNP). RNNP is an objective platform for establishing and evaluating offshore risk levels and risk trends on the NCS (PSA, 2015a). RNNP was initiated due to contradictory statements from the industry, unions and authorities in the late 1990s. The industry stated that the offshore risk levels were decreasing, while authorities and unions claimed that the risk levels moved in the opposite direction (Vinnem, 2010). RNNP has been a success for the 16 years it has been conducted and is the result of a successful tripartite collaboration between regulators, industry and unions (Rosness & Forseth, 2015).

RNNP uses a range of risk indicators to reflect hazardous phenomena related to offshore activity on the NCS (Vinnem, 2010). The indicators are used to evaluate the changes in major accident and occupational health and safety (OHS) risk levels (Vinnem et al., 2006). RNNP performs quantitative and qualitative risk analyses and applies the method triangulation principle in assessing risk. Method triangulation ensures that different disciplines are utilized in analyzing the same phenomena i.e major accident risk levels (Denzin, 1989; PSA, 2015b). Vinnem et al. argues that RNNP is based on the principle that statistical indicators alone will not provide a broad basis for the evaluation and assessment of NCS offshore risk (Vinnem et al., 2006).

Since RNNP's initiation the numbers of major accidents and even near-misses have been low or non-existent (excluding the helicopter accident at Turøy, April 2016). The number of reported incidents has decreased somewhere between 60-70% between 2000-2014 (PSA, 2015c). The reduced number of incidents is a positive sign for the offshore safety, but it questions the current RNNP methodology and its ability to portray offshore risk levels. The low number of incident reports reduces the data basis for quantitative risk assessment (QRA) considerably, where several of the Defined situations of Hazards and Accidents (DFUs) have not occurred in several years, or even since the beginning of the Project. Heide argues that the

QRA methods used in RNNP today should give proper risk level estimations, regardless of the number of incoming reports. He further argues that a shortcoming, perhaps more relevant than the number of yearly incoming reports, is RNNP's inability to reflect the *total* volume of reports, acquired from as long back as 1996 (B. Heide & Hallan, 2016). Is it reasonable to conclude that the risk level is lower, due to the lower degree of incoming reports, or is this a too quick conclusion to be drawn? The question arises if RNNP is still able to establish valid risk level and risk trend results based on the lower DFU frequencies, or if it is in need of new and modern ideas to be developed further. Risk is not a static measure (Reason, 1997), hence RNNP should strive to be a dynamic project.

In addition to the lower incident reports, the PSA has revised their definition of risk to include uncertainty. It could be argued that the recent change in risk definition should have practical implications on PSA's biggest risk level project, which is another motivational aspect for developing RNNP further.

1.2 Objectives

Before settling the objectives of the thesis, an active screening process was carried out to identify areas of improvement in RNNP and potential objectives for the thesis. It has been chosen to focus on the total indicator and making the total risk level presentation less dependent on incident statistics. The total indicator combines major accident risk indicator results to present the overall risk level development on the NCS.

The objectives is to incorporate uncertainty and questionnaire results, combined with DFU and barrier performance data to establish a more holistic risk level presentation (Vinnem, 2016). A case study should then be carried out to establish New Total Indicator results and hence analyse the potential of the new methodology.

To concretize the objectives of this thesis are:

1) Develop a new RNNP total indicator which comprises DFU data, a selection of barrier performance data, uncertainty parameters and questionnaire results to give a more holistic presentation of risk levels.
2) Comparison of New Total Indicator results and methodology with total indicator results and methodology in RNNP today, through a case study.

The objectives of this thesis are ambitious, with different disciplines and risk assessment tools in use for establishing a New Total Indicator.

The case study will establish New Total Indicator results for a 3-6 year period and analyse the resulting risk trends. Based on the case study results a discussion can be made on the New Total Indicator's ability to present valid results, compared with the existing total indicator.

1.3 Delimitations

The thesis will focus on offshore installation data and not data from onshore facilities.

The main objective is to improve how RNNP establishes *major accident* risk levels. Consequently, the main focus is on major accident risk indicators and not indicators describing occupational health and safety (OHS) issues. A major accident is defined as an immediate event, such as a fire, explosion or acute spill, which immediately or later causes the loss of human lives, several serious personal injuries or substantial environmental damage (PSA, 2014a). In this thesis personnel risk will be emphasized.

The thesis focuses on RNNP data prior to 2015, as these were available and published throughout the entire period writing this thesis. Due to this delimitation the tragic helicopter accident at Turøy in April 2016 is not included in the data material used in this thesis. Hence, when noting that the NCS has not experienced major accidents, this is true for the period 2000-2014.

Some of the graphs and figures used in this thesis are extracted from PSA's original RNNP reports which are mainly published in Norwegian. Extracted graphs will therefore be presented in Norwegian where English graphs are unavailable.

It is assumed that the reader has basic knowledge of terms and concepts in classic risk analysis, as they will not be presented in detail in this report. For a thorough presentation of basic risk assessment terms it is referred to Vinnem's "Offshore Risk Assessment" or Rausand's "Risk Assessment: theory, methods and applications" (Rausand, 2011; Vinnem, 2014).

Terms such as "safety climate" and "safety culture" will be used in this thesis and it is assumed that the reader has basic knowledge of both terms and their differences, as they will not be explained in detail in this thesis. It is referred to the doctoral thesis by Olsen (Olsen, 2009) for a thorough introduction and overview of both terms.

A framework will have to be established to reduce the scope of the case study. These delimitations will be presented in the case study chapter of the thesis.

The case study calculations carried out in Excel are not given in the appendices due to confidentiality reasons.

The proposed delimitations will impact the presented methods and case study results considerably, which will be discussed in later chapters.

1.4 Overview of topics

The first topics of this thesis briefly introduces the reader to the Trends in Risk Level Project by presenting the structure and methodology of RNNP. The current status of RNNP is presented by evaluating the RNNP main results for 2014. Subsequently the changes in PSA's risk revision and the uncertainty term are introduced.

Having familiarized the reader with RNNP methodology and the current standings of the Project, the next topic is to develop the New Total Indicator methodology.

Following the method development of the New Total Indicator, the case study tests the methodology and establishes New Total Indicator results. An evaluation and discussion of results is given in the case study.

After establishing New Total Indicator results, the applicability of the new methodology is discussed by scrutinizing the quality of the New Total Indicator methodology and results.

The discussion is followed by a conclusion, presenting the main results and findings of the thesis, and outlining further work and areas of improvement.

1.5 Structure of report

The topics presented in chapter 1.4 are structured as follows:

- Chapter 1: Introduction
- Chapter 2: RNNP methodology and RNNP current status
- Chapter 3: The changes in risk definition and how uncertainty is expressed in RNNP
- Chapter 4: The New Total Indicator methodology
- Chapter 5: Case study: results and discussion
- Chapter 6: Discussion of the topics presented in chapter 4-5

- Chapter 7: Conclusion and further work
- Chapter 8: References

Following chapters 1-8 is a list of relevant appendices.

2. The Trends in Risk Level Project

Chapter two provides a brief introduction to the most relevant RNNP methodology. The 2014 total indicator results are presented to give the reader an overview of the current status of RNNP and the NCS risk levels.

2.1 Introducing RNNP

The major accident risk levels are based on incoming reports on precursor events, more commonly known as “Defined situations of Hazards and Accidents” (DFU’s), and barrier performance data. These risk levels are presented in the first part of the RNNP main report. The second part of the RNNP report presents OHS risk levels, which will not be further discussed in this thesis.

2.1.1 RNNP and the bow-tie diagram

Evaluating RNNP according to the bow-tie diagram, RNNP collects data and performs risk analyses for the right-end part of the diagram, focusing on hazardous precursor events and reactive barriers. The RNNP DFUs can be characterized as the hazardous event in the center in the diagram, and the barrier performance indicators represent the reactive barriers as shown in Figure 3.

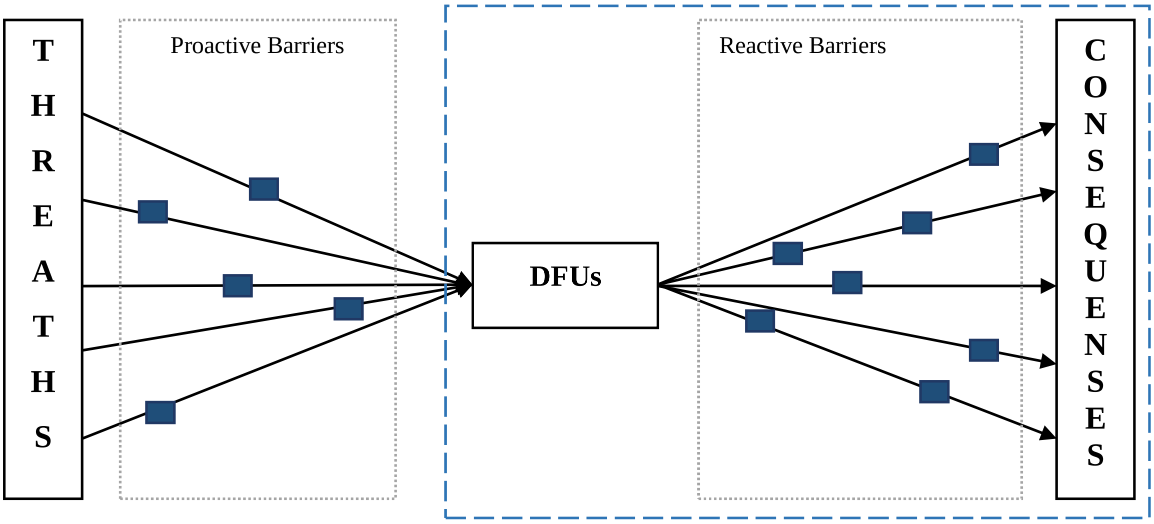


Figure 3: Bow Tie diagram

Heide comments that the DFUs are actually situated a bit more to the left in this diagram, portraying a broader risk image (B. Heide, 2015). When looking at RNNP through "the eyes of the bow tie", the fields enclosed by the blue stapled box are explicitly covered by RNNP.

2.1.2 Quantitative Risk Analysis

2.1.2.1 Defined Situations of Hazards and Accidents (DFUs)

Operators on the NCS deliver reports on precursor events the PSA considers to hold accident potential. PSA has defined 21 precursor incident indicators (DFUs), where 12 of them are classified to have major accident potential. DFU in Norwegian stands for "Definerte fare- og ulykkessituasjoner" which translates into "Defined Hazard and Accident Conditions". A list of major accident potential DFUs is given in Table 1 and a complete list of all DFUs may be found in Appendix I Complete DFU list. DFUs will be presented further in later subchapters.

Table 1: Major accident DFUs

DFU	Description
1	Unignited hydrocarbon leak
2	Ignited hydrocarbon leak
3	Well incident/loss of well control
4	Fire/explosion in other areas, combustible liquid
5	Ship on collision course (headed toward installation)
6	Drifting object (Headed toward installation)
7	Collision with other field-related vessel/installation
8	Construction damage (positioning-/anchoring and stability)
9	Leak from pipes and subsea production installations
10	Damage pipes and subsea production installations
11	Evacuation
12	Helicopter incident

2.1.2.2 Barrier Performance data

Barrier performance data are reported in RNNP to evaluate barrier reliability, functionality and robustness. Barrier data reflect the goodness and efficiency of reactive barriers which are installed to mitigate potential consequences in the occurrence of a DFU (PSA, 2015a). Barrier elements are tested on all installations and the barrier performance is measured and reported to the PSA by; counting the number of faults during testing, counting and marking equipment, maintenance hours etc. The overall barrier performance results give an impression of the barrier standard on the NCS and is a great tool for creating awareness within the industry on adequate barrier performance and barrier monitoring (B. Heide & Hallan, 2016).

RNNP is mainly concerned with assessing the technical reliability performance and for certain barriers the operational reliability (Vinnem & Ravdal, 2006). Organizational barriers are not established indicators in the barrier performance chapter of RNNP. However, organizational indicators are established by evaluation of survey results, which is primarily used in the OHS risk presentation and not for major accident risk level presentation.

Listed below are all barrier elements, whose performance are reported and registered in RNNP. All barrier elements need to be tested and reported for offshore production units. Mobile offshore units only have to test and report performance of the bold-written barrier elements.

- Fire detection (all detectors, no classification)
- Gas detection
- Shut down
    - Riser ESDV
        - Closing test
        - Leak test
    - Wing- and Master valves
        - Closing test
        - Leak test
    - DHSV
- Pressure relief valve (BDV)
- Safety valve (PSV)
- **BOP isolation**
- Active fire protection
    - Deluge valve
    - Start tests (fire pumps)
- Well integrity
- **Marine systems**
    - **Ballast system valves**

    - **Closing of water tight doors**
- **Maintenance management**
- Muster times (evacuation)

(PSA, 2015a)

2.1.3 Qualitative Risk Analysis

For qualitative analyses, the most important results are from the RNNP survey which is distributed biannually to all installations. The survey is accessible to the employees for a set time frame where the availability of the survey should be sufficiently long to enable all employees to respond (B. Heide & Lootz, 2015). The survey addresses several areas of HSE importance to establish the perceived safety levels amongst workers. The survey covers the topics listed below and the survey can be found in its entirety in the RNNP main report for 2013 (PSA, 2014b).

- Demographical data
- HSE Climate in own work space
- Evaluation of accident risk
- Recreation facilities offshore
- Working environment
- Work ability, health and sickness absence
- Sleep, restitution and working hours

(PSA, 2015b)

The percentage of employees responding the survey is relatively low, but considering the high number of workers on the NCS, the response is deemed satisfying by the PSA (B. Heide & Lootz, 2015). It is estimated that 27.3% of the workers responded to the survey in advance of the 2013 report (PSA, 2014b).

Additional qualitative methods are used in establishing risk levels, such as interviews, document control etc. Further details on qualitative risk analysis in RNNP can be found in the RNNP main and method report for 2013 (PSA, 2014b).

2.2 Establishing Risk Levels

Potential Loss of Life (PLL) values for personnel risk is used to express risk levels (PSA, 2015a). The risk level PLL value is established by evaluating DFU statistics and DFU weights (ref. 2.2.2). The PLL values are usually established for each individual installation. The individual PLL contributions are then summarized which gives the expected number of fatalities on the NCS as a whole (PSA, 2015a).

The following equation may be used in establishing major hazard risk levels for the installation (Vinnem et al., 2006);

$$R = \sum_{I} \sum_{J} DFU_{ij} * V_{ij}$$

Equation 1: Risk level estimation

$$v_{ij} = EX_{ij}$$

Equation 2: Weight estimation

Table 2: Methodology parameters

DFU_{ij}	DFU nr i for installation j
v_{ij}	Weight of DFU nr. i for installation j.
EX_{ij}	Expected casualties from DFU nr. i on installation j

These equations assume that installations of the same category (ref. 2.2.1) have the same weights i.e. the equations are category-based and not individual installation-based (PSA, 2015a).

Normalization, weighting of DFUs and predication intervals are statistical and mathematical tools used to establish risk levels. Combined they are meant to give as realistic risk level estimations as possible. These tools are interdependent of each other and sensitive to changes in incoming data size. It is obvious that a greater collection of DFU data give a better foundation for QRA and risk level estimations. It is a potential weakness in RNNP that the current methodology might not be robust enough to estimate risk levels independent of the size of incoming data.

2.2.1 Normalization

DFU statistics are normalized to better present overall risk trends on the NCS (Vinnem, 2014). For DFU 1-10 and 12 the following data are used for normalization of risk levels;

- Man-hours
- Installation specifications
- Number of wells drilled (specifically for drilling associated hazards)
- Person flight hours (helicopter related hazards)

(Vinnem, 2010)

The installations are categorized into five categories used for normalization.

- Fixed production installations
- Floating production installations, with possible well release exposure on the installation
- Floating production installations, without well exposure on the installation (well distant)
- Production complex with bridge linked installations
- Mobile units

(PSA, 2015a; Vinnem et al., 2006)

Vinnem argues that the volume of normalization data changes slowly over time and that risk trends become very much identical when two curves are seen next to each other. Consequently the normalized results need to be evaluated gradually and over time (Vinnem, 2010).

2.2.2 Weighting of DFUs

DFUs introduce different consequences, depending on which of the DFUs occurs. Weighting DFUs ensure that the potential severity of the DFU is addressed by assigning the DFU an appropriate "weight" to reflect the potential number of fatalities by DFU occurrence. Vinnem argues that "*such weights are assumed to represent the statistical risk picture*" (Vinnem, 2014). It is assumed that the weight factor for a DFU is equal for all installations of the same installation group (PSA, 2015b). The generic weight factor is established by looking at the expected values for all initiating events in an event tree, and by adding all probabilities for all events it is possible to establish the DFU weight (v_{ij}) (PSA, 2015b) Figure 4 illustrates the DFU relations to the expected number of fatalities and resembles an event tree by having the "row of boxes" at the bottom which represent terminal events of the event tree (Vinnem et al., 2006).

The weights have been calculated based on a number of risk analyses which have been externally approved outside of PSA (PSA, 2015b). Appendix II DFU Weights (Fixed Production Installations) gives a summary of DFU weights for offshore units categorized as fixed production installations. Weights for all installation categories are given in the RNNP method report (PSA, 2015b).

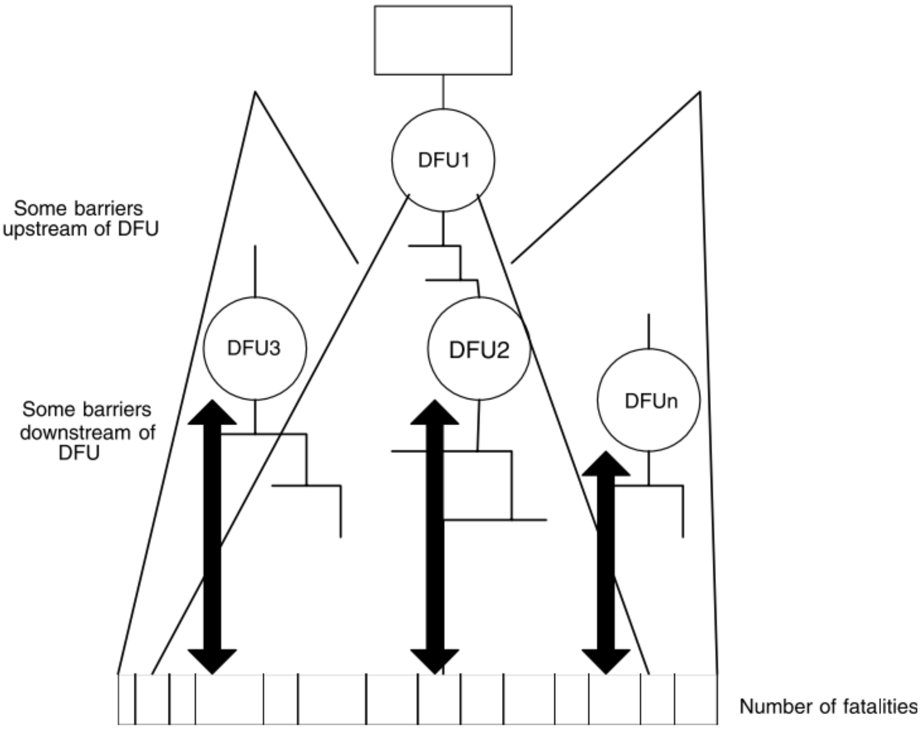


Figure 4: Illustration of event sequences and DFUs (Vinnem, Aven, Husebø, Seljelid, & Tveit, 2006)

2.2.3 Predication Intervals

RNNP uses predication intervals in graphical presentations of the risk levels, which are used to evaluate if DFU frequencies are consistent with, or deviates from earlier trends. The PSA notes:

"The numbers could show significance without it necessarily meaning a real deterioration compared with previous years – a large sized HC leak can be said to be at least as important as several small ones"

(PSA, 2015b)

Based on past years' incident frequencies, a predication value can be estimated. This predication value is the basis for establishing a predication interval which is used to establish the risk level trends (PSA, 2015a). If measurements of a DFU is registered for the years 1, 2, 3,…k, then x_1,x_2,x_3….x_k is a predication of the number of events for the year x_{k+1} (PSA, 2015b). The predication interval is determined between values [a, b] where it is considered a 90% chance that the real value X_{k+1} is within the [a, b] interval. If X_{k+1} is outside the interval [a, b] then this result indicates a value that is significantly higher or lower than predicted (PSA, 2015b). For examples on statistical significant risk level trends it is referred to the RNNP main and method reports and Vinnem et al. “”Major hazard risk indicators for monitoring of trends in the Norwegian offshore petroleum sector” (PSA, 2015b; Vinnem, 2010; Vinnem et al., 2006).

2.3 The Total Risk Indicator

Risk levels are presented for the individual DFUs. However, the variations between risk level results can be considerable, resulting in some DFUs having significantly increased or reduced risk levels, while the majority might show little statistical significance. Vinnem argues that because of such variations it is an advantage to have a total indicator which presents the overall development in risk levels by balancing the effects of individual indicators (Vinnem, 2010).

The total indicator is based on DFU frequencies and their weights and is presented as a PLL value, or alternatively a FAR value, when normalized against the total number of work hours. After establishing the risk level according to Equation 1, the final step is to transform the risk level value to a relative value based on a base year value for year 2000 (RNNP initiation year) (Vinnem et al., 2006). The relative risk levels may be expressed as:

$$R' = \frac{R}{V}$$

Equation 3: Normalised value of R according to exposure (Vinnem et al., 2006)

$$R'' = \frac{R'}{R'_{2000}}$$

Equation 4: Relative value of the normalised value of R' (Vinnem et al., 2006)

Between 2004-2008 a total indicator for barrier performance results was developed. Vinnem arguments that in the same way an overall total indicator is needed, the same need exists for an overall barrier indicator (Vinnem, 2014). Vinnem and Ravdal explain that the total barrier indicator did not have barrier weighting, but was presented by summarising the fractions of failure from all barrier element tests reported in RNNP. The overall barrier indicator was however discarded from RNNP, as it did not communicate its message satisfactory (Stensland, 2013; Vinnem, 2015).

2.4 RNNP Current Status and Risk Level Results

Figure 5 depicts the decrease in major accident precursor events since year 2003. Despite the positive trend, it should be mentioned that RNNP annually detects four to five leaks which are of equal size to the one which initiated the Piper Alpha accident (Petroleumstilsynet, 2015).

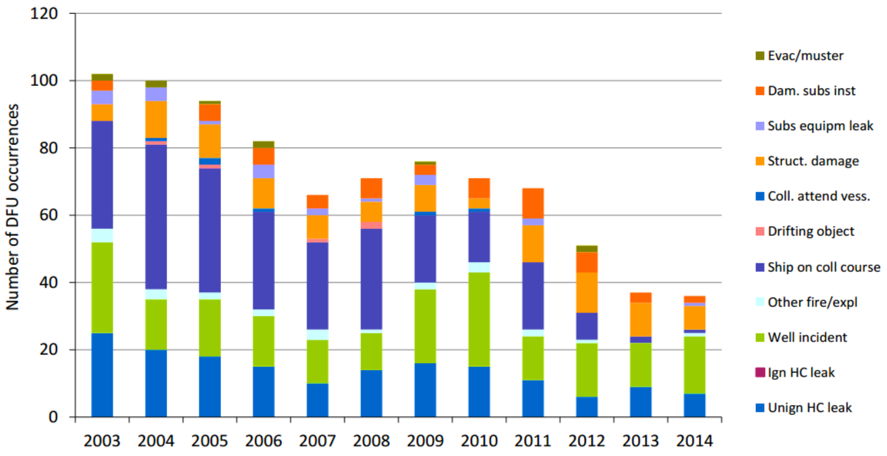


Figure 5: Major accident DFU frequencies 2003-2014. (PSA, 2015c)

The total indicator may be seen in Figure 6, where the relative value for the base year (2000) has been set at 100. PSA comments that some of the yearly risk indicator results, are mainly based on the contribution of single events which have had a great impact on the risk levels of the year in question (PSA, 2015c). Figure 6 displays the values for 2000-2014, where the 2014 results is the lowest total indicator value registered in the history of RNNP, showing a positive (decrease) trend in risk levels since RNNP's initiation. The relative total indicator gives the industry and public an easy overview of which direction the risk levels are moving. But as previously mentioned; with DFU frequencies being relatively low, single events might contribute considerably to the total indicator value for the year in question (PSA, 2015a).

This chapter gives a very brief introduction to the most basic elements of the RNNP methodology. For further reading and a complete overview of RNNP it is referred to the RNNP main and method reports, and Vinnem's article presenting RNNP (PSA, 2014b, 2015b; Vinnem, 2010).

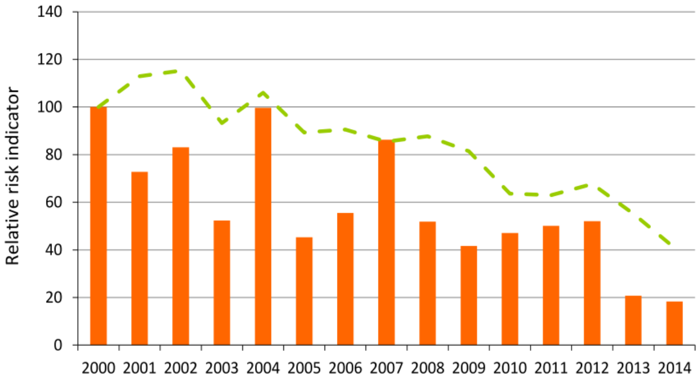


Figure 6: Total indicator, production units normalized against work hours, annual values, three-year rolling average (PSA, 2015d)

3. RNNP and the Revision in Risk Definition

The PSA has revised the definition of risk to include the uncertainty aspect, which could potentially affect the way projects, such as RNNP, are executed. In this chapter the recent changes in risk definition are presented, along with uncertainty and its role in today's RNNP.

3.1 Background

The term "risk" has traditionally been defined as the probability for an event taking place, multiplied with the consequences of the same event. This classical, objective and statistical method to consider risk, (along with the more subjective but also statistical Bayesian approach) has been applied in quantifying risk. However, it has been widely argued that the risk perspective should be understood as more than statistics, naming uncertainty an important aspect to be considered in understanding risk (Aven, 2012) (Aven & Krohn, 2014). Uncertainty, in a risk context, implies that there are things beyond our knowledge and information as to what and how events could occur or not, and what the potential effects would be (Vinnem, 2014).

3.2 Definitions of Risk and Uncertainty

In 2014 PSA revised their definition of risk to include uncertainty. RNNP highlights the change in risk definition by referring to the revision of the guidelines regarding the framework regulations (PSA, 2015a). In other words, the revised definition is not given in the RNNP report, and can only be found in its entirety in the Re Section 11 on the PSA's web pages: *"Risk means the consequences of the activities, with associated uncertainty".*(PSA, 2014a)

Introducing the uncertainty term in the classic risk definition means that in understanding risk, there will be a level of uncertainty associated with how risk is assessed and understood due to lack of necessary knowledge. The problem however, is how to quantify and use the uncertainty aspect in a practical sense. Haugen and Vinnem comments that putting emphasis on the uncertainty term in risk definition should be done with some care and that poor quality risk assessments should not be accepted due to uncertainty (Haugen & Vinnem, 2015).

3.3 Uncertainty

Rausand argues that *"there is great uncertainty about uncertainty*" (Rausand, 2011). From the extensive literature in this field it is evident that there is an ongoing discussion on how to interpret the uncertainty aspect. According to ISO31000 uncertainty is defined as:

"*Uncertainty (or lack of certainty) is a state or condition that involves a deficiency of information and leads to inadequate or incomplete knowledge or understanding. In the context of risk management, uncertainty exists whenever the knowledge or understanding of an event, consequence, or likelihood is inadequate or incomplete."*

(ISO:31000, 2009).

What can be observed from this definition is that uncertainty is a term related to lack of knowledge and doubt about events with associated outcomes.

Rausand interprets uncertainty as a term that expresses the confidence in risk assessment results (Rausand, 2011). Furthermore, Rausand argues that uncertainty may be categorized according to two main types, mainly **aleatory** and **epistemic** uncertainty. The first refers to natural variation and intrinsic randomness where the uncertainty itself cannot be reduced by acquiring more knowledge, whereas epistemic uncertainty is related to the lack of knowledge (Rausand, 2011). Aleatory uncertainty is irreducible uncertainty whereas epistemic uncertainty is in fact reducible by increasing the level of knowledge (Rausand, 2011). Rausand further argues that there are three different contributors to uncertainty in the results of risk analyses;

1) Model uncertainty
2) Parameter uncertainty
3) Completeness uncertainty

Model uncertainty relates to whether or not the chosen model is the best for the risk analysis in question. Furthermore, it aims to measure if the model is correctly understood and applied. Parameter uncertainty is related to the quality of the data used in the analysis, whereas completeness uncertainty takes the quality of the entire risk analysis process under consideration.

Rausand determines to separate "uncertainty" and "risk" as two different terms (Rausand, 2011). Others define risk and uncertainty the same thing, considering the fact that risk portrays future events which are not possible to make definite predictions about. When talking about uncertainty in this manner, the concept of "Black Swans" is often used to illustrate the occurrence of surprising events and to illustrate that risk will always be associated with great uncertainty. In order to understand the different interpretations of uncertainty, it is necessary to look more closely at the "Black Swan" logic.

3.4 The Black Swan logic

The Black Swan logic originates from the earlier assumption that "all swans were white". Until the discovery of black swans in Australia, no one had imagined or thought possible that swans could have any other colour than white (Taleb, 2010). Taleb points out that there was nothing from past experience that could predict, nor contradict a black swan's existence, and therefore the metaphor of Black Swans is used to illustrate the idea of surprising events which have surprising outcomes (Aven, 2013a; Taleb, 2010). Taleb further explains that for an event to be characterized as a Black Swan it has to fulfil the following criteria:

1) The event has to be so *rare* that the perceived possibility of it to occur is as low as practically non-existing.
2) The impact of the event is *extreme*
3) In hindsight, the event is analysed to make the event *explainable* and predictable.

(Taleb, 2010)

The question then arises; which events are unknown and which events are just discarded as irrelevant due to low probability? To try to answer this it is referred to T. Aven, who has contributed considerably to the literature on Black Swans in a risk context and argues that a Black Swan can be interpreted as either:

1) *"An extreme event with very low probability"*
2) *"A surprising, extreme event in situations with large uncertainties"*
3) *"An unknown unknown"*

(Aven, 2013a)

Aven further concludes that a Black Swan can be considered *"An extreme, surprising event relative to the present knowledge"*(Aven, 2013a). Haugen and Vinnem challenge Aven on his categorization of Black Swans, pointing out that events that are discarded as improbable do not fulfil the criteria of an "*extreme, surprising event relative to the present knowledge*". Meaning that an event might have been discarded as improbable, but that is not equal to say that there was no knowledge of its potential existence (Haugen & Vinnem, 2015). Haugen and Vinnem further reduces the Black Swan concept to include only accidents that are unknown unknowns, eliminating the two first categories of Aven's Black Swans.

The Black Swan concept is a fascinating one, and it is an important basis for understanding uncertainty because it has been given a lot of attention in the scientific literature. The question remains as to whether or not the Black Swan concept can be applicable in risk assessment? To answer this question is beyond the scope of this thesis. It is important to note that the Black Swan logic has been given greater attention in scientific literature and has become an important concept in modern risk interpretation.

3.5 Uncertainty in RNNP

The definition of uncertainty is given by the PSA in the guidelines for regulatory framework:

"Uncertainty relates to which incidents can occur, how often they will occur and which detriment of or loss of human life and health, environment and material assets the various incidents can lead to."

(PSA, 2014a).

When inserting the definition of uncertainty in the definition of risk, it appears that uncertainty can be interpreted as uncertainty related to which events can occur. If this is interpreted literally, it could potentially mean that the DFU list established in RNNP today might be insufficient, not addressing all potential hazards.

The PSA notes that uncertainty can be incorporated in RNNP by evaluating strength of knowledge in decision making and robustness of chosen indicators (PSA, 2015a). Thus knowledge strength and robustness are to be considered as tools to measure uncertainty in risk level estimation in RNNP. RNNP does not mention or explore if uncertainty can be expressed by other parameters than these two, and the concept of Black Swans is not discussed.

3.5.1 Knowledge strength

Aven argues that a high level of knowledge strength intuitively means that the uncertainty is low, whereas a weaker level of knowledge implies that uncertainty is higher (Aven, 2013b). Figure 7 illustrates this point by presenting the risk related to a potential outcome of an event, when adding the knowledge as a third dimension.

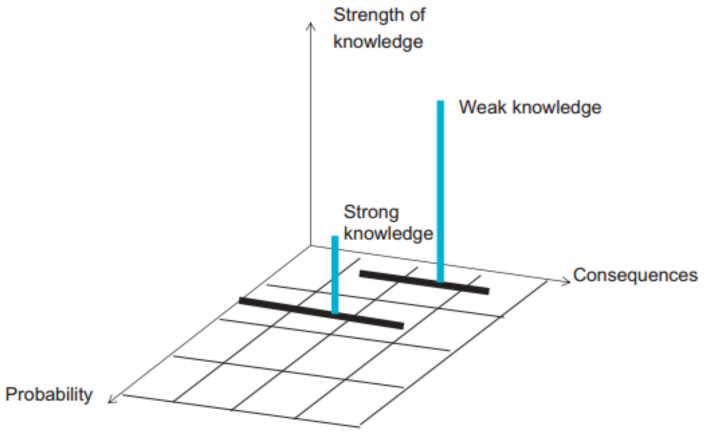


Figure 7: Knowledge strength as the third risk dimension (Aven, 2013b)

PSA have defined strength of knowledge as a measure of confidence in the risk level estimations. PSA argue that several indicators have a high degree of knowledge strength, whereas other have a poor degree of knowledge strength (PSA, 2015a). Risk indicators which have a low level of occurred or almost-occurred DFUs are considered to be indicators with a low degree of knowledge strength in indicator modeling, whereas other indicators in RNNP have a very high level of knowledge strength because they have a higher amount of registered incidents. Knowledge strength also relates to the quality of incoming data.

3.5.2 Robustness

Robustness is related to how well indicators reflect significant changes. If an indicator shows significant change, then it should be able to pin this to alterations in technology or maintenance (or other measures) that have been introduced and could affect the indicator in question. If an indicator does not reflect this (either way) then the indicator is said to have low robustness (PSA, 2015a).

4. Developing a New Total Indicator

Whereas previous chapters have presented RNNP methodology, results and current status, chapter 4 presents the new methodology for establishing the New Total Indicator.

4.1 Method concept

The concept is to develop a New Total Indicator methodology for establishing major accident risk levels in RNNP. Referring to the bow tie diagram in chapter 2.1.1, it is desirable that the New Total Indicator reflects a greater part of the bow tie diagram compared with its predecessor. The new methodology will establish four individual indicators which will be used to compose the New Total Indicator. These indicators will represent a greater area of the bow tie diagram and will be established by both QRA and qualitative risk analysis tools. The purpose of the New Total Indicator is to reflect the method triangulation principle, cover a broader risk spectre and give better data utilization than today's model.

The new model should reflect precursor incident statistics (DFU) along with selected barrier and maintenance performance results. Additionally, the perceived risk among workers is to be addressed by evaluating survey results. Furthermore, uncertainty should be operationalized and included in the New Total Indicator to better reflect the changes in PSA's risk definition.

To summarise the above mentioned aspects; The New Total Indicator will consist of the contributions from four individual indicators which can be categorized as follows:

1) DFU Indicator
2) Barrier Indicator
3) Survey Results Indicator
4) Uncertainty Indicator

After having established the four individual indicators, the assembly and presentation of the New Total Indicator will be established in chapter 4.6.

Figure 8-9 illustrate the structures of the current and New Total Indicator respectively. The structure in Figure 9 reveals the necessary data and parameters which will be used to establish the individual indicators in the New Total Indicator. The development of the individual indicators and the New Total Indicator will be presented in subsequent chapters. A discussion on the design and concept for the New Total Indicator may be found in chapter 6.4.1.

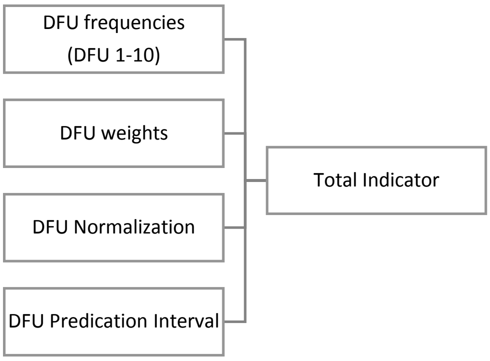


Figure 8: Current Total Indicator structure

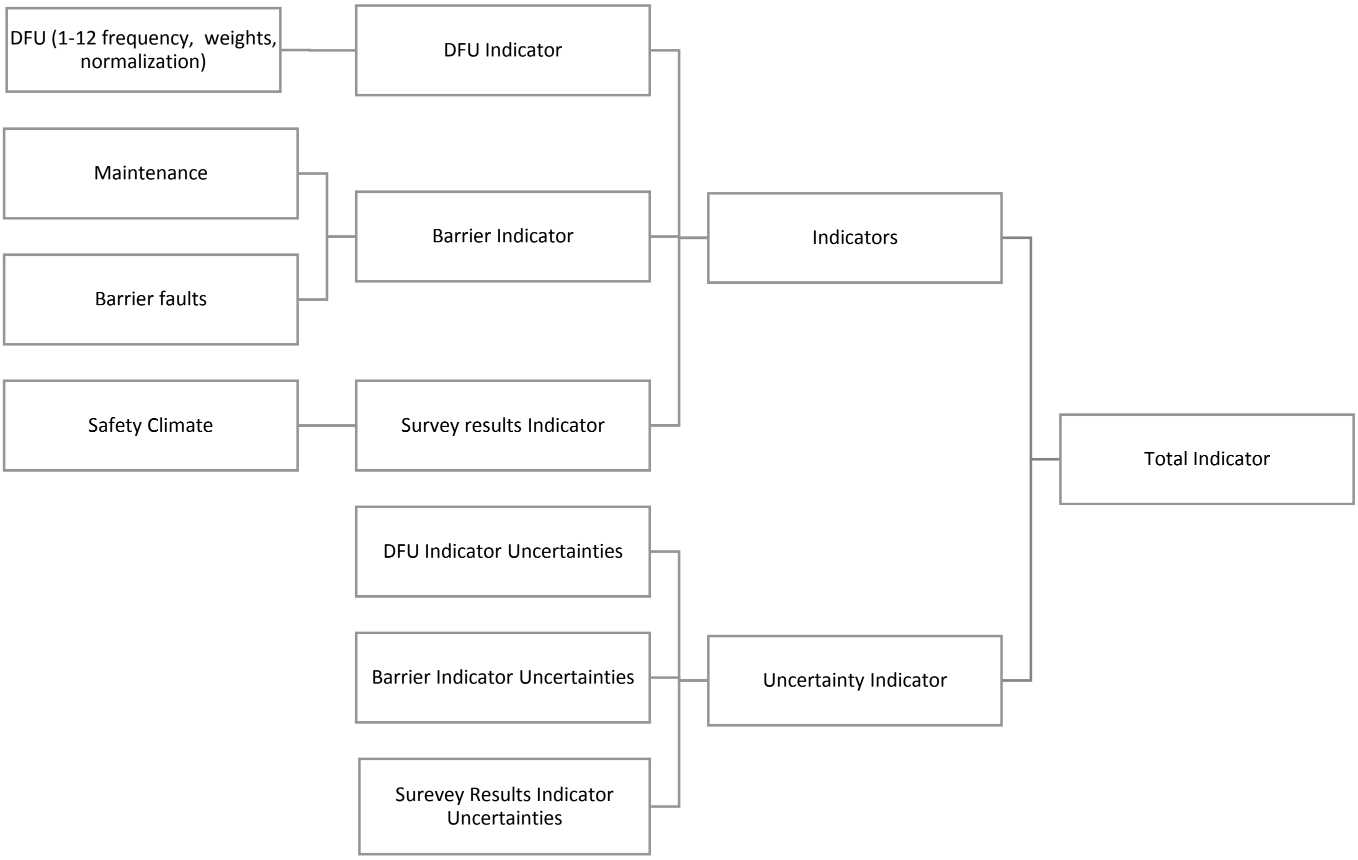


Figure 9: The New Total Indicator structure

4.2 The DFU Indicator

The DFU indicator will be determined by using former and new total indicator methodology. The risk level contribution and DFU indicator value may be established by the formula previously given in chapter 2.2;

$$R = \sum_{I} \sum_{J} DFU_{ij} * V_{ij}$$

Equation 5: DFU Indicator risk level

where “i” represents the DFU number, and “j” is the installation category. What separates the new DFU indicator from today’s total indicator is the number of DFUs included. Helicopter incidents (DFU 12) are currently not included in overall major accident risk levels. This despite that helicopter transport risk is considered a significant offshore personnel risk contributor and classified as one of the major accident DFUs (PSA, 2015a).

The DFU indicator will include DFU 1-10 and 12. DFU 11 “Evacuation”, is incorporated in DFU 1-10 in their individual contributions.

Before the DFU indicator can be established it is necessary to determine which DFU12 indicators should be included and establish DFU 12 indicator weights. DFU 12 weights are necessary in order to establish DFU 12 risk levels according to Equation 5.

4.2.1 DFU 12 – Helicopter Incidents

For a detailed presentation of DFU 12 it is referred to the RNNP main report for 2014 (PSA, 2015a). DFU 12 “Helicopter incidents”, represents helicopter transport risk for all transportation phases for offshore personnel on the NCS. Table 3 lists the categorization of incident indicators for DFU 12.

Table 3: DFU 12 Helicopter incident indicators

DFU 12 Indicator number	Description
1	Incidents with little or medium level of remaining safety margin for major accident prevention
2	Incidents with safety effect in transport service and shuttle traffic
3	Helideck conditions
4	Incidents related to ATM
5	Collision with bird

4.2.1.1 Helicopter Incident Indicators

In consultation with J.E. Vinnem it was decided that incident indicator 1 "Incidents with little or medium level of remaining safety margin for major accident prevention" is the indicator which best reflects helicopter *major accident* risk, and is the most relevant indicator to include in the DFU Indicator (Vinnem, 2016). It can be argued that to exclude the four other incident indicators will make an incomplete DFU 12 contribution to the DFU indicator. It is however believed that indicator 1 represents the greatest major accident risk for helicopter incidents. This decision simplifies the process of incorporating DFU12 into the DFU indicator as fewer weights need to be established. Evaluating incident statistics for incident indicators 2-5 up against the assumed consequence potential supports the decision of including mainly helicopter incident indicator 1 in the DFU indicator.

DFU 12 Incident indicator 1

Incident indicator 1 is categorized according to the number of remaining barriers for the incident in question:

1) No remaining barriers – small safety margin against fatal accident
2) One remaining barrier – Medium remaining safety margin against fatal accident
3) Two/more remaining barriers – Large remaining safety margin against fatal accident

(PSA, 2015a)

A RNNP expert group on helicopter safety categorized serious helicopter incidents according to which events experienced zero remaining or one remaining barrier(s). Based on this expert classification only DFU12 incident indicator 1 events with zero or one remaining barrier will be included in the DFU indicator. Such incidents are assumed to introduce the greatest major accident risk, which is the reason for excluding events with two or more remaining barriers.

In addition to barrier classification, incident indicator 1 is categorized according to incident type:

- Incidents related to helideck movement
- Turbulence
- Static Discharge
- ATM-related events
- Operational Events (Organizational/Human Factors)
- Technical Incidents

Key tables and figures for incident indicator 1, including the results presented by the RNNP expert group, may be found in Appendix III.

4.2.1.2 Weight estimations

Assessing helicopter transport risk is relatively similar to major hazard risk identification on offshore installations (Vinnem, 2014). However, the effects introduced by recent helicopter improvements may be difficult to evaluate in risk assessment results (Vinnem, 2014). The third helicopter safety study (HSS-3) performed by Sintef gives a detailed description of technical and operational development introduced in NCS helicopter activity and presents a wide range of helicopter risk assessment results (SINTEF, 2010). A sample of relevant graphs and figures from this report may be found in Appendix IV.

Both Vinnem and Sintef use incident statistics to assess the personnel risk for helicopter transportation on the NCS in 2008 and 2010 respectively. Vinnem and Sintef's FAR estimates for helicopter personnel flight hours are listed below.

Table 4: Helicopter transport FAR values (Vinnem, 2014) (SINTEF, 2010)

	Estimated FAR value
Sintef (SINTEF, 2010)	80
Vinnem (Vinnem, 2014)	70

Having a known FAR value will simplify the weight establishment process for DFU 12. The Sintef HSS-3 results has been chosen for weight establishment as this is a more conservative FAR-value than the value proposed by Vinnem. Furthermore, this value has been estimated for helicopter transport between years 2010-2019 and is more recently established than the results presented by Vinnem.

The DFU 12 weight needs to be expressed in PLL in addition to FAR, which can be established by rearranging Equation 6, where t_i represents the total hours of exposure for person “i” .

$$FAR = \frac{PLL}{\sum_{i=1}^{n} t_i} * 10^8$$

Equation 6: FAR (Rausand & Utne, 2009)

The hours of exposure i.e. personnel flight hours, can be found in the RNNP data collection, reported from the two helicopter operators on the NCS.

It is suggested that the PLL values should be established by using the mean value of personnel flight hours as the hours of exposure for a certain time period. This is done to simplify the model and should give reasonable answers if the number of personnel flight hours do not differ significantly between years.

Weight estimation strategy

When establishing DFU 12 weights, it is possible to establish an overall value for all incidents in incident indicator 1 i.e. all incidents are equally weighted, regardless of incident type or the number of remaining barriers. A second alternative is to establish weights which address the number of remaining barriers for the incident. A third option is to establish weights which reflect the accident potential for a specific incident category.

To establish one common PLL value for DFU 12 can be considered too general. Different incidents represent different accident potential. To equally distribute the fatality risk on all events would be an insensible simplification. Hence the first suggested approach; to establish one overall DFU 12 weight, is discarded.

The second alternative, establishment of two weights which reflect the number of remaining barriers is a good suggestion for several reasons. Firstly, it is general enough to fit the current

RNNP methodology, which is the basis for the DFU indicator. Secondly it addresses the severity and criticality of events in a better sense than by just having one overall DFU 12 weight. On the other hand, it does not reflect incident type and how this affects the accident potential.

The third alternative is the most detailed and descriptive suggestion. To address every incident type and establish their individual FAR contribution, which would lead to more correct risk level results, but is a more complex task to establish.

The second and third alternative is the approach which will be used further. By combining the second and third suggestion, the incident type and barrier collapse severity is addressed. This is the most detailed approach of the options presented in this thesis. In consultation with Vinnem it was pointed out that to only focus on the number of remaining barriers would be a too strong simplification for establishing DFU weights (Vinnem, 2016).

It is believed that the weights will give reasonable results and project the helicopter risk in a sufficiently realistic manner by basing the weights on the Sintef FAR value. To perform a complete helicopter risk assessment in order to establish DFU 12 weights would be a time consuming process and is somewhat outside the scope of this thesis. The Sintef results will be used as a basis for establishing DFU 12 weights along with several assumptions to determine the necessary values. This will reduce the overall quality of the DFU 12 but is considered a satisfactory solution.

Weight assumptions

Indicator 1 incidents are only responsible for 0,2-2% of all reported helicopter incidents on the NCS (PSA, 2015a). These incidents may represent a greater accident potential despite their lower percentage of total reported incidents. The total number of incidents could first and foremost indicate a good reporting culture and not necessarily low helicopter safety performance (PSA, 2015a).

It is assumed that indicator 1 events represent 70% of the total helicopter transport FAR-value established by Sintef. This value is meant to reflect the severity of indicator 1 events, and at the same time address the remaining high number of incidents which could affect helicopter safety. With a 70% FAR value, the helicopter incident indicator 1 has a FAR value equal to:

$$FAR_{DFU12-indicator1} = 56$$

Furthermore, it is assumed that the technical and operational incidents can be marked as high risk incidents. These incidents are assumed to introduce the greatest risk to personnel and will potentially introduce the most critical accident scenarios. Following the high risk incidents are ATM-related and “Static Discharge” incidents, which are marked as medium risk incidents. Turbulence and helideck incidents are marked as low risk incidents. These assumptions appear reasonable based on incident statistics and risk influencing factors presented in the HSS-3 report (SINTEF, 2010)

This classification will be used to establish FAR values of these incidents to ensure that the weight is estimated to reflect the incident category accident potential. High risk incidents are assumed to represent 50% of the $FAR_{DFU12\text{-}indicator1}$ value. Likewise, it is assumed that medium and low level risk incidents represent 30% and 20% of the $FAR_{DFU12\text{-}indicator1}$ value respectively. It could be argued that this classification might reflect the risk image wrongly, and that all incidents have equal contributions etc. However, these assumptions have been made to simplify the DFU weight estimation process and because they are considered to generate reasonable results.

It has been decided to establish two DFU12 weights based on the number of remaining barriers. It is assumed that incidents with zero remaining barriers will represent 65% of the $FAR_{DFU12\text{-}indicator1}$ value. Incidents with one remaining barrier is assumed to represent 35% of the $FAR_{DFU12\text{-}indicator1}$ value.

The necessary DFU 12 assumptions to establish DFU 12 weights can be summed up as follows:

1. The DFU12 contribution is based on incident indicator 1 statistics
2. $FAR_{DFU12} = 80$, $FAR_{DFU12\text{-}indicator1} = 56$
3. Personnel flight hours are calculated as 1 hour per 100 production hours (if helicopter data are unavailable or not installation specific) (Vinnem, 2016).The mean value of personnel flight hours (for a chosen time period) is the number of hours of exposure used to convert FAR into PLL values.
4. High risk incidents = 50%, medium risk incidents = 30%, low risk incidents = 20% of $FAR_{DFU12\text{-}indicator1}$ value
5. Incidents with zero remaining barriers = 65%, incidents with 1 remaining barrier = 35% of $FAR_{DFU12\text{-}indicator1}$ value

The PLL values in Table 5 were established by rearranging equation 6 by using the mean value of personnel flight hours between years 2008-2014 for fixed production installations. These values were established to be used later in the case study of this thesis. The weights are considered reasonable estimates for establishing the DFU 12 risk level values, but could look different if they were evaluated up against all installations for a longer time period.

Table 5: FAR and PLL estimates, incident indicator 1 categories

Indicator 1 incident		FAR estimate	PLL estimate
Technical	0 barriers	9,1	0,02795
	1 barrier	4,9	0,01505
Operational	0 barriers	9,1	0,02795
	1 barrier	4,9	0,01505
ATM-related	0 barriers	5,4	0,01659
	1 barrier	2,9	0,00891
"Static discharge"	0 barriers	5,4	0,01659
	1 barrier	2,9	0,00891
Turbulence	0 barriers	3,6	0,01106
	1 barrier	1,9	0,00584
Helideck movements	0 barriers	3,6	0,01106
	1 barrier	1,9	0,00584
Total		55,6 ~56	0,08539

DFU12 contribution to the DFU indicator

Having established DFU 12 weights, DFU 12 may be incorporated in the DFU Indicator in a similar manner as the other major accident DFUs.

5.2.2 DFU Indicator presentation

With all weights determined for DFU 1-10 and 12, the major accident risk levels may be calculated according to existing total indicator methodology in RNNP. The incident frequencies combined with DFU weights are individually multiplied, then summarized. Summarization is only applicable for risk level results expressed in PLL values. FAR values are expressed by different hours of exposure for DFU 1-10 and 12, and must be presented individually.

Having established the DFU Indicator in PLL values, the calculated risk level may be converted to a relative value by Equation 4. The base year value is set at 100. By expressing the DFU Indicator as a relative value, the overall DFU risk level development is scrutinized, not necessarily the risk level value i.e. the PLL and FAR values.

The quality of the established DFU 12 weights and DFU Indicator methodology will be discussed in chapter 6.4.2.

4.3 The Barrier Indicator

Whereas the DFU indicator is relatively simple to establish based on already existing methodology, the Barrier Indicator will require greater attention in order to be developed. Pre-existing literature on combined barrier indicators have been written by Heide & Vinnem, De Almeida and Stensland to mention some (Almeida, 2013; Bjørnar Heide, 2009; Stensland, 2013). Their research, along with previous and existing RNNP methodology, will be used as inspiration to establish the Barrier Indicator. For a complete overview of the data structure (barrier elements, reporting criteria, classification etc.) for the barrier performance data it is referred to the RNNP main report for 2014 (PSA, 2015a).

An overall barrier indicator was previously established between 2004-2008 in RNNP. This indicator was based on the fractions of failure during tests for a selection of the most safety critical barrier elements reported in RNNP (Vinnem & Ravdal, 2006).

The ambition for the Barrier Indicator is that it should reflect the breadth in reported barrier performance data and address potential barrier collapse severity. The Barrier Indicator will, as illustrated in Figure 9, consist of the contributions of two individual indicators:

- Barrier fault indicator
- Maintenance indicator

4.3.1 Barrier Fault Indicator

The barrier fault indicator is partly based on existing methods in RNNP, combined with former and new barrier indicator methodology. The necessary RNNP barrier performance data to develop the barrier fault indicator is:

- Number of barrier tests for each installation, for all reported barriers
- Number of barrier test failures for each installation, for all reported barriers

The main focus for the barrier fault indicator is to evaluate barrier performance development for the technical barriers in RNNP.

This thesis aims at establishing the overall risk levels for all offshore installations and will not scrutinize offshore risk levels on an installation level. Consequently, the barrier faults indicator will use the mean number of faults for *all* installations to establish the Barrier Indicator. The total fraction of faults for one barrier element for one year may be calculated as:

$$Y_j = \frac{\sum_{j=1}^{N} x_j}{\sum_{j=1}^{N} y_j}$$

Equation 7: Total fraction of barrier faults (PSA, 2015a)

Where N is the number of installations, x_j is the number of faults on installation “j” and y_j is the number of tests for the barrier element on installation “j”. The fraction of failures should be established for all installations, for each individual barrier element for a certain time period to assess the overall development.

The proposed method is based on current RNNP methodology. This will not suffice in establishing the Barrier Indicator as the method is too general, not reflecting barrier severity or barrier/DFU relations. The Barrier Indicator ultimately needs to reflect major accident risk in a more comprehensive manner than just by barrier failure fractions.

4.3.1.1 Barrier weights

Vinnem suggested to establish Barrier weights in order to address barrier severity in the Barrier Indicator (Vinnem, 2016). By utilizing barrier weights it is possible to calculate the barrier indicator in a similar manner as the DFU indicator. The barrier weights are assumed values of potential barrier severity, as a full risk assessment of barrier failure consequences is beyond the scope of this thesis.

The barriers serve different functions; some are installed to mitigate the risk for potential DFUs occurring, whereas others mitigate potential DFU consequences. The barriers can therefore be weighted to reflect their position in the bow tie diagram.

Figure 10 portrays the barrier element position for the technical barriers in RNNP. The numbered boxes represent barrier elements included in the RNNP barrier performance data. The assigned barrier element position is based on assumptions, where the position of the barrier element is meant to reflect the severity of potential barrier failure. The barriers situated to the left reduce the probability of DFU occurrence, whereas barriers situated at the right are installed to mitigate DFU consequences. The further right the barrier element is situated; the higher the risk introduced by barrier failure. Table 6 lists the bow tie position of each barrier element and the assigned barrier weight in PLL values. The lines where the barriers are located in Figure 10 are of no relevancy.

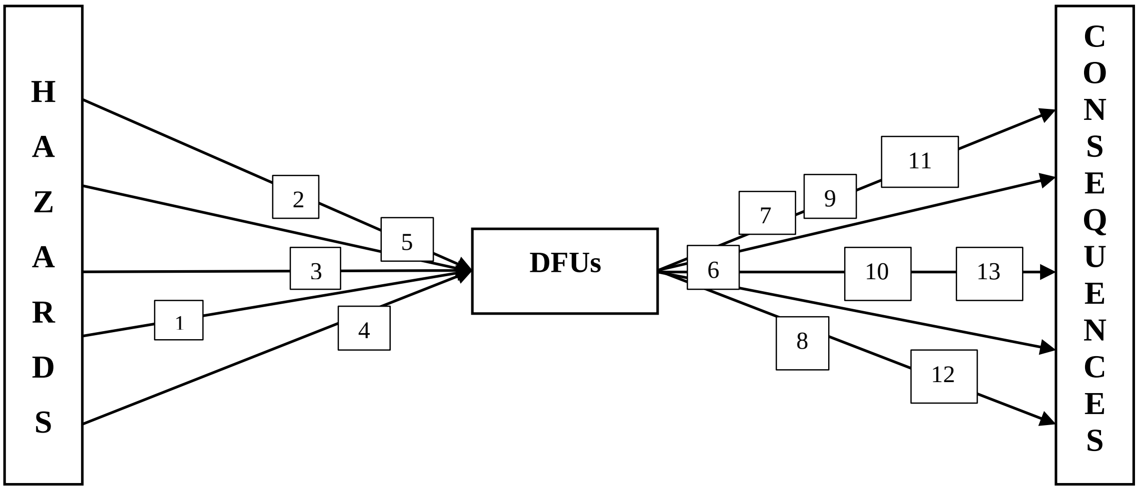


Figure 10:Barrier element positioning

Table 6: Barrier element bow tie diagram position and weight

Barrier Element	**Bow tie diagram position**	**Assigned barrier weight (PLL)**
Fire detection	7	0,35
Gas detection	2	0,02
Shut down *Riser ESDV*	13	0,9
Shut down *Wing/Master Valve*	8	0,4
Shut down *DHSV*	11	0,65
BDV	3	0,03
PSV	4	0,04
BOP Isolation	5	0,05
Active fire protection *Deluge Valve*	9	0,5
Active fire protection *Fire pumps (start tests)*	12	0,7
Well Integrity	1	0,005
Ballast system valves	6	0,1
Waterproof doors	10	0,6

The barrier weights have been established seen in relation to the DFU PLL values and have been given relatively large weights to reflect the severity of barrier failure. The quality of the assumed barrier weights will be discussed in more detail in chapter 6.4.3.

4.3.1.2 Barrier and DFU relations

The previous chapter established barrier weights to reflect which barriers impose the greatest risk to the system by potential barrier failure. The aim of establishing DFU and barrier relations is to assess which DFUs are the most vulnerable to such barrier failures. Barrier elements may be critical for one DFU, whereas others are relevant for several DFUs. The RNNP method report lists some of the relations between barrier elements and specific DFUs (PSA, 2015b). It is of interest to establish RNNP barrier and DFU relations and use this in combination with the suggested barrier weights to establish the barrier fault indicator. Table 7 lists the identified barrier and DFU relations, which are based on the barrier and DFU relations described in the RNNP method report (PSA, 2015b) and on logical assumed relations between certain DFUs and barrier elements.

“Fire detection” is marked as related to DFU 2 (Ignited HC leak), DFU 4 (Other fires/explosion and DFU 11 (Evacuation). This means that Fire protection is an important barrier for the marked DFUs (DFU 1, 4 and 11) and not necessarily important for the other DFUs. It is logical that the potential most hazardous precursor events have a greater number of barriers installed to reduce consequences, should they occur. This is demonstrated clearly when evaluating the number of barrier/DFU relations in Figure 11 and comparing the DFUs up against their individual weight. Figure 11 actually depicts the worst case scenario for each precursor event, with the worst case scenario being that all barriers relevant for a DFU were to experience failure. This could potentially lead to a much worse accident outcome than if the barriers were functioning.

Several barriers are installed to reduce DFU risk which are not tested and reported in RNNP. When noting that some DFUs have no barriers to mitigate their accident potential this is not necessarily the case; the issue is rather that there are no *reported* barriers which are considered in relation to the DFU in question.

It can be argued that the barrier/DFU relations marked in table X could have been established in a different manner, potentially displaying different results. Alternatively, the relations could have been expressed differently, reflecting the *degree* of relation, rather than just marking of the barrier/DFU relations. This will be discussed further in chapter 6.4.3.

Table 7: Barrier/DFU relations

Barrier Element	**DFU number**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Fire detection		X		X							X	
Gas detection	X										X	
Shut down *Riser ESDV*		X	X	X					X	X		
Shut down *Wing/Master Valve*		X	X						X	X		
Shut down *DHSV*		X	X						X	X		
BDV	X	X	X	X					X	X		
PSV	X	X	X	X					X	X		
BOP Isolation			X									
Active fire protection *Deluge Valve*		X		X								
Active fire protection *Fire pumps (start tests)*		X		X								
Well Integrity			X						X			
Ballast system valves						X	X	X				
Waterproof doors							X	X				
TOTAL	**3**	**8**	**7**	**5**	**0**	**1**	**2**	**2**	**6**	**5**	**2**	**0**

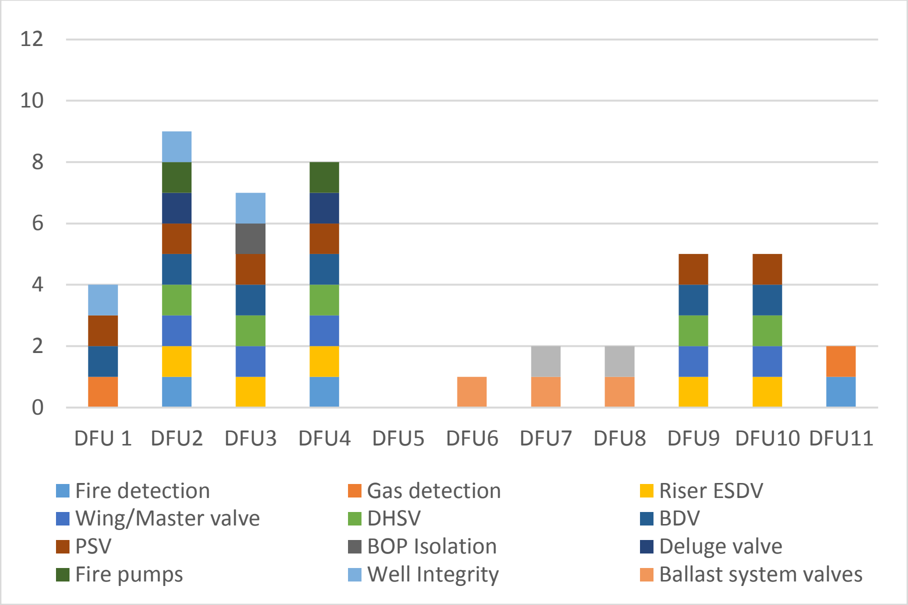


Figure 11: Barrier/DFU relations

4.3.1.3 Composing the barrier fault indicator

The barrier fault indicator is determined by evaluating the worst case scenario for DFUs 1-11. The worst case scenario can be described as the accident scenario where all DFU related barriers fail and the DFU experiences complete barrier collapse. Combining DFU relations with barrier weights, it is possible to establish the barrier fault indicator.

The risk level by complete barrier chain failure for DFU "i" for the chosen year may be calculated as:

$$R = \sum_{i=1}^{M} \prod_{s=1}^{N} W_s * Y_{i,s}$$

Equation 8: DFU worst case scenario barrier failure

where W is the barrier weight for barrier element s and $Y_{i,s}$ is the average barrier failure fraction for barrier element s, related to DFU i. The risk level R for all DFUs is established by summarizing all worst case scenarios for all DFUs for the year in question. This value is a PLL value multiplied with the fraction of barrier failures.

The relative barrier fault indicator can be determined by Equation 9. The relative value is set at 100 for a chosen base year in the same way as the DFU Indicator.

$$Barrier\ fault\ indicator = \frac{R}{R_{base\ year}}$$

Equation 9: Relative barrier fault indicator

4.3.2 Maintenance indicator

To establish a Barrier Indicator based on RNNP maintenance data may be considered somewhat controversial. The maintenance data have had a history of being difficult to interpret in RNNP, and the applicability of data has been questioned (Dammen & Ekle, 2015; B. Heide & Hallan, 2016; B. Heide & Lootz, 2015).

Vinnem and Røed discovered that preventive maintenance, which is in fact intended to reduce risk, was responsible for 30% of the hydrocarbon leaks on the NCS between 2008 and 2014 (Vinnem & Røed, 2015). In establishing the maintenance indicator, it is assumed that the introduced system risk due to maintenance is negligible. This is a simplification to reduce the indicator complexity, but is in contrast to the results by Vinnem and Røed. Uncertainty issues related to the reported maintenance data will be addressed by the Uncertainty Indicator and not by the Barrier Indicator.

The selected maintenance data for establishing the maintenance indicator is:

- Number of maintenance hours (each installation).
- Number of lagging maintenance hours (preventive and corrective) (each installation).
- Number of lagging maintenance hours (preventive and corrective) for HSE critical components (each installation).

No emphasis is given to the number of HSE tagged equipment in establishing the maintenance indicator. This is done for the sake of simplicity, but could be a potential area of improvement for the proposed methodology.

4.3.2.1 Establishing the maintenance indicator

The maintenance indicator is established by evaluating the lagging HSE critical maintenance share of the overall maintenance hours for preventive and corrective maintenance respectively

$$M_{PMtot} = \sum_{k=1}^{N} Total\, maintenance\, hours_{\,k} + \; lagging\ PM_k$$

Equation 10: Total hours of preventive maintenance

$$M_{CMtot} = \sum_{k=1}^{N} Total\, maintenance\, hours_{\,k} + \; lagging\ CM_k$$

Equation 11: Total hours of corrective maintenance

M_{PMtot} and M_{CMtot} are the total hours of maintenance that have, and should have been invested on all installations on the NCS for the year in question, “k” is the number of the installation. The share of lagging HSE critical maintenance hours (corrective and preventive) are established by dividing the total lagging HSE critical maintenance on M_{PMtot} and M_{CMtot}.

$$R_{PM} = \frac{\sum_{k=1}^{N} Lagging\ hours\ of\ HSE\ critical\ PM_{\,k}}{M_{PMtot}}$$

Equation 12: Share of lagging preventive maintenance

$$R_{CM} = \frac{\sum_{k=1}^{N} Lagging\ hours\ of\ HSE\ critical\ CM_{\,k}}{M_{CMtot}}$$

Equation 13: Share og lagging corrective maintenance

The relative maintenance indicator is established by Equation 14, where the base year value is set at 100. Instead of having one relative CM and PM indicator, their average value is used. This should be a satisfactory solution, if not an optimal one. If the CM and PM indicator results were to differ significantly, the proposed average value solution could be questioned.

$$Maintenance\ indicator = \frac{\left(\frac{R_{PM}}{R_{PM-base\ year}}\right) + \left(\frac{R_{CM}}{R_{CM-base\ year}}\right)}{2}$$

Equation 14: Relative maintenance indicator

4.3.3 Assembling the Barrier Indicator

The Barrier Indicator presents the two indicators individually by their relative values. By presenting the indicators separately it is possible to evaluate the individual trends before deciding their relative contribution to the New Total Indicator. It was decided that this solution will better portray the contributions to the Barrier Indicator (Vinnem, 2016).

A discussion on the proposed Barrier Indicator methodology may be found in chapter 6.4.3.

4.4 The Survey Results Indicator

The aim of the Survey Results indicator is to establish organizational indicators by utilizing survey results. Leading organizational indicators will better address why DFUs occur in comparison with today's RNNP where mainly reactive barriers are evaluated and analyzed. (B. Heide, 2015; Vinnem, 2010). RNNP establishes survey result indicators, reflecting organizational factors. However, these indicators are not used in assessing major accident risk levels.

Organizational factors are often referred to as root causes for accident causation and may be a critical contributor in the sequence of events leading up to an accident (Reason, 1997). Vinnem and Røed highlighted the relevancy of organizational factors by studying the hydrocarbon leaks that occurred on the NCS between 2008 and 2014. They discovered that personnel was involved in system operations which lead to the causation of more than half of the HC leaks from process plants on offshore installations on the NCS (Vinnem & Røed, 2015). The same study established that several of the incident investigations expressed (clearly or subtly) that operators had practices that allowed employees to systematically avoid compliance with the procedures set by the organization (Vinnem & Røed, 2015).

The current safety stage in the petroleum industry has been called "the cultural solution" with particular emphasis on creating a strong safety culture to reduce major accident risk (Haukelid, 1998; Tharaldsen, Olsen, & Rundmo, 2008). The HSS-3 study by Sintef confirms this, and argues that today's safety mentality aims at evaluating how technical, operational, human and organizational factors interact in a dynamic context, where all factors must be evaluated as a whole (SINTEF, 2010).

Based on the above mentioned aspects organizational factors should be given greater visibility and impact in establishing major accident risk, than in today's RNNP.

4.4.1 Choice of Organizational Indicators

Rausand & Utne remarks that to develop organizational indicators is considered more controversial and challenging than technical indicators (Rausand & Utne, 2009).The question arises; which organizational factors should be established from the survey results and how can they be used to establish a Survey Results Indicator?

Safety culture and safety climate are two organizational indicators which could be extracted from the survey results and used to assembly the Survey Results Indicator.

For a presentation of both terms it is referred to “Safety climate and safety culture in health care and the petroleum industry: Psychometric quality, longitudinal change, and structural models” (Olsen, 2009) which gives an extensive introduction to both terms and their differences.

It has been decided to establish the Survey Results Indicator by a safety climate indicator. The reason for excluding safety culture is due to its close relation to safety climate and that it may be considered a more complex task to establish the safety culture compared to the safety climate (Olsen, 2009).

4.4.1.1 Safety Climate as an Organizational Indicator

Safety climate is considered an organizational indicator for e.g. process and offshore industry, and may be determined from survey results with acceptable results (Mearns, Flin, Gordon, & Fleming, 1998; Zohar, 1980). Estimating safety climates can give a *“snap-shot of the current state of safety”*(Tharaldsen et al., 2008) based on the perceptions, attitudes, and beliefs employees share on risk and safety (Olsen, 2009; Tharaldsen et al., 2008).

Zohar’s study in 1980 defined, measured and tested safety climate by analyzing survey results in companies with different safety results. Furthermore Zohar concluded that the safety climate could be satisfactory established from survey results (Zohar, 1980). Kongsvik et al. discovered further that the safety climate can be considered both a leading and lagging indicator for incidents, and that the safety climate scores correlate with safety performance results in the offshore industry (Trond Kongsvik, Kjøs Johnsen, & Sklet, 2011). Some experts argue that other qualitative methods should be used to establish safety climates (T. Kongsvik, 2016) or question if correlations between safety climate and safety performance actually can be measured with reliable results (Tharaldsen et al., 2008). The general argument amongst scientists and researchers supports surveys as a reliable data source for estimating the safety climate (Trond Kongsvik et al., 2011; Mearns et al., 1998; Nielsen, Mearns, Matthiesen, & Eid, 2011; Tharaldsen et al., 2008; Zohar, 1980).

4.4.2 The Survey Results Indicator methodology

4.4.2.1 Establishing the Safety Climate

The safety climate may be determined through a survey results factor analysis (FA) in SPSS (Statistical Package for Social Sciences). SPSS is a computer program which is used to perform statistical analyses of quantitative data (Johannessen, 2009).

It is referred to Johannessen for an introduction to SPSS and Ulleberg & Nordvik for an elementary introduction to Factor Analysis (Johannessen, 2009; Ulleberg & Nordvik, 2001).

The safety climate should be established based on all survey results to get an overall evaluation of the perceived safety levels on the NCS. To evaluate the overall safety climate can be considered a very strong generalization. Hence, the safety climate will not be able to reflect safety climate differences between installations, operators, distinguish between entrepreneurs etc. It is however the overall perceived risk levels which are of interest when establishing the New Total Indicator.

From the FA it is possible to extract factors which reflect distinct sociological phenomena (safety motivation, work vs. safety etc.). Survey questions related to the resulting factors often describe the same sociological phenomena. By evaluating the factor related survey questions, it is possible to classify and name the factors resulting from the FA. The safety climate is established based on the individual factors and the factor scores resulting from the FA.

4.4.2.2 Determining the Survey Results Indicator

After having established safety climate factors through the factor analysis in SPSS, the scores of the factors are established and used to express the Survey Results Indicator on a relative scale. The respondents answer the survey by giving a score on a 5-point Likert scale. This scale reflects the level of agreement with the survey questions, which are presented as negative or positive statements (PSA, 2014b). The factor score is the mean value for all factor related question responses on the 5-point Likert scale. The desired factor value could be high or low, depending on the question formulation.

The relative value for one safety climate factor may be established as:

$$S' = \frac{S}{S_{base\ year}}$$

Equation 15: Relative safety climate factor value

Where S is the mean value of the factor value and $S_{base\ year}$ is the mean factor value for the chosen base year. The relative value for the Survey Results Indicator's base year is set at 100.

The number of resulting factors could be different depending on the execution of the FA. The overall safety climate score and Survey Results Indicator is the average value of all relative factor values. The Survey Results Indicator can be established as:

$$Survey\ Results\ Indicator = \frac{\sum_{i=1}^{N} S'_i}{N}$$

Equation 16: Survey Results Indicator

where N is the number of FA established factors and S'_i is the relative factor value for factor "i".

The survey is distributed biannually; consequently, it is suggested that the safety climate value, for a year with no survey results, is set equal to the value of the antecedent year. This is an obvious shortcoming, but considering that the survey is distributed on a biannual basis this solution is considered satisfactory.

4.5 The Uncertainty Indicator

An important aspect of this thesis is to attempt to incorporate uncertainty and give it visibility in RNNP. The motivation for doing this is to prevent uncertainty from becoming a term which has little real impact on risk level estimations, but rather use it as a constructive contributor in RNNP risk assessment.

As mentioned in chapter 3, RNNP presents knowledge strength and robustness of indicators as uncertainty parameters. However, these are not systematically reflected in today's methodology (Abrahamsen, Heide, Vinnem, & Gelyani, 2015) but rather taken into consideration by the RNNP HSE expert group in their evaluation of RNNP results (B. Heide & Hallan, 2016).

Possible epistemic uncertainty factors should be better reflected in RNNP to ensure that the changes in risk revision have an impact on RNNP. Several approaches could potentially be carried out to establish uncertainty levels in RNNP, and several designs of the Uncertainty Indicator could be suggested. As for previously developed indicators, the Uncertainty Indicator should be simple to incorporate in the New Total Indicator.

4.5.1 Operationalizing Uncertainty

Uncertainty should be operationalized in order to establish the Uncertainty Indicator. The question arises; How to operationalize uncertainty in a QRA context? Uncertainty as a term can be easily understood based on common knowledge, but how to quantify and measure uncertainty is an answer which has been proven difficult to establish. (Dammen & Ekle, 2015; B. Heide & Hallan, 2016; Vinnem, 2016).

A framework for an uncertainty model in RNNP has been developed by Abrahamsen et al. in their paper "An improved method to express risk level and detect trends in risks in the Norwegian petroleum industry " which is currently submitted for publication (Abrahamsen et al., 2015). The model proposed in this paper evaluates the knowledge strength and robustness of the RNNP major accident indicators and barrier elements.

Vinnem argued that it in order to operationalize uncertainty, it might be beneficial to establish uncertainty variables for RNNP which have the ability to reflect changes over time (Vinnem, 2016).

Uncertainty variables and chosen elements from the uncertainty method by Abrahamsen et al. will be established and utilized in the following subchapters.

4.5.2 Identifying Uncertainty variables

The first step of the Uncertainty Indicator methodology is to establish uncertainty variables. The main property and first criteria for the uncertainty variables is that they should have the ability to change over time. The second criteria is that static uncertainty factors, which show little or no annual change, are not to be included as uncertainty variables. Based on these criteria the Uncertainty Indicator will not be a direct measure of the overall uncertainty in DFU, barrier and survey results data. The Uncertainty Indicator will rather reflect the *changes* in indicator quality over time, due to the uncertainty introduced by the uncertainty variables.

Table 8 lists the identified uncertainty variables for the previously established indicators (DFU, Barrier and Survey Results). In consultation with Vinnem it has been concluded that the uncertainty variables are satisfactory to reflect the most evident uncertainties in RNNP (Vinnem, 2016). A discussion on this subject may be found in 6.4.5.

Table 8: Uncertainty variables

	DFU Uncertainty factors
1	New installation designs
2	New field developments
3	Changes in operational structure (Integrated operations, work rotations etc.)
4	Interpretation and follow up of guidelines and regulations
	Barrier Uncertainty factors
5	Component technology (characteristics/functions)
6	Test Procedures (Intervals, self-testing, routines, knowledge)
7	Changes in definitions (or interpretations of definitions) of important terms and criteria, relevant for barrier performance reporting
	Survey Results Uncertainty
8	Survey respondent percentage
9	Survey respondents’ representativeness

4.5.2.1 DFU Indicator Uncertainties

New Installation designs

New installation concepts and designs are explored to increase efficiency, safety and cost optimization in the offshore industry. Innovative design solutions such as “Goliat” and increased subsea field solutions, could increase or decrease the overall risk levels. With a known platform concept, the risks might be better mapped than for a platform having a new design. RNNP maps the installation trends on the NCS, but does not reflect the impact new designs might have on the overall risk level. Such uncertainties, which may develop over a longer time period, questions the developed methodology, the robustness of indicators and the knowledge strength behind the incoming data.

New field developments

The establishment of the “Snøhvit” field, which started gas production in 2006, along with the two-year delayed production start of the Goliat oil and gas field in 2016, have marked the start of a potential new era of the Norwegian oil and gas industry with expanding potential field development in the Barents Sea (NPD, 2015). When RNNP was developed in the late 1990s, arctic offshore operations were not considered in the design of RNNP methodology, as no fields were in operation at that time in the Barents Sea. Operational risk in the arctic areas is an important area of uncertainty, as the risk picture may be complex in these harsh and remote areas. Johan Castberg and Wisting Central are pointed out as potential areas of offshore activity in the future. These fields are situated in areas which introduce higher demands for emergency preparedness (Henningsgård, 2013; Ims, 2013), helicopter activity (Jakobsen & Ehlers, 2015) and installation designs. Field developments in the northernmost part of the NCS accentuates the relevancy of addressing the risk image uncertainties in these areas (Vinnem, 2016).

Changes in operational structure

If the industry trends continue toward a higher level of integrated operations with onshore control and lower manned installations, then there could be a change in risk levels which RNNP might not be able to detect with today’s methodology. Such changes are often introduced argued that they will reduce the offshore personnel risk. Perhaps these changes are for the better considering personnel risk, but could such changes potentially increase environmental risk? Answers to questions like these are uncertain and unanswered in today’s RNNP. Vinnem argues that the resulting risk image by changing existing operational patterns is uncertain (Vinnem, 2016). In addition to increased focus on integrated operations onshore, Vinnem argues that operators are considering introducing a new work rotation for e.g. maintenance personnel in order to reduce costs. How changes in operational patterns affect safety levels is uncertain and currently not systematically reflected as an uncertainty contributor in RNNP (Vinnem, 2016).

Interpretation and follow up of guidelines and regulations

How guidelines and regulations are to be interpreted (and followed up) could sometimes be unclear. Vinnem argues that there are different reporting interpretations for DFUs 1, 3, 4 and 8 in RNNP from both a regulator and industry point of view (Vinnem, 2016). Vinnem accentuates these DFUs in particular, as there have been *"obvious interpretation issues"*(Vinnem, 2016) with these DFUs in the past. Uncertainties related to which events should be reported, misinterpretation of their classification and different follow up of events is a root for uncertainty.

5.5.2.2 DFU Uncertainty variables and their DFU connections

The DFU Uncertainty factors listed in Table 9 reflect uncertainty issues which are relevant for the DFU data and DFU risk level presentation in RNNP. The DFU uncertainty factors may be relevant for some DFUs and not necessarily all DFUs.

Table 9: DFU and uncertainty variable relations

Uncertainty variable	**DFU Nr.**											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1			X			X	X	X				
2						X			X		X	X
3	X		X		X							X
4	X		X	X				X				

New Installation designs are considered relevant for DFUs: "well incidents", "drifting objects", "field related vessel collision" and "damage to constructions". Installation design could be relevant for well design and ensuring safe operations on the sea bed. New subsea solutions could potentially affect the well integrity and safe well operations. Drifting objects could potentially become more hazardous to new installation designs if the design is more vulnerable to potential damage. Potential icebergs toward the northernmost installations could be a drifting object which would require high structural integrity of the design, if a collision were to occur. Field related vessel collision is an area of uncertainty following changes in design which could reduce or increase the safety level and structural integrity considering a potential collision. Construction damage could experience greater accident uncertainty by introducing new installation designs. The design could either increase or reduce the installation's ability to withstand potential consequences resulting from the construction damage.

New field developments are considered relevant for DFUs: "drifting objects", "riser leak", "evacuation" and "helicopter incidents". Drifting objects refers to the same issue as for installation design; ice moving toward the installation, which is a phenomenon which could become more frequent further north. The uncertainty with riser leaks relates to potential clean-up work and the effectiveness of stopping the leakage considering the potentially remote and harsh areas where these fields are situated. Field developments introduce uncertainty particularly for helicopter transport and evacuation as arctic climate, remote areas and tough environment impacts the ability and adequacy of the emergency preparedness in the area (ref.(Henningsgård, 2013; Ims, 2013; Jakobsen & Ehlers, 2015)).

The uncertainty introduced by changes in operational structure is considered relevant for DFUs: "unignited HC leaks", "well incidents", "ship on collision course" and "helicopter incidents". If HSE critical equipment is monitored ashore, then this could introduce HC leak uncertainty by monitoring equipment and handling potential hazardous events. Additionally, if maintenance crew are only available for a certain time period and not standby at all times, then this is believed to potentially affect the HC leak safety (Vinnem, 2016). The same issues for HC leaks are considered relevant for well incidents. Uncertainty has in fact been reduced for ships on collision course by having ship surveillance monitored onshore. IO is considered beneficial for uncertainty levels related to ships on collision course. Integrated operations and changes in operational patterns are considered relevant for potential changes in helicopter transport routines.

The DFUs considered relevant for the fourth uncertainty variable have been established in consultation with Vinnem, who have pointed out the chosen DFUs in chapter 4.5.2.1 as particularly relevant.

It could be argued that the uncertainty variables and DFU relations in Table 9 could have been established differently. It could be argued that other DFU and uncertainty variable relations exist. In consultation with Vinnem it was concluded that the suggested relations are reasonable for the proposed Uncertainty Indicator.

4.5.2.2 Barrier Indicator Uncertainties

Component technology

The Norwegian offshore industry is an innovation driver, where component technology is being constantly developed for efficiency, cost reduction and safety optimization of systems. The installation age on the NCS vary significantly, hence the installed component technology will differ in quality and design. Improved sensor technology contributes considerably in barrier performance monitoring, and newly installed equipment have a higher degree of self-testing, which is not reported as barrier performance tests in RNNP (Vinnem, 2016). Hence, some barrier performance data show a higher rate of barrier tests and barrier faults among the older installations than the newer installations. A higher degree of self-testing on system components, and other technology improvements, should increase safety and test consistency. This is not systematically reflected in the current RNNP barrier performance data.

Test procedures

The uncertainty associated with the barrier performance data could be considered a weakness in the portrayal of barrier goodness on the NCS (B. Heide & Lootz, 2015). RNNP states that the barrier indicator results show great variation between installations on the NCS (PSA, 2015a). It has been revealed that operators grease valves before testing, and don't report failed tests if the succeeding test shows proper function of the barrier element (PSA, 2015a). The PSA points out three factors which are considered the main contributors to the variation of barrier performance results:

- *"Differences in test intervals (between installations and operations).*
- *Differences in the number of installations the operators hold responsibility for.*
- *Different number of tests".*

(PSA, 2015a)

These issues directly influence the barrier fault indicator and confirms the need for test procedure uncertainty to be reflected in the Uncertainty Indicator.

Changes in definitions (or interpretations of definitions)

There could potentially be a conflict with the PSA's and industry's criteria and definitions used in gathering and evaluating barrier performance data. Some operators have different failure definitions on specific barrier elements, resulting in a failure rate which could be higher/lower compared to other operators performing the same tests on the same barrier elements (Vinnem, 2016). Additionally, Heide argues that some operators have altered their definition of lagging maintenance, resulting in a considerable drop in the total hours of lagging maintenance compared to previous performance, without notable efforts being responsible for such a development (B. Heide & Hallan, 2016).

4.5.2.3 Survey Results Indicator Uncertainties

Survey response

The low survey response is an uncertainty issue which affects the validity of the Survey Results Indicator considerably. As mentioned in chapter 2.1.3, it is estimated that 27,3% of the workers responded to the survey in advance of the 2013 report (PSA, 2015b). It is estimated that the response percentage on average has been between 30-55% (PSA, 2015b). Lootz argues that the number of incoming responses is not low, after all there are several thousand workers offshore (B. Heide & Lootz, 2015). Uncertainty in safety climate estimations would be considerably reduced if the survey response was greater.

Survey respondents' representativeness

RNNP states that a prerequisite for analyzing the data is assuming that the survey respondents make up a representative sample of offshore workers (PSA, 2014b). At the same time RNNP comments that it is difficult to establish if the responding workers are representative for the opinions of all offshore workers on the NCS (PSA, 2014b). Lootz questions if the offshore workers answering the survey potentially could have motives for responding; *"They might want to express discontent and concern with their work place? Perhaps the ones responding are more interested in HSE aspects than some of their co-workers?"* (B. Heide & Lootz, 2015). Vinnem additionally comments that workers having safety commitments and responsibilities in the company might feel more inclined to respond the survey (Vinnem, 2016). Not knowing the complete representativeness of the survey respondents is a source of uncertainty for survey results interpretation.

4.5.3 Developing an Uncertainty Indicator methodology

The Uncertainty Indicator will be established by rating the uncertainty variables through knowledge strength and robustness of indicators in a similar manner as proposed by Abrahamsen et al. (Abrahamsen et al., 2015). Choosing to evaluate the indicators through knowledge strength and robustness is an attempt to reflect the uncertainty variables' effect on risk indicator quality.

4.5.3.1 Rating of knowledge strength and robustness

The rating model by Abrahamsen et al. is expanded to a five-point scale rather than a three-point scale. This will increase the uncertainty range, which is believed to give better Uncertainty Indicator results. A high score implies that uncertainty is low and vice versa. A detailed overview of the rating classifications may be found in Appendix V.

Assigning scores for knowledge strength and robustness needs to be seen in relation to the uncertainty variable's development. For instance; "Field developments" is of little relevance for year 2007 (since Snøhvit was not in operation before 2008) but could be a potentially greater uncertainty contributor in subsequent years.

To assess the actual effect uncertainty variables have on indicator quality is a difficult aspect of operationalizing uncertainty. The assigned scores will be based on logical conclusions and assumptions rather than concrete facts. Uncertainty is an abstract concept, and this demonstrates the difficulty operationalizing the term; there are little operationalized uncertainty information to utilize in developing an uncertainty indicator in RNNP.

4.5.3.2 Presentation of the Uncertainty Indicator

The Uncertainty Indicator is not presented on a relative scale such as the DFU, Barrier and Survey Results Indicators. The Uncertainty Indicator is presented as a percentage score, which is used as a correctional factor for the individual indicators to reflect the degree of uncertainty influencing the indicator results.

After having evaluated the knowledge strength and robustness for a chosen time period i.e. assigned scores, the next step is to evaluate the overall uncertainty score for knowledge strength, K, and robustness, R respectively:

$$K = \frac{\sum_{i=1}^{N} x_i}{X}$$

Equation 17: Indicator knowledge strength score

$$R = \frac{\sum_{i=1}^{N} y_i}{Y}$$

Equation 18: Indicator robustness score

x_i is the knowledge strength score and y_i is the robustness score for indicator "I". The total number of indicators is denoted by N. X and Y are the sum of maximum knowledge strength and robustness scores which may be achieved. If K and R are high, then uncertainty is low and vice versa. The Uncertainty Indicator for each indicator can be established:

$$U_K = 1 - K$$

Equation 19: Uncertainty Indicator (knowledge strength)

$$U_R = 1 - R$$

Equation 20: Uncertainty Indicator (robustness)

$$U_{tot} = \frac{U_k + U_r}{2}$$

Equation 21: Uncertainty Indicator

This method is valid for establishing DFU uncertainty, Barrier uncertainty and Survey Results uncertainty. U_{tot} is the uncertainty level for one of the indicators, not all indicators combined.

Whereas the DFU uncertainty is established by evaluating the knowledge strength and robustness for the DFUs listed in Table 9, the barrier uncertainty is established by only evaluating knowledge strength and robustness for "barrier elements" and "maintenance" as two indicator categories. This may be considered a simple solution, and it could be argued that all barrier elements should be evaluated individually and not as one category. It is assumed that the uncertainty variables are general enough to apply for all barrier elements and that few individual differences would have been established by evaluating barriers individually. Survey results uncertainty is established by only evaluating safety climate as an indicator.

Having established U_{tot}, this value will be used as a correctional factor for the individual indicators when establishing the New Total Indicator. Consequently, the Uncertainty correctional factor will be introduced when establishing the New Total Indicator presentation.

4.6 The New Total Indicator

The New Total Indicator will consist of the contributions from the four individual indicators presented in chapters 4.2-4.5.

The design and presentation of the New Total Indicator will influence how results are interpreted, and how intuitive it is to understand the New Total Indicator. The current total indicator is based on DFU statistics, presented in FAR values normalized on certain parameters, such as installation type (ref. 2.2.1). The current total indicator benefits from its presentation because it is simple to understand the results for all interested parties. It is desirable that the New Total Indicator is easily understandable and relatively straightforward in its presentation.

4.6.1 Global Risk Indicator methodology by De Almeida (ANP)

De Almeida suggests to establish a global risk indicator by classifying risk indicators as leading or lagging (Almeida, 2013). The distinction between leading and lagging indicators lies in the indicator’s ability to change before the risk level has changed (Vinnem, 2014). Leading indicators (proactive indicators) change before the risk level has changed, whereas lagging indicators (reactive indicators) such as precursor events, reflect that there has been a change in risk level (Vinnem, 2014).

It is desirable to categorize the individual indicators according to their leading/lagging qualities. This categorization could potentially show an interesting development over time, where the leading/lagging indicator results could be compared up against each other, as suggested by De Almeida (Almeida, 2013).

4.6.2 Categorizing Leading and Lagging Indicators

Vinnem argues that DFUs obviously may be categorized as lagging indicators, reflecting that risk levels have changed by the occurrence of DFU (Vinnem, 2014). The DFU Indicator is categorized as a lagging indicator, following Vinnem’s argument.

The barriers are meant to mitigate consequences should a DFU occur, however, the barrier performance tests are leading indicators of offshore safety and thus the Barrier Indicator is categorized as a leading indicator (PSA, 2015a; Vinnem, 2014).

Kongsvik et al, argued that the safety climate can be considered both a leading and lagging indicator (Trond Kongsvik et al., 2011). It has been decided to treat the Survey Results Indicator as a leading indicator for the New Total Indicator.

The Uncertainty Indicator falls within both categories since it incorporated in the individual indicators as a correctional factor.

Table 10: Leading and lagging indicator categorization

Leading Indicators	**Lagging Indicators**
Survey Results Indicator	DFU Indicator
Barrier Indicator	
Uncertainty Indicator	

4.6.3 New Total Indicator presentation

Before the leading and lagging indicators are established, the uncertainty contribution is calculated and added to the individual indicators. Consequently, the DFU, Barrier and Survey Result Indicators are individually presented before establishing the leading and lagging indicators. The reason for this is to accentuate the relative influence of the uncertainty contribution to each indicator. The DFU Indicator, Barrier Indicator and Survey Results Indicator (SR) values (including the uncertainty correctional factor) may be established as:

$$DFU\ Indicator_{\ tot} = DFU\ Indicator + (\ DFU\ Indicator * \ \alpha_{DFU\ Indicator})$$

Equation 22: Relative DFU Indicator including uncertainty

$$Barrier\ \ Indicator_{\ tot} = Barrier\ Indicator + (\ Barrier\ Indicator * \ \alpha_{Barrier\ Indicator})$$

Equation 23: Relative Barrier Indicator including uncertainty

$$Survey\ Results\ Indicator_{\ tot}\ =\ SR\ Indicator + (SR\ Indicator * \ \alpha_{SR\ Indicator})$$

Equation 24: Relative Survey Results Indicator including uncertainty

where α is the uncertainty factor for the year in question and SR is an abbreviation for Survey Results.

Having established the individual Indicator values the next step is to establish the leading and lagging New Total Indicators. The New Total Indicator will be presented as its antecessor, by expressing the leading and lagging indicators on a relative scale. By estimating relative values and not expressing risk by the various risk measures used to express the indicators, the risk trend development is accentuated, not necessarily the actual risk level value.

$$Leading\ New\ Total\ Indicator = \frac{Barrier\ Indicator_{tot} + Survey\ Results\ Indicator_{tot}}{2}$$

Equation 25: Relative Leading New Total Indicator

$$Lagging\ New\ Total\ Indicator = DFU\ Indicator_{tot}$$

Equation 26: Relative Lagging New Total Indicator

The leading and lagging New Total Indicators are presented alongside each other in the same graph, where both graphs have a relative value equal 100 for the chosen base year. In addition to presenting the New Total Indicator as two graphs in the same figure, they may be presented individually, highlighting the relative uncertainty contribution for the leading and lagging indicators.

A discussion on the proposed methodology, its limitations and potential shortcomings are given in chapter 6.4.

5. Case: The New Total Indicator

Chapter five presents a case study which will test the New Total Indicator methodology and will establish New Total Indicator results. Following the presentation of results is a discussion and evaluation of results.

5.1 Case description

5.1.1 Case objectives

The aim of the case study is to test the new total indicator methodology by establishing New Total Indicator results based on available RNNP data.

The case study results should be analyzed to evaluate if the New Total Indicator is able to give a more holistic risk level presentation for the NCS. Furthermore, the results should be compared with existing RNNP total indicator results to determine the goodness of the developed methodology and quality of results.

To be able to evaluate the changes in risk trends, the case study will present New Total Indicator results for years 2008-2014. A six-year time frame should give an impression of how the New Total Indicator results behave over time, which will be compared with today's RNNP total indicator results for the same time frame.

5.1.2 Case delimitations

The time frame is set between years 2008 and 2014 and the total indicator will be established for fixed production installations only. The reason for these delimitations is to reduce the volume of necessary RNNP data for DFU and barrier performance. These delimitations will reduce the quality of the New Total Indicator results, but at the same time make the case study more executable.

The Barrier Indicator should be established by evaluating maintenance data and barrier performance i.e. test failure for HSE critical components. However, maintenance data are only available from 2010. In order to establish maintenance data for years 2008 and 2009, the case has to establish maintenance indicator results for 2008 and 2009 equal to the value in 2010. This is a simplified solution which is deemed satisfactory, but not optimal.

Survey results are collected biannually, consequently, the survey results from 2009, 2011 and 2013 will be used to establish the survey results indicator.

In consultation with Professor Trond Kongsvik it has been decided to establish the safety climate for a smaller group of offshore workers to reduce the volume of survey data for the SPSS analyses. It has been decided to consider the survey results from workers with the following characteristics:

1) Stationed at a fixed production installation
2) Spending 75-100% of work hours offshore
3) Work tasks including either: Process, drilling, well service, construction/modification, maintenance, crane/deck, administration
4) Regular offshore rotation
5) Stationed at same installation every rotation

As previously mentioned the excel calculations will not be given in the appendices due to confidentiality reasons. Therefore, the results presented in this chapter are the available results and calculations.

The delimitations presented in the methodology will follow the case study as well. A discussion on case limitations and their impact on the New Total Indicator results may be found in chapter 5.7.

5.2 Establishing DFU Indicator Results

The DFU indicator is established by the methodology presented in chapter 4.2, where DFU 1-12 are incorporated in the DFU indicator. The results are calculated in Excel where DFU incident frequencies are multiplied with their assigned DFU weight (including the established weights estimated for DFU 12). An updated DFU weight list (including DFU 12 weights) is given in Appendix VI.

DFU 1-11 and DFU 12 results are presented individually in PLL and FAR values. FAR values differ between DFU 12 and the other DFUs because the parameter for hours of exposure differ. For DFUs 1-11 the hours of exposure are based on the number of working hours, DFU 12 is based on the number of personnel flight hours. These cannot be added together and are presented individually as FAR values. Risk level presentation with PLL values can incorporate both contributions and give one total risk level score expressed in PLL. The values for 2008-2014 are presented in Table 11-12 and are based on the available RNNP data for this period.

Table 11: DFU Indicator results in PLL values

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU Indicator in PLL (DFU 12)	0,12	0,10	0,06	0,08	0,02	0,02	0,03
DFU Indicator in PLL (DFU 1-11)	0,22	0,68	0,31	0,06	0,02	0,01	0,14
Total DFU Indicator in PLL	0,34	0,79	0,37	0,14	0,04	0,12	0,17

Table 12: DFU Indicator in FAR values

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU Indicator, normalized FAR (DFU 12)	42	37	21	25	5	7	9
DFU Indicator, normalized FAR (DFU 1-11)	0,8	2,4	1,1	0,2	0,1	0,3	0,4

Figure 12 gives a graphic presentation of the PLL risk levels where DFU 1-11 and DFU 12 contributions are presented separately, to demonstrate the changes in risk levels by incorporating DFU 12 in the DFU Indicator.

The relative DFU Indicator is presented in Figure 13, where the results are relative to the base year results. The relative base year value for 2008 has been set at 100, equal to the current total indicator in RNNP. An evaluation of results is given in chapter 5.7.2.

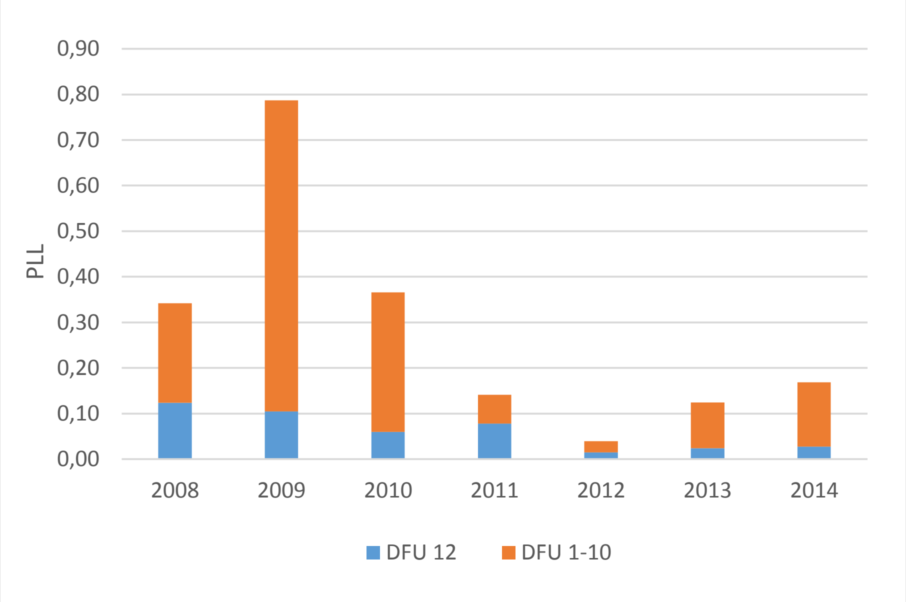


Figure 12: DFU Indicator in PLL values

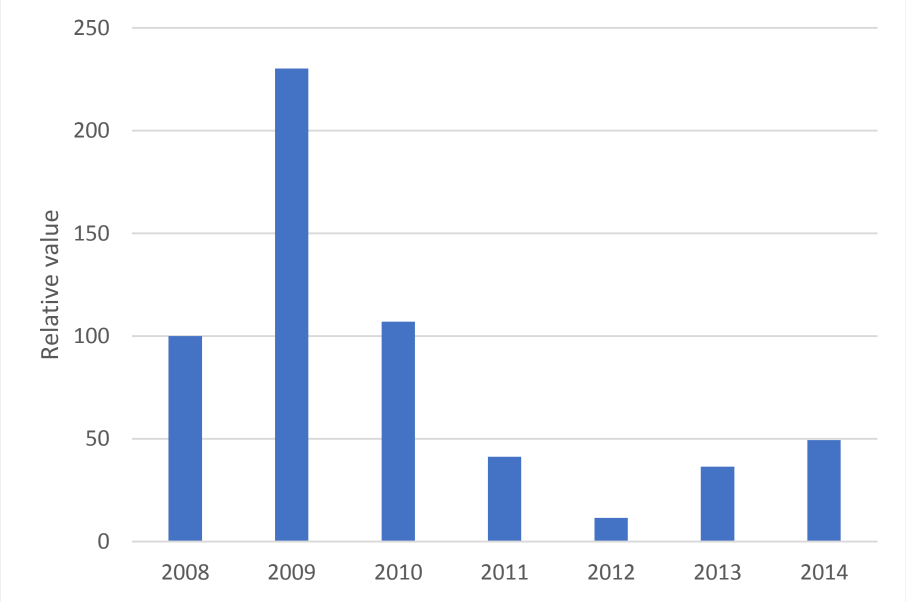


Figure 13: Relative DFU Indicator (Base year 2008)

5.3 Establishing the Barrier Indicator

5.3.1 Barrier Fault Indicator

Following the methodology presented in chapter 4.3, the barrier fault indicator is first established when establishing the Barrier Indicator.

The available RNNP barrier performance data did not have test data for barrier elements: “well integrity”, “ballast system valves” and “waterproof doors”. Consequently, it was decided that the barrier fault indicator should be established without their contributions.

Having established the total fraction of barrier faults for each barrier element for each year by Equation 7, the next step is to evaluate the barrier/DFU relations and the potential worst case scenarios by DFU occurrence and complementary DFU-relevant barrier failure. The relations given in Table 7 is used as a barrier/DFU relations guideline to calculate the worst case scenario probabilities by Equation 8. The worst case scenario barrier failures have been summarized for the year in question through Equation 8 and is now converted to a relative barrier fault indicator value by Equation 9. The relative barrier fault indicator values may be seen in Figure 14, where the base year is 2008 with a relative value set at 100.

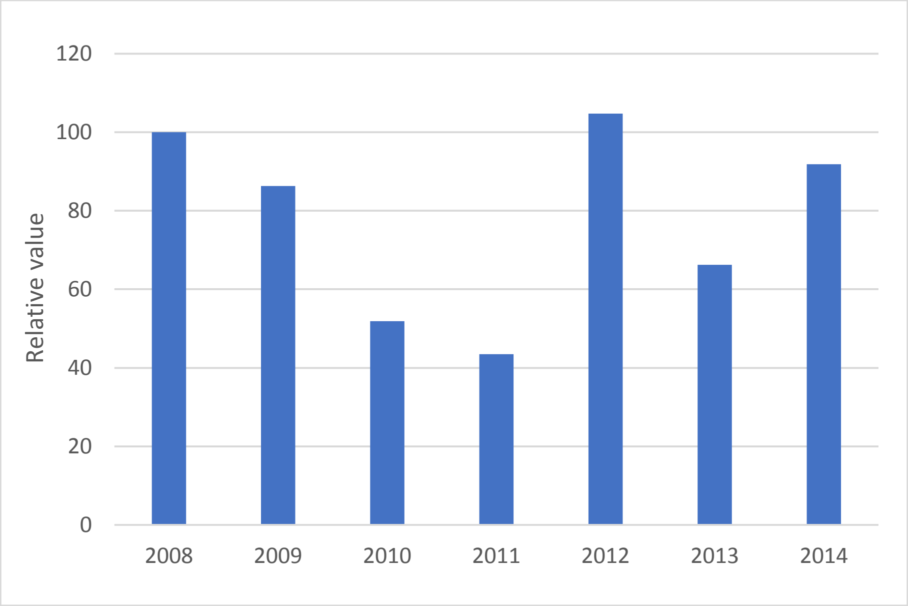


Figure 14: Relative barrier fault indicator (Base year 2008)

5.3.2 Maintenance Indicator

The maintenance indicator is established by evaluating the share of lagging HSE critical preventive and corrective maintenance up against the total hours of preventive and corrective maintenance. The total hours of maintenance have been established as the number of maintenance hours that *have* been and *should* have been (lagging) carried out on the NCS and may be estimated by Equation 10 and Equation 11.

The share of HSE lagging preventive and corrective maintenance is established through Equation 12-13. These are converted to one relative maintenance indicator value by Equation 14. Maintenance data are only available from 2010, hence the 2008 and 2009 results will be set equal to the 2010 results in order to establish a maintenance indicator for the chosen time period. This will not give the realistic maintenance indicator values between years 2008-2009. It will however serve the purpose of testing the developed methodology for the time frame 2008-2014.

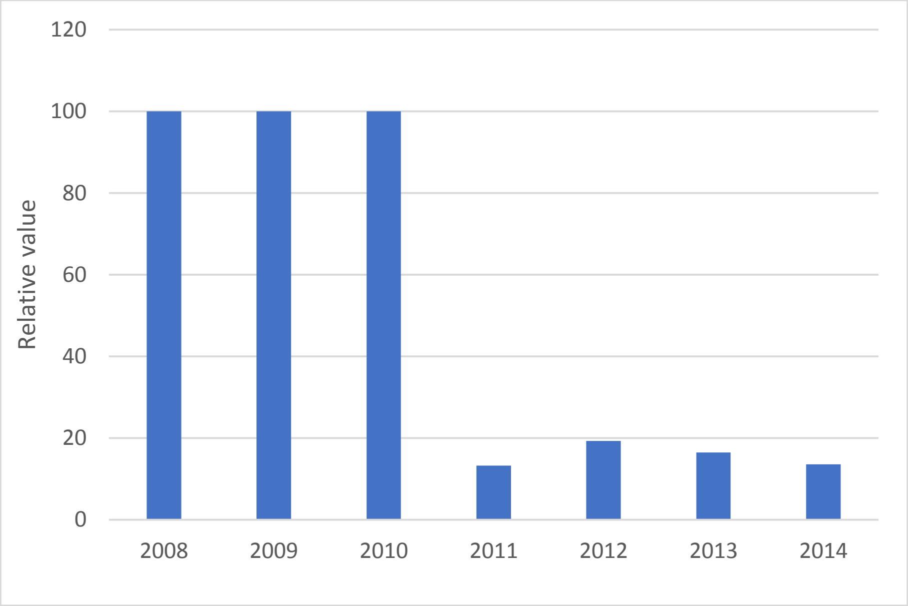


Figure 15: Relative maintenance indicator (Base year 2008)

5.3.3 Barrier Indicator results

The Barrier Indicator does not express the results in FAR or PLL values, but through a relative value, as has been done for the two indicators presented above. Year 2008 is the base year for the Barrier Indicator with a relative value set at 100 for both indicator values. Table 13 lists the relative values for the barrier faults indicator and the maintenance indicator. The resulting Barrier Indicator results for fixed production installations is given in Figure 16.

Table 13: Relative values for barrier fault and maintenance indicators

	Relative value						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Barrier Fault indicator	100	86	52	43	105	66	92
Maintenance indicator	100	100	100	13	19	16	14

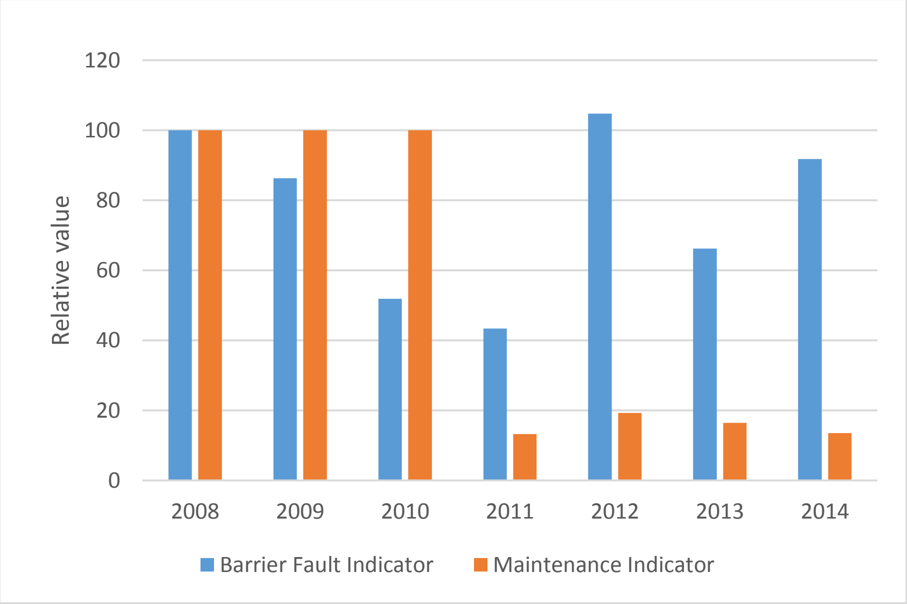


Figure 16: Relative Barrier Indicator (Base year 2008)

5.4 Establishing the Survey Results Indicator

Professor Trond Kongsvik helpfully carried out SPSS factor analyses of the survey results to help establish safety climate results for this thesis.

5.4.1 Factor Analysis results

Professor Kongsvik established two factors correlating to a selection of questions which were used to establish safety climate scores. Factor one questions were found to address the company management's commitment to safety i.e. how safety and risk is taken seriously and followed up by the company. Factor one is therefore named: "Organizational prioritization of safety" (T. Kongsvik, 2016). Likewise, the questions correlating with factor two were found to revolve around the individual's motivation and actions for increasing safety and reducing risk. Based on these observations factor two is called "Safety behavior" (T. Kongsvik, 2016).

5.4.1.1 The Factors

Table 14 depicts the questions shown to correlate with factors (components) 1 and 2 in year 2008. Kongsvik argues that the Cronbach's alpha values listed in Table 14 may be considered satisfactory (T. Kongsvik, 2016). Ideally the values should be between 0,7 - 0,9 to be considered very convincing (T. Kongsvik, 2016). Some values for factor 1 show a negative value which is caused by questions which are formulated positively, as opposed to the other questions which are negative statements. Hence the minus sign reflects how the question is formulated and is a correct value.

The standard deviation is considerably lower for the factor "organizational prioritization of safety" compared with the standard deviation for "safety behavior". Kongsvik argues that if the standard deviation exceeds 1, then the deviation may be considered significant (T. Kongsvik, 2016).

Each of the questions listed in Table 14 is answered by a 5 point Likert scale. Table 15-16 illustrate the mean Likert scale value for factors 1 and 2 respectively. For factor 1 the best mean value is one which approaches 1. For factor 2, the best mean value is one that approaches 5. The reason for this difference is related to the formulation of the questions. To establish the two safety climate indicators by comparable values, one of the factors needs to be converted in order for the graphs to move in the same direction. Factor 2 mean values are subtracted from the maximum value which gives a value following the same pattern of factor 1; the lower the value, the better the safety climate.

Table 14: SPSS Analysis' RNNP survey question components

Survey question	**Component**	
	1	**2**
I report in case I see/experience hazardous situations		,761
Safety is the first priority when doing my job		,702
I ask my colleagues to stop working when I consider the work to be carried out in a risky/hazardous manner		,729
I stop working if I consider the work dangerous for me or others to continue		,586
In practice, production is regarded more important than HSE	,739	
Accident or hazardous incident reports are often “fixed on”	,739	
Often there are parallel work operations which can lead to hazardous situations	,665	
Lack/lagging of maintenance has led to poorer safety	,712	
The necessary work equipment I need is easily available	-,510	
Input from safety representatives are taken seriously by the management	-,629	

Table 15: Safety climate scores - Factor 1

Safety Climate scores – Factor 1 “Organizational prioritization of Safety”					
Year	**N**	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
2009	2384	1,3203	,45506	1	4
2011	2567	1,2945	,44869	1	5
2013	2312	1,2745	,44762	1	5
TOTAL	7263	1,2966	,45077	1	5

Table 16: Safety climate scores - Factor 2

Safety Climate Scores – Factor 2 “Safety behavior”					
Year	**N**	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
2009	2329	3,6265	,81104	1	5
2011	2476	3,6616	,80741	1,17	5
2013	2246	3,7291	,78114	1	5
TOTAL	7051	3,6715	,80134	1	5

5.4.2 Survey Results Indicator results

The relative Survey Results Indicator is established by first using Equation 15 to determine the relative values of factor 1 and 2. Following the methodology suggestions of chapter 4.4, the years which do not have survey results will have the value of the antecedent year. Since there are no survey results for 2008 and 2010, both values are given the relative value which was established for 2009. The relative safety climate factor scores are individually presented in Figure 17.

The Survey Results Indicator is established by Equation 16 and estimates the relative score as the average value of all relative factor scores. The Survey Results Indicator results may be seen in Figure 18. The results are discussed in detail in chapter 5.7.4.

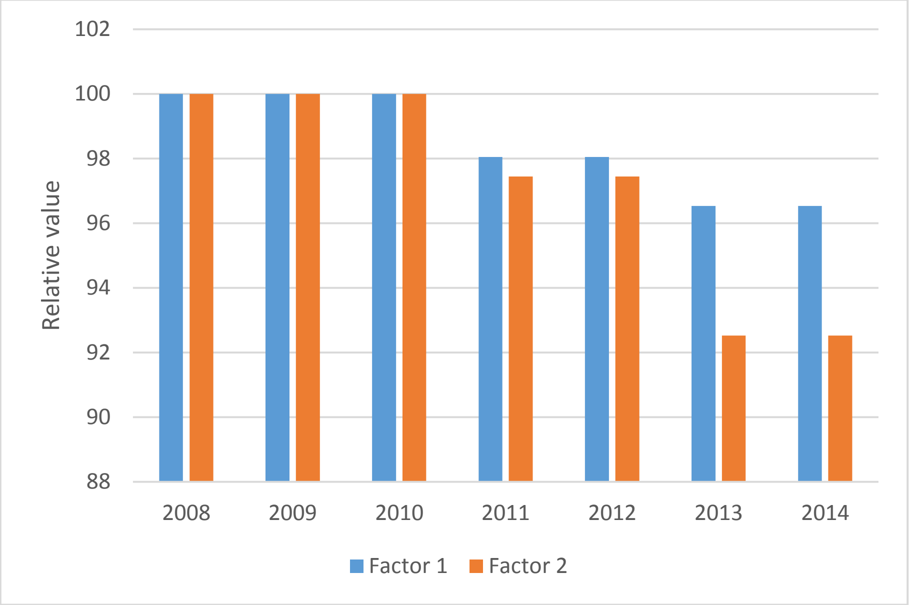


Figure 17: Relative safety climate factor values (Base year 2008)

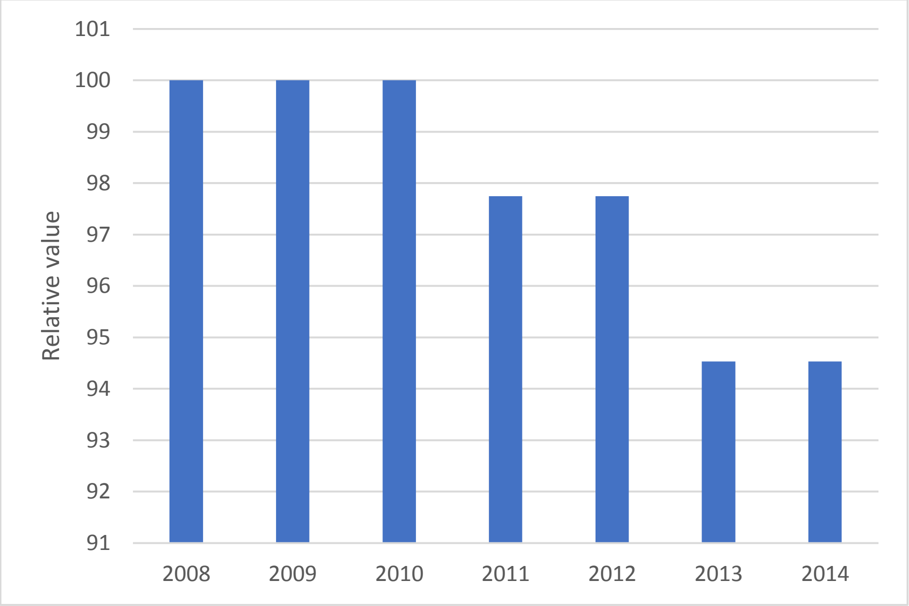


Figure 18: Relative Survey Results Indicator

5.5 Establishing the Uncertainty Indicator

The Uncertainty Indicator is established by evaluating uncertainty variables' influence on knowledge strength and robustness of indicators.

The scoring of knowledge strength and robustness is given according to the 1-5 rating system given in Appendix V. The assigned scores are based on the assumed development of the uncertainty variables and how they affect knowledge strength and robustness of indicators. As an example: Uncertainty variable 3 has increased knowledge and indicator strength for DFU 5 "ships on collision course" which have experienced a considerable drop in registered events in RNNP (PSA, 2015a). Furthermore, the assigned scores are based on general observations such as: i) Field developments in arctic areas will increasingly become a relevant uncertainty contributor to RNNP in future years ii) Younger component technology reduces uncertainty related to barrier testing and improves system safety iii) Higher survey response will reduce uncertainties related to safety climate scores, to mention some. Appendix VII lists all assigned uncertainty scores for the various indicators.

Figure 19-20 present the individual scores of knowledge strength and robustness of indicators. As stated in Table 8 a selection of uncertainty variables are considered relevant for the individual indicators, not all.

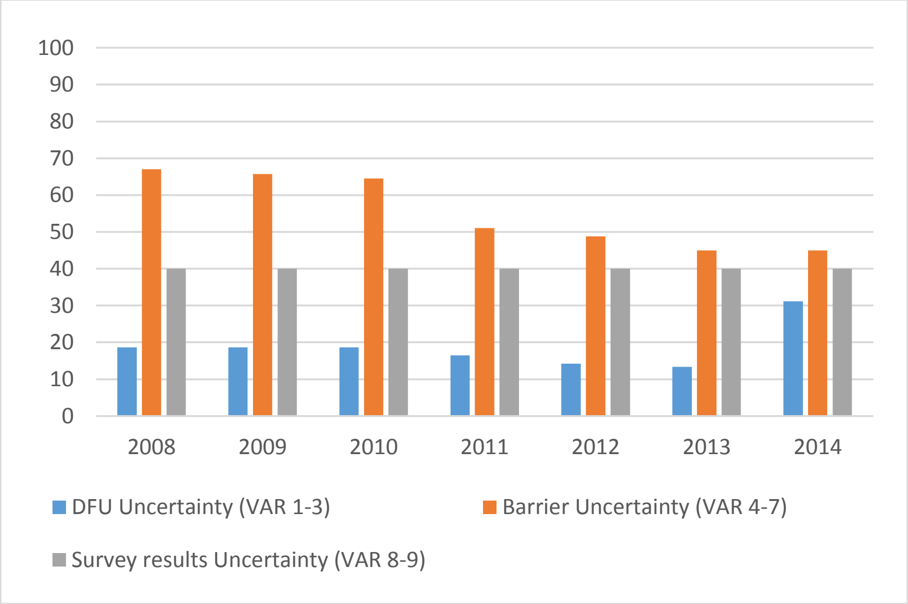


Figure 19: Knowledge strength uncertainty score (percentage) for DFU Indicator (uncertainty variable 1-3), Barrier Indicator (uncertainty variable 4-7) and Survey Results Indicator (uncertainty variable 8-9)

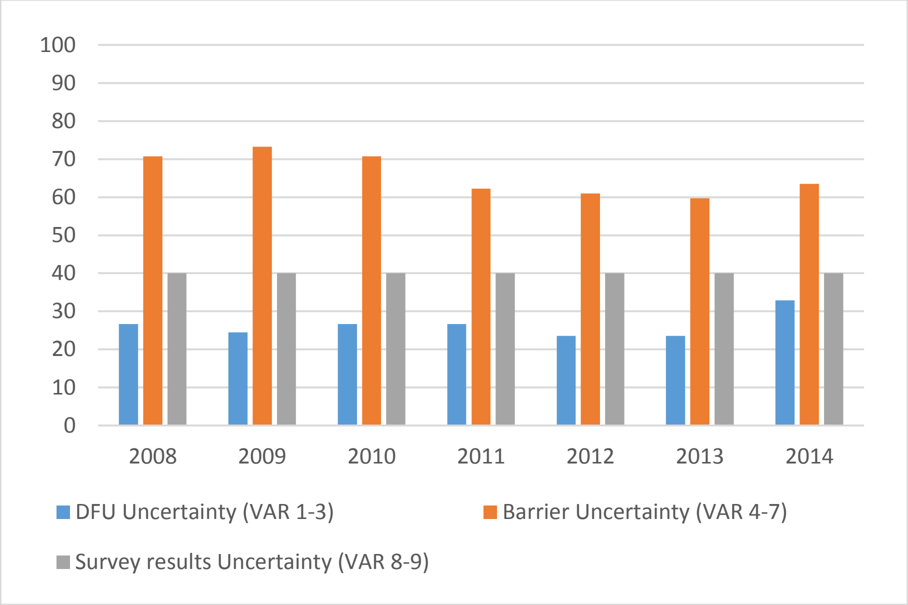


Figure 20: Robustness uncertainty score (percentage) for DFU Indicator (uncertainty variable 1-3), Barrier Indicator (uncertainty variable 4-7) and Survey Results Indicator (uncertainty variable 8-9

When establishing the U_{tot} for each of the indicators, the average value of K and R is used. The Uncertainty Indicator is presented as the individual U_{tot} values, which is the overall uncertainty score for the indicator. If the value is low, the uncertainty level is low and vice versa.

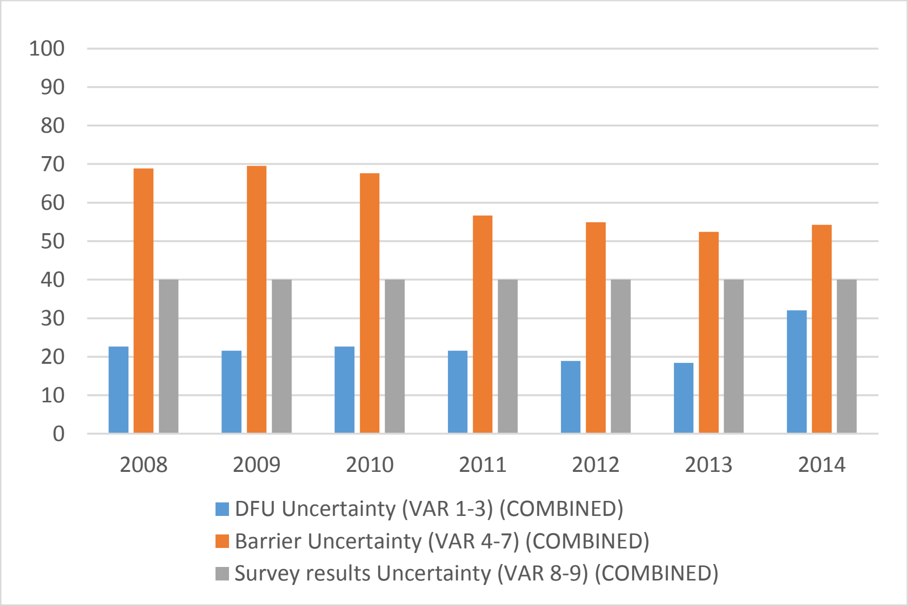


Figure 21: Uncertainty Indicator (percentage) for DFU Indicator (uncertainty variable 1-3), Barrier Indicator (uncertainty variable 4-7) and Survey Results Indicator (uncertainty variable 8-9

The uncertainty correction factor is established through the Uncertainty Indicator and incorporated in the New Total Indicator presentation. The uncertainty correction factors for the DFU, Barrier and Survey Results Indicators are given in Table 17 . These results will be used in establishing the New Total Indicator.

Table 17: Indicator uncertainty correctional factors

	Average Uncertainty Correctional factor						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU Indicator Uncertainty (α)	0,23	0,22	0,23	0,22	0,19	0,18	0,32
Barrier Indicator Uncertainty (α)	0,69	0,70	0,68	0,57	0,55	0,52	0,54
Survey Results Indicator Uncertainty (α)	0,40	0,40	0,40	0,40	0,40	0,40	0,40

5.6 Establishing the New Total Indicator

Having established the individual indicators in preceding chapters, the New Total Indicator can be established. The relative values of all indicators are used to establish the uncertainty contribution to each indicator. The Barrier Indicator contribution is established as the average value of the relative barrier fault and maintenance indicator values.

Table 18: Relative values of the individual indicators

	Relative value						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU Indicator	100	230	107	41	11	36	49
Barrier Indicator	100	93	76	28	62	41	53
Survey Results Indicator	100	100	100	98	98	95	95

Table 19: Indicator uncertainty correctional factors

	Average Uncertainty correction factor						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU Indicator Uncertainty (α)	0,23	0,22	0,23	0,22	0,19	0,18	0,32
Barrier Indicator Uncertainty (α)	0,69	0,70	0,68	0,57	0,55	0,52	0,54
Survey Results Indicator Uncertainty (α)	0,40	0,40	0,40	0,40	0,40	0,40	0,40

5.6.1 Individual Indicators Results

The uncertainty contribution for each of the individual indicators is established by multiplying the indicator uncertainty factor (α) with the indicator's relative value for the same year. Adding this value to the relative indicator value gives the DFU Indicator, Barrier Indicator and Survey Results Indicator values including their uncertainty contribution. These values are presented in Table 21 and Figure 22-24.

Table 20: Relative uncertainty contribution for the individual indicators

	Uncertainty contribution (Relative value)						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU Indicator	23	50	24	9	2	7	16
Barrier Indicator	69	65	51	16	34	22	29
Survey Results Indicator	40	40	40	39	39	38	38

Table 21: Relative DFU Indicator, Barrier Indicator and Survey Results Indicator values (Base year 2008)

	Relative value including uncertainty contribution						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU Indicator	123	280	131	50	13	43	65
Barrier Indicator	169	158	127	44	96	63	82
Survey Results Indicator	140	140	140	137	137	133	133

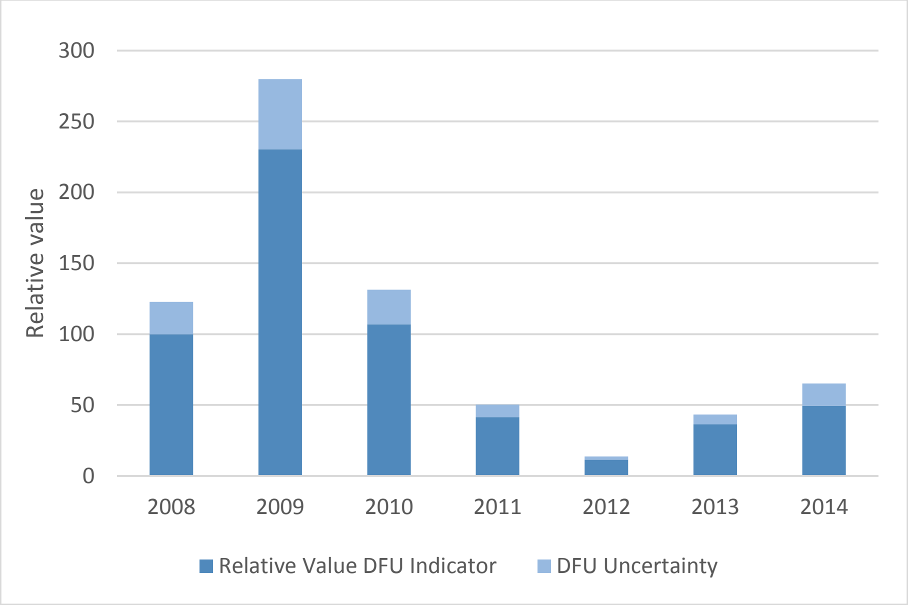


Figure 22: Relative DFU Indicator (including uncertainty)

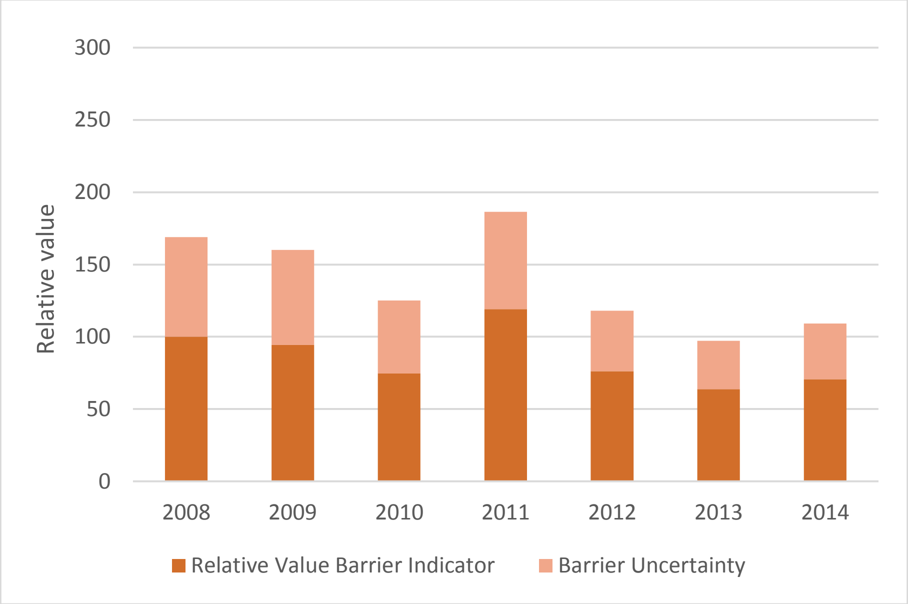


Figure 23: Relative Barrier Indicator (including uncertainty)

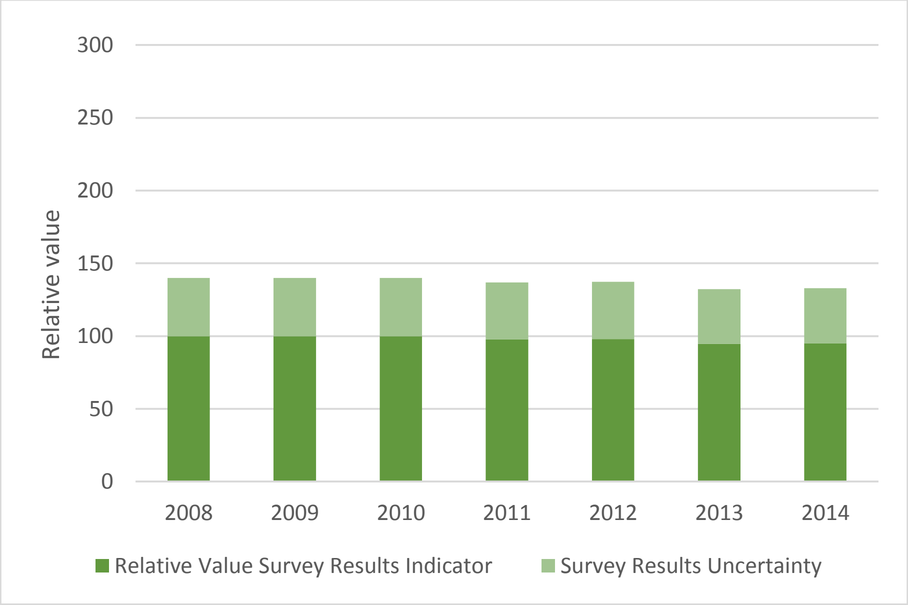


Figure 24: Relative Survey Results Indicator (including uncertainty)

5.6.2 New Total Indicator Results

The final step is to present the individual indicators as leading and lagging indicators; hence the New Total Indicator is presented as two relative indicators. The leading and lagging indicators include the relative uncertainty contributions of the individual indicators and may be seen individually in Figure 25-26, and together in Figure 27.

Table 22: Relative Leading and Lagging New Total Indicator values

	Relative value including uncertainty contribution						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Leading Indicator	123	280	131	50	13	43	65
Lagging Indicator	154	156	134	86	109	92	103

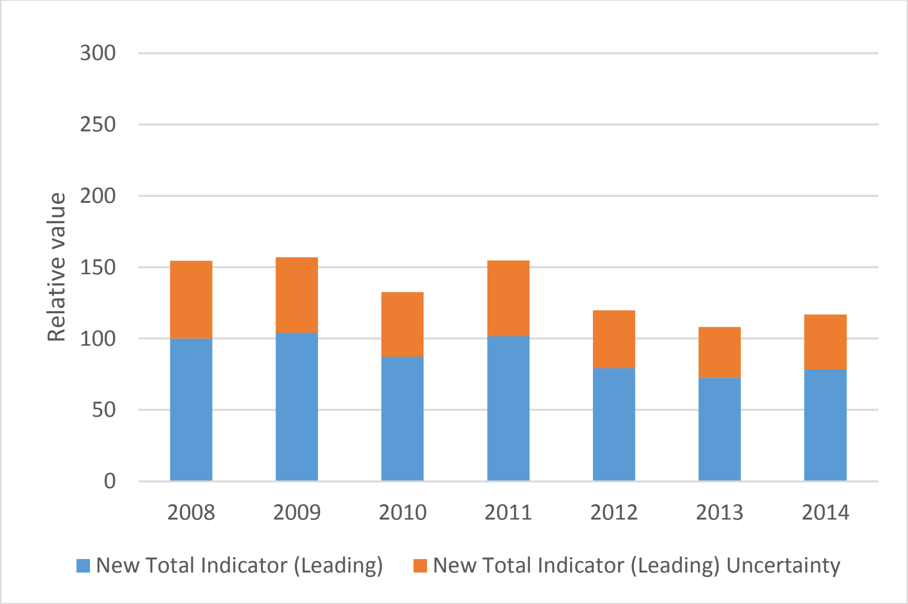


Figure 25: Leading New Total Indicator

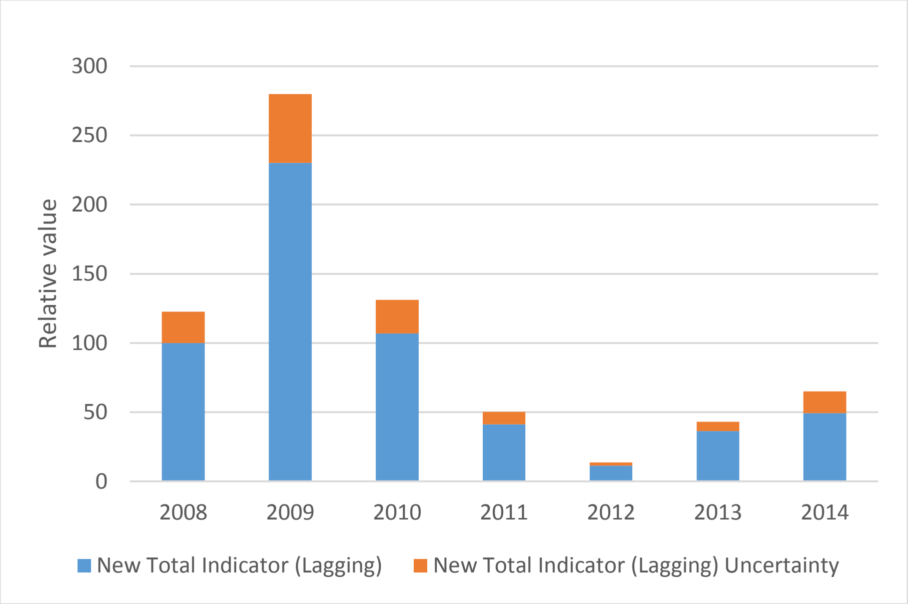


Figure 26: Lagging New Total Indicator

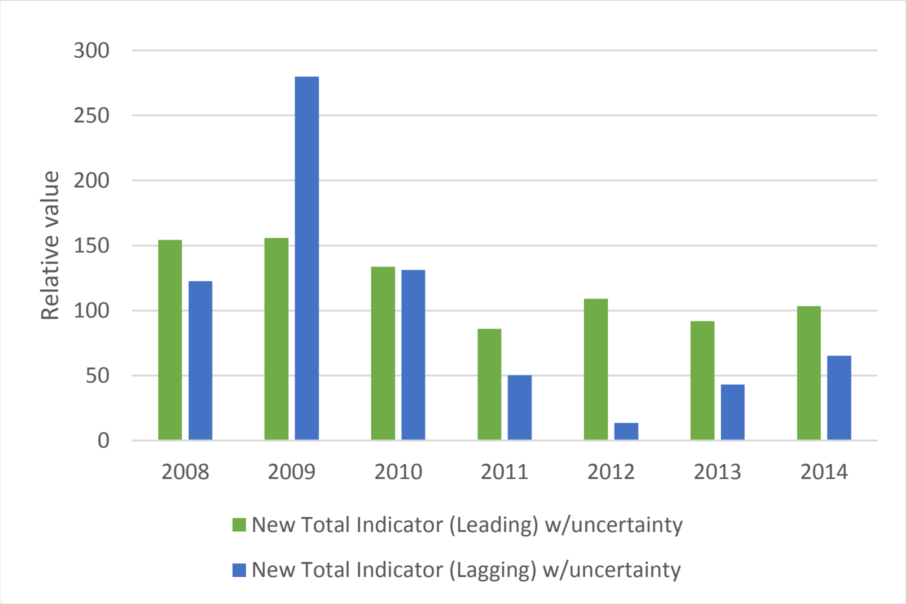


Figure 27: New Total Indicator

The results from the case study will be evaluated and discussed in the next subchapter, assessing the quality of the produced results. A complete discussion on the quality of the method and the applicability of the New Total Indicator is given in chapter 6.

5.7 Evaluation and Discussion of Case Study Results

The validity and goodness of the case study results will be discussed in this chapter.

5.7.1 Scope and Delimitations

It was chosen to look at years 2008-2014 in order to work with the most recent data over a long enough period of time to be able to establish a risk trend. This was done in consultation with supervisor Vinnem who suggested to establish results for a minimum five-year period (Vinnem, 2016).

It was decided to look at fixed production installations only, in order to reduce the amount of necessary RNNP data for establishing New Total Indicator results. The reason for choosing fixed production installations is due to the relatively stable number of installations in the chosen time period. Heide noted that the overall quality of the case results would be considerably reduced by only evaluating RNNP data for fixed production installations. DFU frequencies are low for the NCS, and by only evaluating DFU frequencies for one installation type the DFU data basis becomes considerably limited for establishing DFU Indicator results (B. Heide & Hallan, 2016). The author shares this concern and agrees that only considering fixed production installations reduces the available RNNP data basis. Ideally, all installations should have been considered in establishing New Total Indicator results.

Narrowing down a survey response group was necessary to limit the number of survey responses for the factor analysis in SPSS. Hallan argued that the survey respondent group should be revised to include workers which do not regularly work on the same installation, to evaluate a broader survey respondent group when establishing the safety climate scores (B. Heide & Hallan, 2016). In consultation with Professor Kongsvik it was ultimately decided that the chosen group was a satisfactory sample for establishing the safety climate scores, and that it would serve the intention of this case study to evaluate the survey results from this group only, despite the legitimate arguments from Hallan.

The delimitations for the case study have been introduced solely for practical reasons, but the methodology may be applied for all NCS offshore installations and for all survey results.

The chosen case limitations are considered more necessary, than beneficiary for producing results.

5.7.2 DFU Indicator Results

The presented DFU Indicator results (Figure 12-13) are considered satisfactory, displaying a risk level trend peaking in 2009, having its minimum value in 2012 before showing a negative (increase) trend in 2014. According to these results the risk level is increasing and not declining compared to the current total indicator. This is an interesting development which will be discussed in chapter 5.7.2.2.

Considering that the DFU Indictor methodology is based on already existing RNNP methodology, the results are considered reasonable and that the DFU Indicator is highly able to present DFU risk levels. The weights used in establishing the DFU indicator are extracted from the RNNP method report. Thus the validity of the presented results is interdependent of the quality of the assigned weights, DFU statistics and their accuracy.

The limited incident frequencies affect the risk level estimation, where single events are still able to influence the results considerably.

5.7.2.1 DFU 12 contribution

The DFU Indicator results are relatively strongly influenced by the contribution of DFU 12. This is however a confirming sign, considering that helicopter risk is estimated to (roughly) represent 30% of all personnel risk in offshore activity (Vinnem, 2014). The DFU 12 contribution to the DFU Indicator's total value is given in Table 24.

Table 23: DFU 12 Contribution to the DFU Indicator

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
DFU 12 Contribution	36%	13%	16%	55%	38%	19%	17%

Even though the individual years show great variations in DFU 12 risk contributions, the mean value for DFU 12 contribution is 28% between years 2008-2014. This value is very close to the estimate for overall helicopter transport risk exposure proposed by Vinnem. However, to say that these numbers confirm the assumptions made in the DFU 12 weight estimation would be too bold and an inadequate argument. These results can, if not validate the DFU 12 weight assumptions, confirm that the DFU 12 weights are realistic enough to be deemed satisfactory.

Despite numerous assumptions in establishing the DFU 12 weights and composing the DFU Indicator the results may be summarized as satisfactory, easy to understand and interpret.

Based on these results it is believed that the DFU Indicator contribution to the New Total Indicator will be based on sensible results and that the DFU Indicator results are highly acceptable.

5.7.2.2 Comparing DFU Indicator and Total Indicator results

The DFU Indicator results (Figure 12-13) can be compared with the current RNNP total indicator results given in Figure 28. Both indicators are built on the same methodology, excluding the DFU 12 contribution which has been incorporated in the new DFU Indicator.

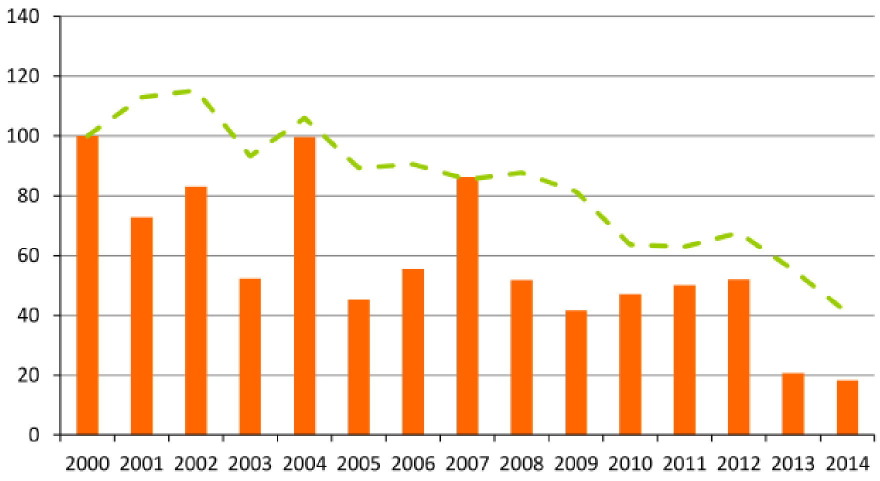


Figure 28: RNNP total indicator results, normalized on production installations, relative value, Base year 2000

The total indicator results in RNNP are presented for production installations, which in addition to fixed production installations, include normally unmanned installations and production complexes. The DFU frequencies and weights behind the results presented in Figure 28 will differ compared to the DFU frequencies used in establishing the DFU Indicator. The results show different trends because their data basis are different and due to the added DFU12 contribution. Furthermore, for better comparison of the indicator results the base year should have been the same for the DFU Indicator and the total indicator.

5.7.3 Barrier Indicator Results

The quality of the Barrier Indicator results is influenced by limitations in available RNNP data:

1) The lack of barrier performance data for “well integrity”, “ballast system valves” and “watertight doors” for the barrier fault indicator
2) Lack of maintenance data for 2008 and 2009 for the maintenance indicator

The contribution of well integrity, ballast system valves and watertight doors is not negligible when establishing the barrier fault indicator (ref. Table 7), consequently the quality of barrier fault indicator results is reduced. Additionally, as mentioned in chapter 6.4.3.1 there are several data uncertainties which are not accounted for when establishing the total fraction of barrier faults through Equation 7. The risk level trends depicted in Figure 14 are worth discussing regardless of these shortcomings. The barrier fault indicator presents the worst case scenario for DFUs which experiences complete barrier failure. The resulting trends from the available RNNP data demonstrate the same trend as the DFU Indicator; an increase in relative value between 2013 and 2014. The trend in Figure 29 illustrates that barrier performance has shown a positive trend up to the latter years, where there has been a regression and risk levels have shown a negative (increase) development. It is difficult to evaluate the overall quality of barrier fault indicator results, since there are no barrier performance indicator results (excluding year 2008) which the results can be compared with. Consequently, it is difficult to evaluate if the results are even close to reflect the real barrier performance risk contribution.

For the maintenance indicator the relative value between 2008-2010 are equal, this is because no maintenance data is available for years 2008 and 2009 and the values have been set equal to the 2010 value. Evaluating the gap between 2010 results and the 2011-2014 results, it can be questioned if the 2010 maintenance data are reliable enough for this year to be the base year for the maintenance indicator. Increased focus from the operators on maintenance data after 2011 enhances the reported data quality (J.E.Vinnem, 2016). Consequently, the base year should be set at 2011, where maintenance data are more consistent and have a higher quality.

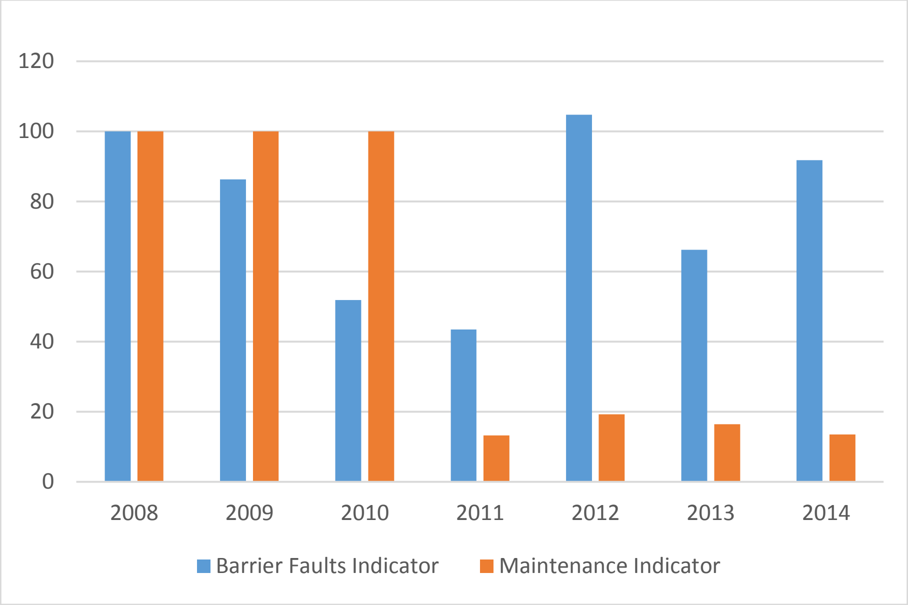


Figure 29: Barrier Indicator Results (Base year 2008)

The Barrier Indicator results have obvious shortcomings; where the most prominent is the maintenance indicator which should have had 2011 as the chosen base year. The barrier fault indicator is deemed satisfactory despite the data shortage, which ultimately affects indicator quality for all years. It is believed that the Barrier Indicator will give better results with the added uncertainty contribution, as this will reflect uncertainty issues in the data quality.

5.7.4 Survey Results Indicator Results

The relative safety climate scores between 2009-2013 show a positive (decreasing) trend in safety climate scores. These results are positive as a decline in relative values represent higher safety climate scores. The relative difference for this time period is small, showing little variance between years. The results indicate that the safety climate is relatively consistent i.e. the overall perceived risk levels do not make rapid changes, but rather changes over a longer period of time. The reason for this lies in the nature of the safety climate, it is a slow moving process to develop and shape a good safety culture within companies.

What is interesting to see from the results is that the "organizational prioritization of safety" is perceived as relatively stable whereas "safety behavior" of employees experiences more variation. Considering the present market situation in the offshore industry, these are interesting results to potentially evaluate further. It would rather be assumed that the factors focusing on the organization, rather than the individual, would experience the most variation and not vice versa. As an example the author would have thought that the organizational pressure to perform might be in conflict with the individual's interest to uphold safety. However, if the organization double communicates to its employees to increase productivity and effectivity, and at the same times focuses on safety, a possible theory could be that the employees have to interpret which company focus has the main priority and act accordingly. Numerous hypothesis could be established on this topic. At the same time these differences could be relatively random and be caused by survey question formulation etc.

5.7.4.1 Comparison of Survey Results Indicator and the Total Indicator

The Survey Indicator Results show little variation in relative values for the chosen time period. As total indicator statistics have shown a decrease the latter years, the safety climate scores have been improving steadily between 2009-2013. The safety climate results could appear to be interdependent with safety performance results and could potentially substantiate the results presented by Kongsvik et al. (Trond Kongsvik et al., 2011).

5.7.4.2 Survey Results for 2015

Survey results have been established for years 2009, 2011 and 2013 for this case study. It was intriguing to potentially look at safety climate scores for 2015 to investigate if the abrupt market and industry changes has had an effect on the perceived safety levels. Professor Kongsvik helpfully established a factor analysis for 2015 in addition to the results from 2009, 2011 and 2013, following the same criteria as for the antecedent years, except that "catering" was an included work area, which was not included in the earlier safety climate scores. The following results were calculated:

Table 24: Safety climate factor scores for 2015 survey results

	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Safety Behavior	2821	1,00	5,00	1,2892	,44886
Organizational prioritization of Safety	2689	1,00	5,00	3,6719	,88400
Valid N (listwise)	2668				

Based on the results in Table 25 the relative Survey Results Indicator could be established and compared up against the results for 2009, 2011 and 2013.

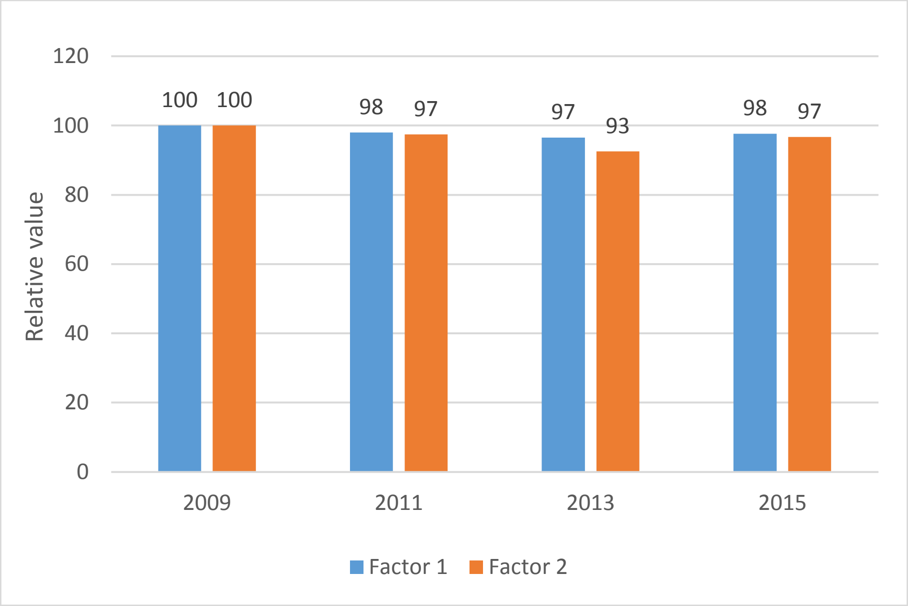


Figure 30: Relative Survey Results Indicator 2009-2015 (Base year 2009)

The trend for 2015 is negative, showing an increase in Survey Results Indicator values. Compared with the 2009-2013 results Kongsvik argued that "*It looks as though the positive trend has turned, and that results are back at 2011 levels*" (T. Kongsvik, 2016) .

Even though the 2015 results are not included in the New Total Indicator case study, they are perhaps the most intriguing results of all safety climate scores between 2008 and 2015. The negative turn in safety climate scores, along with the increased incident statistics for 2015 (NRK, 2016)could demonstrate a potential relation between current total indicator results and safety performance results. This illustrates the potential this indicator might have in establishing risk levels, and it clearly highlights the relevancy of organizational indicators in assessing major accident risk.

5.7.5 Uncertainty Indicator Results

Based on the results depicted in Figure 21 the Uncertainty Indicator results are considered high for the Barrier Indicator in particular. The results are moderate for the Survey Results Indicator and moderate/low for the DFU Indicator. These results illustrate that the Uncertainty Indicator is able to reflect where the uncertainty is the greatest, and substantiates the proposed methodology. Furthermore, the Barrier Indicator results are reduced up to 2014, whereas the DFU Indicator has an increased value in 2014 compared with the base year results. This is consistent with the development of the DFU uncertainty variables which increase uncertainty in the later years, whereas the barrier uncertainty variables are considered to be reduced due to the higher degree of self-testing etc.

The results are based on the assigned uncertainty scores, which have been established based on the author's perception of how the uncertainty variables have behaved since 2008. The results need to be analyzed with this in mind.

The quality of the uncertainty indicator results will be further discussed in subsequent chapters when establishing the uncertainty contribution to the individual factors.

5.7.6 New Total Indicator Results

5.7.6.1 Individual Indicators including Uncertainty Contributions

Establishing reliable uncertainty contribution values to the individual indicators is highly dependent on the goodness of the Uncertainty Indicator scores (ref. chapter 5.7.5). Presenting the individual indicator results with the added uncertainty contribution gives a good indicator of the quality of the indicator results. High levels of uncertainty immediately imply that the knowledge strength and robustness behind indicators is low and vice versa.

When evaluating the results listed in Table 26, there are considerable differences between the barrier fault indicator and maintenance indicator results. Hence the validity of the Barrier Indicator's contribution to the New Total Indicator can be questioned.

Table 25: Relative values for the barrier fault indicator and maintenance indicator

	Relative value						
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Barrier Fault indicator	100	86	52	43	105	66	92
Maintenance indicator	100	100	100	13	19	16	14

Figure 22-24 depicts the relative uncertainty contribution as an added value. However; the relative uncertainty contribution could have been subtracted from, and not added, to the existing indicator value. This means that the relative value could have been portrayed on both sides of the indicator value and not only added on top which has been done in Figure 22-24.

5.7.6.2 New Total Leading and Lagging Indicators including Uncertainty contributions

The New Total Indicator presents the leading and lagging indicators as two individual columns on a relative scale (ref. Figure 27). These results do not accentuate the size of the uncertainty contribution to the leading and lagging indicators, but present the uncertainty contribution as an incorporated part of the indicator values. This is the intention; uncertainty is meant to be an incorporated part of the New Total Indicator results. Figure 31 and Figure 32 show that the uncertainty contributions (overall) are higher for the leading indicator. Considering the uncertainties present in barrier performance and survey results data, these results seem realistic.

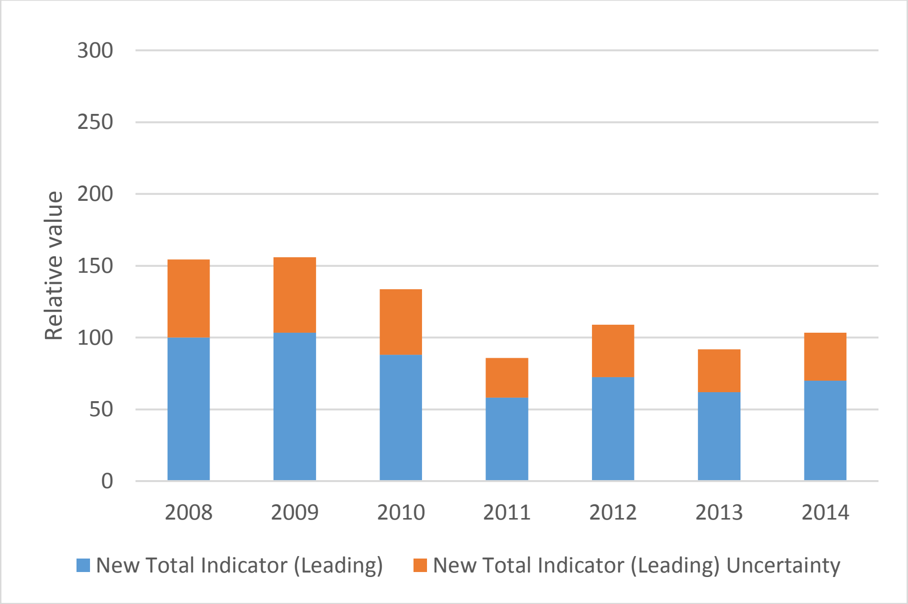


Figure 31: New Total Leading Indicator results (Base year 2008) including uncertainty

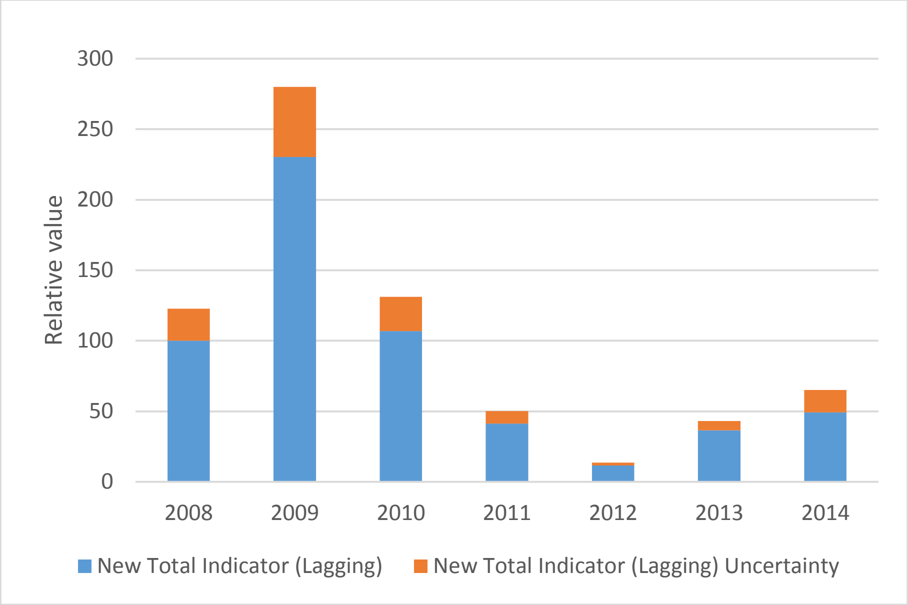


Figure 32: New Total Lagging Indicator results (Base year 2008) including uncertainty

The case study results are considered reasonable despite the limitations in data and shortcomings in the developed methodology. If the New Total Indicator results are able to reflect the real risk level trends is however a question of concern. Assuming that the chosen assumptions and delimitations are satisfactory, then the case study has been able to test the methodology and produce realistic results.

The New Total Indicator trend shows that risk levels were reduced up until year 2012. After 2012 the risk levels show a negative trend where the risk levels increase. This is in contrast to the results presented by the PSA for 2008-2014. The New Total Indicator and current total indicator demonstrate opposite trends in this time period. PSA claims that risk levels are at a record low value in 2014. This is in sharp contrast to New Total Indicator results for 2014 where both leading and lagging indicators show a considerable increase in relative values.

The most valid risk level results are considered to be the DFU Indicator and the Survey Results Indicator. The Barrier Indicator results are difficult to evaluate because little information may be extracted from RNNP on the state of the *overall development* of NCS barrier performance (excluding for year 2008). The Uncertainty Indicator results appear reasonable, considering that they are able to reflect where the uncertainty is the highest, which is for the leading indicator.

Overall the total indicator results are difficult to compare up against the New Total Indicator because of their different designs and structures.

6. Discussion

This chapter discusses the applicability of the New Total Indicator, based on the substance of results and the quality of the methodology.

6.1 The further development of RNNP

The current RNNP methodology has been able to present risk levels in a satisfying manner for the last fifteen years, but there are areas of improvement for the Project (Dammen & Ekle, 2015; B. Heide & Lootz, 2015; Knardahl, 2015).

The reduced levels in incident reports demonstrate that the HSE efforts have had a positive effect on offshore safety and is most definitely a positive sign. However, if the current methodology is dependent on a certain input amount to have valid results, this could be a point of concern (Vinnem, 2015). A potential suggestion could be to lower the reporting criteria for DFUs. Considering that the offshore industry is perceived as “safer than ever” there might be controversies within the industry to report more incidents when the incident rates have actually been dramatically reduced. In a struggling market, it is not considered recommendable to lower the reporting criteria in order to increase the level of incoming data, if it is unknown if it will give the desired effect on the QRA data basis. With the current market situation in mind, this thesis has not proposed to lower the reporting criteria to increase the level of incoming reports. The thesis has rather focused on finding an objective which focuses on method development in order to make risk level estimations less DFU data volume dependent.

6.2 The chosen objective

There was an active screening process to establish the objective of this thesis. The first suggested objective was to establish arctic DFUs reflecting the offshore risk challenges in the Barents Sea. The screening process detected other areas of improvement and Vinnem suggested that the total indicator, potentially comprising a selection of indicators, could be a suitable topic for further development (Vinnem, 2016).

The current total indicator could (in the same manner as single DFUs) be described as sensitive to the volume of incoming data, where single events have great impact on total indicator results. This is confirmed by the PSA who points out that *«for the last two years the total indicator has been further reduced. Single events with substantial risk potential can introduce greater* *variations"* (PSA, 2015c). Such variations become evident in the frequency statistics for each DFU, as described by Heide (Bjørnar Heide, 2009), and may additionally show statistical significance for the normalized presentation of the risk level (PSA, 2015a).

The chosen objective of developing the total indicator is one of potentially several approaches which could have been done to develop RNNP further. The objective addresses a relevant issue in today's RNNP and could contribute positively in the further development of the Project.

6.3 The revision in risk definition

When establishing the objectives of this thesis it was quickly concluded that the changes in risk definition should be reflected in developing the total indicator. To discuss uncertainty's role in the new risk definition is beyond the scope of this thesis, but it is a controversial area in the relevant scientific literature (Aven & Krohn, 2014; Rausand, 2011; Vinnem, 2016). Regardless of how uncertainty is interpreted; changes in the fundamental guidelines should be reflected in PSA's biggest risk level project since the risk definition is the main foundation for understanding risk. Uncertainty should be a constructive tool in RNNP risk assessment and not become a term whose relevance could be questioned.

For the objective of this thesis it has been decided to focus on the uncertainty parameters which have already been established in RNNP; strength of knowledge and robustness of indicators. The more intricate uncertainty concept of "Black Swans" has not been elaborated in this thesis. The "Black Swan" logic is an intriguing concept, but is considered too difficult to operationalize. This has been the shared perception in conversation with Heide and Vinnem (B. Heide & Hallan, 2016; Vinnem, 2015).

Strength of knowledge and robustness of indicators reflect the most evident RNNP indicator uncertainty issues. However, PSA does not explore the possibility for other uncertainty parameters to be established in RNNP. Additional uncertainty indicators could potentially alter the design of the Uncertainty Indicator in the New Total Indicator, but have not been investigated further in this thesis.

Operationalizing uncertainty is one of the biggest challenges of this thesis because little information is available in RNNP, and the abstract term is considered difficult to convert into quantifiable measures. It should be noted that operationalization of uncertainty is still a novel and controversial topic. For this thesis it ultimately become important to give uncertainty visibility despite its controversy.

6.4 Method development and Method Quality

The concept of the New Total Indicator is to reflect a broader risk picture through a traditional, and at the same time innovative New Total Indicator presentation. The New Total Indicator concept has been revised and developed multiple times during this thesis, and the main challenge has been to establish how the chosen indicators, with different indicator values, should be incorporated into one New Total Indicator. Choosing the individual indicators was a simpler task than establishing the New Total Indicator presentation.

Vinnem et al. argues that often there exists a misconception that a set of indicators can objectively portray the true levels of risk, and that by establishing the right set of indicators, the "true risk" can be estimated (Vinnem et al., 2006). The proposed New Indicator concept will not be able to give a completely true image of risk levels. However, by establishing indicators representing a broader offshore risk picture, the risk level estimation could improve.

6.4.1 The chosen Indicators

The choice of individual indicators resulted from evaluating RNNP and its current methodology, where the following issues were detected:

1) The current total indicator is considered too sensitive to the low volume of incident reports (Vinnem, 2010).
2) Developing leading indicators would enable RNNP to reflect organizational factors in assessing major accident risk.
3) The overall use, value and quality of reported barrier data in RNNP could be questioned.
4) The survey results are not utilized to their full potential (B. Heide & Lootz, 2015; Knardahl, 2015).
5) Uncertainty is currently not a systematically incorporated part of RNNP (Abrahamsen et al., 2015).

It could be argued that the four indicators could be expressed in other ways than by a New Total Indicator, and likewise a New Total indicator could consist of contributions from other indicators.

To establish a new total indicator by the chosen four indicators are believed to reflect the original concept of RNNP; that of method triangulation. Several disciplines and methods were involved in establishing these indicators, as they include both qualitative and quantitative risk assessment tools. Furthermore, they widen the risk picture considerably by including the safety climate and uncertainty, two parameters which previously have not been systematically included in major accident risk level estimations. Furthermore, the chosen indicators give better RNNP data utilization than the current total indicator.

6.4.2 The DFU Indicator

The DFU Indicator is established by utilizing current RNNP total indicator methodology. It could be argued that this is a simple solution, and that the DFU Indicator should be more innovative, not leaning on today's practices. However, the total indicator methodology is considered a reasonable approach, bringing continuity and a certain quality approval to the DFU Indicator methodology.

The developed DFU Indicator is considered less controversial when it comes to methodology quality than other indicators developed in this thesis. However, the DFU Indicator is not optimized to be more size independent of the number of incoming incident reports in RNNP. The reason for this is that the thesis has focused on developing the four individual indicators rather than evaluating how the risk level can be estimated in a different way than by its current method. This thesis argues that the lower levels of incident reports is one of the main reasons why RNNP needs to be developed further. It can be argued that by using current RNNP methodology in developing the DFU Indicator undermines this initial argument, and that the DFU Indicator is not really addressing the issue described in previous chapters. The author recognizes this as an area of improvement and currently a shortcoming in the DFU Indicator.

Despite the DFU Indicator not being designed to reflect the lower levels of incident reports, the New Total Indicator relies on three additional indicator contributions. The New Total Indicator is based on a greater span of data than just incident statistics, hence it is overall less dependent on the number of reported DFU incidents than the current total indicator.

6.4.2.1 Incorporating DFU 12 in the DFU indicator

In light of the tragic helicopter accident at Turøy April 29th this year, the offshore industry, regulators and society are reminded that helicopter transport is a risk factor which needs to be addressed in governing and monitoring risk on the NCS. The fatal accident happened the day after the RNNP 2015 results were presented by the PSA, where helicopter safety was highlighted by Safety Forum as one of the indicators showing the best development (NRK, 2016).

As RNNP is designed today, the total indicator will not reflect the fatalities caused by this tragic accident nor will it impact the total indicator. This is an obvious shortcoming in RNNP risk level presentation today, and could become an issue for the 2016 risk level presentation. It may potentially be difficult for the public and industry to understand why such a major accident is not a part of overall offshore risk level estimations.

Heide argues that there have been two reasons for not incorporating DFU 12 in the total indicator in RNNP:

1. Helicopter transport safety is under Civil Aviation Authority jurisdiction and responsibility domain, not PSA's.
2. DFU 12 weights have not been established.

(B. Heide & Hallan, 2016)

It became the ambition for this thesis to incorporate DFU 12 in the New Total Indicator at an early stage. Vinnem argues that helicopter transport risk is a considerable personnel risk contributor and estimates that the average offshore employee is exposed to three main categories of fatality risk; occupational, major accidents and helicopter transportation, as listed in Table 26 (Vinnem, 2014):

Table 26: Main personnel risk contributors in the offshore industry (Vinnem, 2014)

Fatality risk category	**Production installations**	**Mobile drilling and accommodation units**
Occupational accidents	27%	29%
Major accidents on installations	31%	43%
Helicopter transport accidents	42%	28%

The DFU Indicator incorporates DFU 12 in a sensible manner and more importantly; recognizes DFU 12 as considerable risk contributor. The weight assumptions could have been chosen differently, but in consultation with Vinnem the proposed weighting were deemed reasonable, addressing barrier failure severity and the number of remaining barriers (Vinnem, 2016).

The DFU Indicator is considered an independent methodology alternative, which could replace the current total indicator.

6.4.3 The Barrier Indicator

It has been argued that previous attempts to establish a barrier indicator did not communicate the desired message clearly (Stensland, 2013). Dammen additionally comments that Safetec has made various attempts in establishing an overall barrier performance indicator, but found difficulties in establishing such an indicator (Dammen & Ekle, 2015). Heide notes that the barrier performance data are successful in creating industry awareness on barrier performance, but that the data itself may be difficult to utilize in establishing a barrier indicator, considering the lack of knowledge behind the incoming data (B. Heide & Hallan, 2016).

It could be argued that to perform a sensitivity analysis (ref. (Bjørnar Heide, 2009)) would help eliminate the data showing the greatest deviating values. A sensitivity analysis could be a great tool to reduce uncertainties and establish a more consistent data basis for the Barrier Indicator. It has however been decided not to perform a sensitivity analysis and rather focus on such uncertainties in the Uncertainty Indicator.

The proposed method for the Barrier Indicator may be considered a simple solution to a rather complex task, as it will not address the uncertainties related to the barrier performance data e.g. number of tests, differences in installation specifications, differences in test execution etc. which will impact the results considerably. However, it is believed that the best way to establish the Barrier Indicator is to base its results on actual reported barrier performance data, even though there are considerable quality issues regarding these data. Before commenting on the design and development of the Barrier Indicator a discussion on the overall barrier performance data quality is necessary.

6.4.3.1 Barrier Performance Data Quality

The uncertainty associated with the barrier performance data could be considered a weakness in the portrayal of barrier goodness on the NCS (B. Heide & Lootz, 2015). RNNP states that the barrier indicators' results show great differences between installations on the NCS (PSA, 2015a). The PSA highlights the following factors as contributors to the variation of barrier performance results:

1. Differences in test intervals (between installations and operations)
2. Differences in the number of installations the operators hold responsibility for

3. Different number of tests

(PSA, 2015a)

Stensland agrees that not knowing the different test intervals is the most critical factor for variation in barrier performance (Stensland, 2013). Indeed, these are important issues for evaluating barrier data quality, but it merely touches the surface of the range of issues concerning these data. Stensland points out several data weaknesses which are not taken into account in RNNP:

a) The reported data does not differentiate between components of tested barrier functions (e.g heat or smoke detectors).
b) Does not differentiate between component manufacturers (e.g different component characteristics).
c) Does not take into account component age.
d) Does not take into account component location.
e) Reports are made on barrier elements and not necessarily barrier systems. This implies that redundancy is not covered in the reported data.
f) The test procedures are not specified.

(Stensland, 2013)

In addition to Stensland's findings, Trond Kongsvik comments that the industry and operators have considerable influence when it comes to the interpretation of barrier performance terms, e.g. "lagging maintenance" (T. Kongsvik, 2016). When the freedom exists to interpret terms and concepts individually by companies, the scale and outcome of barrier performance results may differ. The barrier performance data are so multifarious in quality that their utilization potential can be questioned. Kilskar & Øien points out that there are differences between operators and installations in reporting culture, reporting criteria and other factors which can affect the indicator value (Kilskar & Øien, 2015). These issues will have an effect on the New Total Indicator values.

Terje Dammen angles the barrier data quality issue from another perspective: *"Perhaps the operators which show the worst results actually are "best in class" when it comes to reporting quality and accuracy"* (Dammen & Ekle, 2015). The RNNP main report notes that there are significant differences between operators in barrier performance results (PSA, 2015a), but the perspective by Dammen remains unreflected in the barrier performance analyses in RNNP.

The question arises if the number of barrier faults can be interpreted correctly when the above mentioned factors remain unknown. In addition to the issues listed by Stensland, Dammen and Kongsvik, the author has detected additional issues which are not addressed, nor reflected, in the RNNP presentation of barrier performance data.

1) Component maintenance strategies
2) Installation specifications (age, size, design etc.)

A simple example illustrates the first issue; Installation 1 has a maintenance strategy stating that only 30% of the components on board should have preventive maintenance, whereas 70% of the equipment undergoes only corrective maintenance (perhaps somewhat improbable, but it serves to demonstrate the point). Installation 2 has the reversed maintenance strategy of installation 1 with 70% of the equipment undergoing preventive maintenance and 30% of the equipment has a corrective maintenance strategy. If the two installations are considered to be identical and have the same number of components with equal equipment characteristics and the same parameters for maintenance operations (system down time, equipment ordering and logistics etc.), then installation 1 will experience a higher lag in hours of preventive maintenance than installation 2. Likewise, installation 1 will experience fewer lagging hours of corrective maintenance than installation 2. If both installations were to report their total lagging hours of preventive and corrective maintenance, they would contribute differently to the maintenance data. This example highlights issue number 1; maintenance data should be seen in relation to the chosen maintenance strategies for the installation in question in order to assess the level of lagging maintenance. The second issue relates to the installation specifications. Installations differ in design, complexity, size, age etc. Such factors influence the barrier performance data regarding the number of tests, the number of HSE critical components etc.

The weaknesses in barrier data quality certainly influences the quality of the results presented in this report. If barrier performance is to have an influence on risk level estimations, it is vital to reduce the uncertainties presented above. It is clear that to sort out all issues presented by Stensland, Kongsvik, Dammen and the author herself is a complex and near impossible task. Despite this, uncertainty needs to be reduced in order to be able to utilize these data constructively.

Regardless of the implementation potential of the New Total Indicator, it is advised that the issues mentioned above are addressed and that barrier performance data uncertainty is reduced.

6.4.3.2 Barrier Fault Indicator

Barrier Weights

The barrier weights were assigned according to the barrier element positioning in the bow tie diagram. The positioning of barrier elements was based on the assumed criticality of barriers, and were established based on the barrier knowledge of the author. The suggested barrier positioning is deemed a sensible suggestion, but it could be argued that the barrier positioning could have looked different.

The assigned barrier weights are assumed values, and will not demonstrate the PLL value by barrier failure correctly. Vinnem encouraged to assign large weights for the barrier elements to reflect barrier collapse criticality (Vinnem, 2016). Hence, the barrier failure weights are relatively large PLL values, especially for the barriers situated further right in the bow tie diagram (ref. Figure 10). The assigned barrier weights have been seen in relation to the DFU weights, which reduces the uncertainty of values somewhat.

Considering that barrier weights are constant for each year, they will have little impact on the *changes* in relative value of the barrier fault indicator. The barrier fault indicator results will differ due to the differences in in average barrier failure rate, Y_{is}, for the year and barrier element in question, and not due to the assigned barrier weights (ref. Equation 9).

Barrier and DFU relations

In consultation with Vinnem the barrier and DFU relations depicted in Figure 11 were considered satisfactory, where DFU 2, 3 and 4 are the DFUs which have the highest number of barrier relations (Vinnem, 2016). This appears reasonable considering the major accident potential these DFUs are considered to have.

The barrier and DFU relations are expressed as related or not related. It could be argued that the *degree* of relation should be expressed, rather than the chosen approach. For instance: It could be argued that watertight doors' primary function is to ensure sufficient damage stability. Could this barrier additionally be used to contain fire in specific areas and be a barrier for DFUs regarding fire in addition to structural integrity? Vinnem concluded that this might not be relevant enough to categorize it as a barrier and DFU relation (Vinnem, 2016). This illustrates that barriers could be categorized according to their primary and secondary barrier functions for establishing DFU relations. Other solutions could have been developed in establishing barrier and DFU relations and that the suggested approach is one of many possibilities for establishing the barrier fault indicator

When establishing the barrier fault indicator, the proposed method only addresses the risk introduced by *complete* barrier chain collapse in DFU/barrier relations. The method does not express the risk level caused by a lesser number of barrier failures. Such scenarios will impact the offshore risk level, and it could be argued that to only consider the worst case scenario i.e. complete barrier chain collapse is a strong simplification when establishing the barrier fault indicator.

The group categorization alternative

Vinnem argued that it would be beneficial to evaluate barrier and DFU relations according to DFU groups than by individual DFUs (Vinnem, 2016).A framework was developed but later discarded, as it did not give reasonable results when performing the case study.

The DFU group method categorized the DFUs according to accident type.

1) Hydrocarbon leak – Process areas (DFU 1, 2)
2) Other hydrocarbon emissions, other fires (DFU 3, 4, 9, 10)
3) Structural integrity of maritime structures and systems (DFU 5, 6, 7, 8)
4) Evacuation (DFU 11)

The DFU categories 1) - 3) are extracted from the DFU presentation in today's RNNP (PSA, 2015a). "Evacuation" was suggested as the fourth DFU incident category since this DFU was not included in any of the other categories, but had barrier DFU relations as listed in Table 7. Figure 11 illustrated the *individual* barrier/DFU relations, whereas Figure 33 illustrates the barrier/DFU relations for the established DFU *groups*.

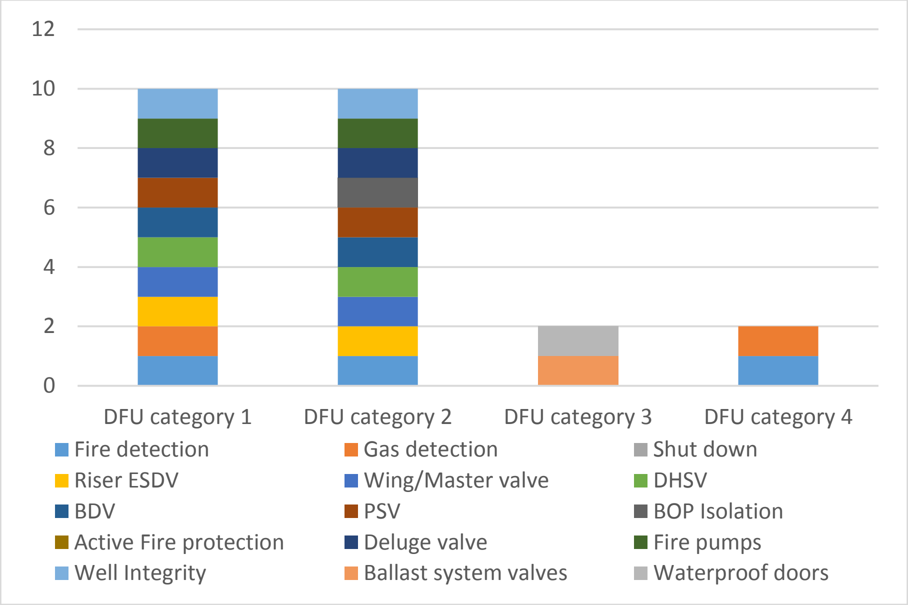


Figure 33: Barrier/DFU Group relations

For this method, the barrier fault indicator was established by the same equations presented in chapter 4.3.1.2. The poor results were ultimately the reason for not continuing with this method. In principle this method was deemed a better methodology for establishing the barrier fault indicator, than the one presented in chapter 4.3. The reason for this was because the model reduced the number of “double counts” for the barrier elements which were related to several DFUs (Vinnem, 2016).

It is recommendable for further work to investigate if the group categorization of DFU and barrier relations could give better results, and perhaps substitute the proposed methodology. This would reduce the number of “counts” for each barrier element in establishing the barrier fault indicator.

6.4.3.3 Maintenance Indicator

At an earlier stage it was suggested to consider the overall lagging maintenance (including HSE critical equipment maintenance) in establishing the maintenance indicator. Vinnem noted that hours of maintenance work such as painting etc. will not represent major accident risk and suggested to mainly focus on the lagging HSE critical maintenance (Vinnem, 2016). Lagging maintenance for HSE critical components was therefore chosen as the basis for the proposed methodology.

The maintenance indicator is based on the hours of lagging maintenance and not by the number of HSE critical tagged equipment, which is also a part of the RNNP maintenance data. The lag in maintenance hours were emphasized, as they are assumed to be a greater risk contributor than the number and labelling of HSE critical equipment. It is a deliberate choice to exclude other maintenance data, as it would add to the complexity of the maintenance indicator. Further work could potentially revise if the maintenance indicator should consist of more than lagging maintenance data in reflecting major accident risk levels.

Instead of focusing on the relative change in HSE lagging maintenance up against the lagging hours of maintenance it was chosen to compare the HSE lagging maintenance up against the total hours of maintenance. As was described in chapter 4.3.2, this was done to focus on the relative share of HSE critical lagging maintenance of the total hours of maintenance which *had* and *should* be invested on the NCS. The suggested approach could have been done differently, but it is considered a sensible approach to evaluate the share of HSE critical lagging maintenance up against the *total* maintenance hours, since the total number of hours might differ between years.

One of the greatest shortcomings of the maintenance indicator is that it does not differentiate preventive and corrective maintenance (PM/CM) in a sufficiently satisfactory manner. It was concluded that the maintenance indicator was the average value of the relative lagging PM and CM values. This does not portray the risk image adequately, as lagging PM and CM will introduce different risks to the system. The maintenance indicator could be revised to better differentiate the risk contributions by lagging PM and CM. The solution is considered satisfactory but could be improved.

6.4.3.4 Barrier Indicator presentation

The initial idea for the Barrier Indicator was that the barrier fault indicator and the maintenance indicator should be presented as one relative Barrier Indicator. Vinnem argued that the Barrier Indicator would perhaps benefit from presenting the two indicators individually, giving a better display of results and rather compose one relative contribution in the completion of the New Total Indicator (Vinnem, 2016).

The proposed Barrier Indicator has its flaws and limitations, but the overall barrier performance development should be expressed in RNNP to establish overall barrier performance trends. The Barrier Indicator should give a satisfactory barrier performance risk level presentation, but further work could be invested in parts of the methodology to enhance the method quality.

The Barrier Indicator has been the hardest indicator to establish.

6.4.4 Survey Results Indicator

It is believed to be one of the greatest assets of the developed New Total Indicator methodology that it incorporates different disciplines and methods in establishing the New Total Indicator. This should also be in line with the vision of RNNP; method triangulation to ensure that risk levels are established by evaluating a broad risk picture.

By establishing the safety climate as a major accident risk indicator, organizational issues are better reflected in the presented major accident risk level trends. It could be disputed if the safety climate in fact is a major accident risk indicator since it is not used as a major accident indicator in today's RNNP. Based on the research by Kongsvik et al. it is considered a good indicator which can potentially correlate with safety performance results (Trond Kongsvik et al., 2011). In this sense the safety climate indicator is a leading indicator; reflecting risk level trends which have the ability to change before the risk level changes.

The safety climate reflects the perceived risk amongst employees, but how to measure it may be disputed:

"Perceived risk is multifaceted and involves interaction between humans, organisations, framework conditions, culture, and work practices. How the individual employee "takes" it and "feels" it in relation to perceived risk is therefore multifaceted and involves much more than a number on a scale for perceived risk"

(Bye & Lamvik, 2007; SINTEF, 2010).

In this thesis the survey is used to establish safety climate scores through a FA, but the results should be analyzed with some care and not be interpreted as an absolute measure of the perceived risk, such as commented by Bye and Lamvik. Additionally, the number and sample of respondents is a limiting factor which will affect the quality of results.

In years where no survey results (even-numbered years) are available, the Survey Results Indicator value is set equal to the previous year (odd-numbered year). This is the best suggestion based on the current data availability. However, for even-numbered years the average value of the odd-numbered years before and after may be estimated as the Survey Results Indicator results for the even-numbered year in question. This solution could be reasonable as the safety climate is expected to change slowly and show relatively stable trends.

Through the factor analysis several factors may be found. As was demonstrated in the case study, two factors were established. In the RNNP report from 2014 five safety climate factors were presented: 1) Safety priority 2) Safety management 3) HMS vs. Production 4) Mastering 5) Competence (PSA, 2014b). RNNP establishes the safety climate but does not review the results up against major accident risk directly. The methodology for the Survey Results indicator is considered applicable regardless of the number of factors which are established from the FA, as long as the factors are consistent on a yearly basis.

The motivation for establishing organizational indicators, which are only derived from the survey, is to reduce the complexity of the Survey Results Indicator. To only look at survey results is a simplified solution which will have an impact on the overall quality of the organizational indicator. However, to establish an indicator which consists of the contributions of all relevant organizational indicators would be a master's thesis in its own. The data basis in RNNP is of such considerable scale, that the decision to only proceed with safety climate as an organizational indicator is done in order to simplify the process. Organizational indicators cannot be reduced to safety climate only, but simplification is necessary.

Other results may be extracted from the survey results in addition to the safety climate. As an example: The survey respondent is asked to rate the level of fear/worry the worker feels toward specific DFUs on a five point scale (PSA, 2014b). This could be a potential area of further development, to incorporate an indicator reflecting these views in the Survey Results Indicator.

The relative Survey Results Indicator results are expected to express little variation, considering that the safety climate develops slowly over time. An additional hypothesis is the safety climate values will have the ability to reflect safety performance results and potentially substantiate the findings by Kongsvik et al. (Trond Kongsvik et al., 2011). Meaning that a negative (increase) trend in DFU Indicator values will be reflected in a negative (increase) trend in safety climate scores.

6.4.5 The Uncertainty Indicator

The Uncertainty Indicator methodology evaluates how uncertainty variables affect knowledge strength and robustness of indicators on a five-point scale. The Uncertainty Indicator attempts to operationalize a relatively abstract term. Some of the most evident shortcomings of the proposed method are:

1) Other uncertainty variables could have been identified

2) Some uncertainty variables are general for all indicators but are only evaluated for one
3) Guidelines for rating knowledge strength and robustness could be clearer
4) Another rating system could potentially be developed
5) Categorization of DFU/uncertainty variable relations could give other outcomes
6) Uncertainty factors which are static could be developed, evaluated and incorporated in the Uncertainty Indicator

To increase the quality of the Uncertainty Indicator these issues should be addressed. Particularly should the rating system be developed in order to give correct scores, based on the uncertainty variable development. The Uncertainty Indicator is very dependent on the assigned scores, which affects the uncertainty correctional factor introduced in the New Total Indicator.

The initial idea of presenting the Uncertainty Indicator as an individual relative indicator was early abandoned. It simply made more sense to use the uncertainty score as a correctional factor for each indicator, displaying where the risk levels *potentially* lie for each indicator.

It could be argued that several of the uncertainty variables may be relevant for more than one of the DFU, Barrier and Survey Results Indicators, and that the variables should not be limited to one indicator category. It has however been decided to categorize the variables, to make the task of establishing the Uncertainty indicator easier.

To rate uncertainty variables by the parameters knowledge strength and robustness for each indicator is the proposed methodology of this thesis. It can be argued that the uncertainty variables could have been utilized differently to assess the level of uncertainty.

6.4.6 The New Total Indicator

In the beginning of this thesis, the intention was to establish an overall total indicator which presented risk levels by a classical column chart, as is normal in today’s RNNP. The columns for each year would consist of four contributions, which were meant to reflect a broader risk image on the NCS; addressing organizational factors as well as incident statistics and barrier performance, highlighting uncertainty and its role in risk assessment. However, in conversation with Roger Flage the opportunity was discussed to use uncertainty as a parameter for weighting the three other indicators in establishing the New Total Indicator (Flage, 2016). This was an intriguing idea, because uncertainty would be incorporated in a systematic way and the New Total Indicator results would be based on the uncertainty weighting of each indicator. The problem was how to estimate sensible risk levels based on uncertainty weighting. Should for instance the barrier indicator uncertainty (which is considered much higher than DFU indicator uncertainty) define the barrier performance contribution to the New Total Indicator? Uncertainty would potentially be given greater importance than the actual RNNP data by such a model, and was discarded.

The main difficulty in composing the New Total Indicator was to decide how to express an overall indicator which consist of four very different contributions. Roger Flage argued that the total indicator should be expressed by a real value, e.g. FAR/PLL, in order to express the risk level in an applicable and understandable way (Flage, 2016). Vinnem argued that this was not necessarily an issue of concern, and noted that the New Total Indicator could potentially be expressed as the current total indicator by a relative scale (Vinnem, 2016).

6.4.6.1 Leading and lagging indicator categorization

The leading/lagging indicator presentation is considered a good solution for the New Total Indicator, as the results are simplistic in their presentation and should be relatively easy to understand for the interested parties. The proposed solution is considered the best for the developed methodology.

The classification of indicators as leading or lagging was decided by evaluating the indicator’s ability to change before or after risk levels had changed (ref. chapter 4.6). The categorization of the indicators is considered reasonable, but the Survey Results indicator could potentially be classified as both a leading and lagging indicator in accordance with the findings from Kongsvik et al. (Trond Kongsvik et al., 2011).

6.4.6.2 Leading and Lagging Indicator contributions

The leading indicator has been established by relatively simple mathematic solutions. The Barrier Indicator is established as the average barrier fault and maintenance indicator value, assuming that both contributions should be equally weighted in establishing the relative Barrier Indicator. These assumptions are a potential shortcoming in the proposed methodology. It could for instance be argued that barrier failure is more critical than lagging maintenance and should be given a greater “weight” in establishing the relative Barrier Indicator value. Likewise, the Survey Results Indicator is based on the average factor mean value, not reflecting the number of factors established by the FA, assuming that all factors are equally relevant in establishing the Survey Results Indicator. The leading indicator value for the New Total Indicator is also established as an average value, the average value of the Barrier and Survey Result Indicators. The same concern is shared for the leading indicator as for the Barrier Indicator and Survey

Results Indicator mentioned above. Implicitly this method states that barrier performance and safety climate are equal major accident risk contributors on the NCS. The legitimacy of such an assumption can and should be questioned.

The leading indicator has considerable quality issues since it is the average value of the Survey Results Indicator and the Barrier Indicator. It could be argued that by investing time and efforts into developing the four individual indicators that they should be presented individually, and that the leading/lagging presentation is not the best solution for the New Total Indicator. It is however interesting to establish the New Total Indicator as leading and lagging indicators to potentially evaluate over time if the leading indicator changes before the lagging indicator changes (Vinnem, 2014). To investigate and confirm this is beyond the scope of this thesis, but it is a relevant suggestion for further work.

The lagging indicator is based on the DFU Indicator only and does not face the same problems as the leading indicator.

6.4.6.3 Shortcomings

Current RNNP total indicator results investigate if the changes in results are statistically significant in order to comment on the development in risk trends. The developed New Total Indicator does not reflect if the changes in risk trends are statistically significant, as this has not been an incorporated part of the New Total Indicator methodology. Given that the New Total indicator is relatively complex with different contributing factors it was chosen not to incorporate methods which could prove statistical significance or not.

Considering all the elements involved in establishing the New Total Indicator, it can be somewhat difficult to get an intuitive understanding of what lies behind the relative risk level of the New Total Indicator results. An alternative could have been to establish a table, listing all the indicator results from the four individual indicators. By doing this, a list of *reference risk levels* could be presented alongside the total indicator, illustrating what the relative value actually represents. This has not been done for the case study, but it could be an alternative to meet the concerns by Flage; that the New Total Indicator should to be expressed by understandable measures (Flage, 2016).

6.5 Quality and Applicability of the New Total Indicator

Having scrutinized the quality of the methodology and the case study results, the next step is to evaluate the applicability and quality of the New Total Indicator.

6.5.1 Is developing a New Total Indicator the best solution?

This question was raised by B. Heide during a meeting in April 2016. Heide suggested that it could be useful to question if a total indicator is the best way to present the offshore risk levels in RNNP (B. Heide & Hallan, 2016). Heide commented that the individual indicators might be more explanatory than an overall indicator, in order to assess where the risk truly lies (B. Heide & Hallan, 2016). In addition to this it was pointed out by Flage that a new total indicator might be difficult to establish and interpret, and questioned if the objective of this thesis was solvable, considering the many indicator values involved (Flage, 2016).

Based on the conversations with Flage and Heide it could appear more reasonable to focus on individual indicators and an overall DFU total indicator, as is the practice today. This method enables PSA and industry to detect where improvements need to be made and locate where the greatest risk is. However, the trends in offshore risk for 2015 shows an overall negative (increase) trend, even though little statistical significance can be shown in the individual indicator values. Anne Næss Myrvold, the director of PSA, commented during the 2015 RNNP results presentation that it was *"the breadth of all results"* which show that the offshore risk levels are moving in the wrong direction (NRK, 2016). This could be a strong signal that it is the overall risk development which is perhaps the most interesting to assess, and is in contrast to the individual indicator solution mentioned by Heide.

The simple answer to Heide's question is that there is no conclusion on whether or not a combined total indicator is the best solution for presenting offshore risk levels. De Almeida argues that establishing a global risk indicator is a reasonable approach for offshore risk assessment (Almeida, 2013). Furthermore, Vinnem argues that a total indicator is a good tool to establish the overall trends in DFU statistics (Vinnem, 2010). In contrast to the findings by De Almeida and Vinnem, Heide argues a valid point by highlighting the individual indicators' ability to illustrate where the points of concern are. A total indicator does not have the same ability to highlight where efforts need to be introduced, especially if the total indicator is complex, as the New Total Indicator. It could be argued that the discussion on individual vs.

total indicators is not an either/or issue for RNNP. RNNP could use individual indicators and total indicators without them interfering with each other and their messages.

It is believed that RNNP could benefit from a risk level presentation which consists of both individual indicators and total indicators reflecting the overall trends. Individual indicators can be great for establishing where there is room for improvement, but an overall Total Indicator is believed to provide the PSA, industry and public an easy and intuitive understanding of how the overall risk picture currently is headed in the offshore industry.

The New Total Indicator does not have the ability to identify specific areas of improvement, but rather display the changes in trends, and potentially be used to evaluate the leading and lagging indicator trends up against each other. It is believed that developing the New Total Indicator will provide a holistic presentation of the overall risk levels. Overall risk levels are interesting for demonstrating the development of risk trends over time, which the PSA argues are the most interesting results to analyze from RNNP (PSA, 2015a).

This thesis explores the possibility of expressing risk by one total indicator, but will not attempt to conclude that one indicator or several is the better solution for RNNP. This is an important point of discussion for RNNP in the future. The proposed methodology in this thesis might not be the best answer for RNNP in its current presentation, but it definitely adds to the debate on how the future RNNP should look.

6.5.2 Does RNNP need a Substitute for the Total Indicator?

The total indicator in RNNP today should be able to reflect all classified major accident risk DFUs in establishing annual risk levels. With helicopter incidents (DFU 12) not being incorporated in the total indicator, the total indicator is considered unable to present the overall major accident risk levels adequately. DFU 12 is extensively presented in RNNP, but it is not incorporated in the major accident risk levels (PSA, 2015a). The current total indicator should be revised to include DFU 12, but this does not necessarily mean that the methodology itself needs to be revised.

The total indicator is a good tool to reflect the incident frequencies on the NCS and their potential consequences. However, the total indicator is based on a fraction of the available RNNP data and major accident indicators (DFU 12, DFU frequencies and barrier performance data). Establishing *how* to incorporate other major accident indicators into the total indicator is perhaps a greater challenge than agreeing that it would be sensible to do so.

As long as RNNP finds it satisfactory to portray the major accident risk levels based on DFU statistics, the current total indicator is not considered in dire need of a substitute.

Husebø argued earlier this year: *"RNNP observes risk level changes, but does not answer why these changes occur"* (NRK, 2016). If RNNP in the future wishes to be able to explain why DFUs occur, then the total indicator will have to be revised. But as mentioned in the previous chapter, individual indicators are a strong tool for reflecting risk trends, and the total indicator might not be the only solution for presenting the risk development.

The total indicator is not in need of replacement per se, but if RNNP wants to continue to develop and represent a broader risk image, then it should be considered an option to revise or potentially replace the current total indicator.

6.5.3 Does the New Total Indicator reflect a broader Risk Picture?

This was one of the questions which should be answered based on the case study results. The simple answer is yes; the New Total Indicator is able to assess major accident risk levels by indicators which reflect a broader risk image than the current total indicator. When evaluating the New Total Indicator through the bow tie diagram, the leading and lagging indicators cover both ends of the diagram, as can be seen in Figure 34. Furthermore, the Uncertainty indicator is incorporated in both leading and lagging indicators by the individual uncertainty correctional factors. The current total indicator is based on incident statistics and does not reflect barrier performance, uncertainty or survey results.

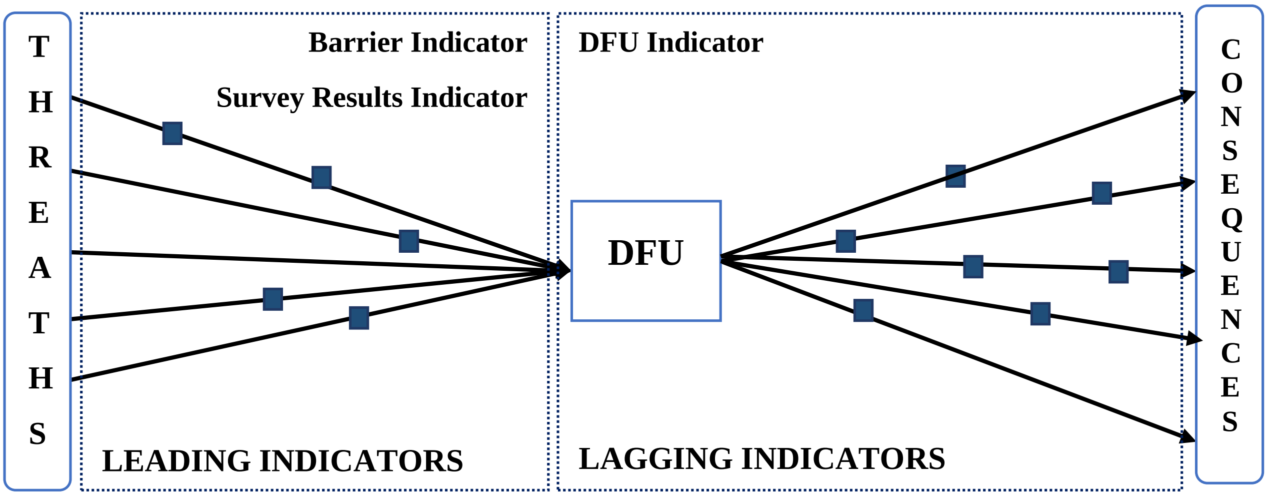


Figure 34: New Total Indicator bow tie representation

Not only do the individual indicators represent a broader risk image, they reflect the method triangulation principle. For instance: One of the greatest contributions the New Total Indicator is that of the Survey Results Indicator. It addresses the perceived risk levels of the workers, and reflects the method triangulation principle and qualitative risk assessment in a greater way than the original total indicator. Safety climate scores resulting from the surveys are not used in assessing major accident risk levels in today's RNNP. Considering the offshore industry today as an example: Employees that are unsure of their job prospects can be assumed more prone to working overtime, late shifts, taking operational "short cuts" and in general take greater OHS risks. The Survey Results Indicator can help express such changes and be a leading major accident indicator.

6.5.4 Is the New Total Indicator a real Alternative for RNNP?

The prosed New Total Indicator methodology is based on numerous assumptions ultimately influencing the quality of results and the applicability of the method. Assuming that all assumptions were reasonable and the case study results are valid, then the New Total Indicator could be a relevant proposal for RNNP risk level presentation. Further development of the methodology would however be necessary. To establish the overall trend in DFU, barrier, survey results and uncertainty levels is considered a relevant option for risk level presentation and should not necessary conflict with the individual indicator presentation as it is today.

If a correlation were to exist between the leading and lagging indicators of the New Total Indicator, then RNNP could potentially be able to answer *why* the risk levels change in addition to observing *how* the risk levels change. The New Total Indicator would then be a highly relevant proposal for RNNP risk level presentation since it would be able to broaden the RNNP perspective.

It is considered beneficial to have a total indicator in RNNP, displaying the breadth of results. The New Total Indicator is able to do this with several methods, involving several disciplines. It is a progressive step for the total indicator to incorporate organizational indicators to reflect major accident risk on the NCS. Regardless of the quality of the developed indicator in this thesis, the possibility should be explored to systematically incorporate and reflect organizational factors in assessing major accident risk levels in RNNP.

The conclusion to this discussion is that the New Total Indicator is too novel for embodiment in RNNP at the current stage. Assuming that all assumptions were accurate and that all necessary data was available and so forth, there would still be considerable quality issues especially regarding the Barrier Indicator. The New Total Indicator is a future alternative if it undergoes more development. For the time being the New Total Indicator is rather a contribution to the discussion on future risk level presentation in RNNP and the use of total vs. individual indicators.

6.5.5 Recommendations

Even though the New Total Indicator is not recommended for implementation in its current state, there are elements from the proposed methodology and the case study which are particularly recommended for further development or potentially RNNP embodiment.

6.5.5.1 Incorporating DFU 12 in the current total indicator

The latest helicopter accident at Turøy demonstrates that helicopter transport is an offshore safety issue which has an impact on offshore risk levels and potentially the perceived risk levels amongst workers in the offshore industry. In light of this event, and based on the findings by Vinnem, stating that helicopter risk is responsible for approx. 30% of the total exposed risk to offshore workers (Vinnem, 2014), it is recommended to incorporate DFU 12 in the current total indicator.

The framework developed in this thesis could be a possible approach to incorporate DFU 12 in the current total indicator. Through conversations with Vinnem, the weights developed for DFU 12 have been reviewed as satisfactory, and the overall results from the case study supports the 30% helicopter/total risk exposure projection by Vinnem, when looking at the average DFU indicator distribution results between DFU 1-11 and DFU 12, for years 2008-2014. The helicopter weights have been established mainly based on assumptions. This has been a point of concern for the reliability of the model. Despite these uncertainties Vinnem commented that *"It might be better to be approximately right, than exactly wrong"* (Vinnem, 2016) in establishing DFU 12 weights. It is advisable for a third party to evaluate if the DFU 12 weights are satisfactory, but overall, the proposed weights are deemed a reasonable suggestion for DFU 12 weight estimation, which should be considered for implementation in the current RNNP total indicator.

6.5.5.2 Maintenance data presentation

It is suggested to present maintenance data as the distribution between the parameters: total maintenance hours, total hours of lagging maintenance and total hours of lagging maintenance for HSE critical components, in order to display the relations of maintenance parameters in simple, yet informative way. By displaying the maintenance data in this manner the number of maintenance hours become less relevant and the distribution of maintenance hours are accentuated. It is recommended to implement this in the RNNP report in order to provide the reader an intuitive understanding of where the hours of maintenance are invested. A large percentage of HSE critical lagging maintenance could potentially be a warning sign which could be easier to detect by such a presentation of results.

6.5.5.3 Safety Climate vs. Safety Performance

It is recommended to investigate if there is a correlation between the total indicator results and safety climate scores. At first glance, the results presented in this thesis could indicate that there is a correlation between the safety climate scores and the offshore safety performance.

If further research could validate such relations, then the Survey Results Indicator could have an implementation potential in RNNP and could potentially be presented alongside the total indicator results. Considering that the safety climate may have leading and lagging indicator qualities this could be of relevance for the risk level presentation. Hypothetically the safety climate should be able to change before the risk levels changes. Additionally, it should be able to change, following changes in risk levels. This potential relation between the total indicator and the Survey Results Indicator is the reason for suggesting the Survey Results Indicator to be presented alongside the total indicator.

6.5.5.4 Investigating correlations between leading and lagging indicators

Chapter 6.5.5.3 encourages to evaluate if there is a correlation between safety climate and safety performance. In addition to investigating individual indicator correlations, the potential New Total indicator correlations should be investigated. If there exists a correlation between the leading and lagging New Total Indicator this would strengthen the argument as to why the New Total Indicator should be presented as leading and lagging indicators. Furthermore, such correlation could start a discussion on the current total indicator’s ability to single handedly reflect major accident risk levels.

6.6 Closing remarks

It has been difficult to develop a new methodology for a New Total Indicator in RNNP. Even though there are areas of improvement, RNNP cannot be described as anything else than a very successful project.

In times when the industry is struggling and where risk levels have shown a negative (increase) trend in incident statistics (NRK, 2016), it should be recognized that RNNP still serves as an objective platform to analyze and review offshore risk, and that the Project is important to raise awareness in specific areas in the industry (Vinnem et al., 2006).

The objectives of this thesis were described as ambitious and interesting by the PSA (Bjørnar Heide, 2016), which was confirmed when meeting PSA in person in early April 2016 (B. Heide & Hallan, 2016). Other approaches could have been carried out to continue the further development of RNNP, and the development of a New Total Indicator is just one of potentially many ways to develop RNNP further.

It has always been the intention for this thesis to produce results which could be a contribution to RNNP. Either to the discussion on RNNP's future development or by presenting results which could be directly implemented. The methodology presented in this thesis is in need of further development and is not considered suitable for implementation. The methodology is too novel, and in certain areas too incomplete for it to be embodied in RNNP. However, what the thesis currently lacks in implementation potential, it makes up for by contributing to the discussion of the role of the total indicator, and how risk levels should be presented in RNNP.

This thesis suggests an alternative way to present risk levels and attempts to question if RNNP can do better. The author considers this thesis a relevant contribution to the discussion on the future development of RNNP, even though the applicability of the model, at the current stage is not good enough for implementation.

7. Conclusion and further work

The first objective of this thesis was to establish a New Total Indicator methodology for the further development of RNNP. The second objective was to perform a case study to establish New Total Indicator results and compare them with current RNNP total indicator results to assess the quality of the methodology. The purpose of the New Total Indicator is to reflect a broader risk picture on the NCS than today's methodology and give a more holistic risk level presentation.

The New Total Indicator methodology was based on four individual indicators i) DFU Indicator ii) Barrier Indicator iii) Survey Results Indicator iv) Uncertainty Indicator. The New Total Indicator was presented as two relative indicators; leading and lagging. The DFU indicator was classified as a lagging indicator. the Barrier Indicator and Survey Results Indicator were categorized as leading indicators and the Uncertainty Indicator was used as a correctional factor for the individual indicators.

Figure 35 portrays the established New Total Indicator case study results for fixed production installations for years 2008-2014. The results show an overall decrease in risk levels. At the same time the results portray that risk level values increase after 2013. This is in contrast to the current RNNP total indicator results which claim that risk levels are record low for 2014. The case study focused on fixed production installations only, whereas the current total indicator presents results for all production installations. Hence the comparison of New Total Indicator and current total indicator results cannot be exact due to their different data basis.

The numerous method and data assumptions question the quality of New Total Indicator results. Despite potential shortcomings the results are considered satisfactory and demonstrate the ability of the developed methodology. The developed methodology is able to reflect a broader risk image and is more complex than its predecessor i.e. it is able to present more holistic risk level results than the current total indicator.

The proposed methodology is an important contributor to the discussion on overall vs. individual indicators in RNNP. It is considered sensible to have an overall indicator in addition to the individual indicators in RNNP, which is able to reflect the breadth of risk indicator results.

The overall conclusion is that the developed New Total Indicator is considered too novel for implementation in its current state in RNNP. The mathematical foundation of the methodology is currently too weak, even though the ideas and overall concept of the New Total Indicator methodology are deemed highly relevant.

It is advised to implement DFU 12 into the current total indicator to better address helicopter transport risk. The DFU Indicator could replace the current total indicator, giving DFU 12 an influence on NCS major accident risk levels.

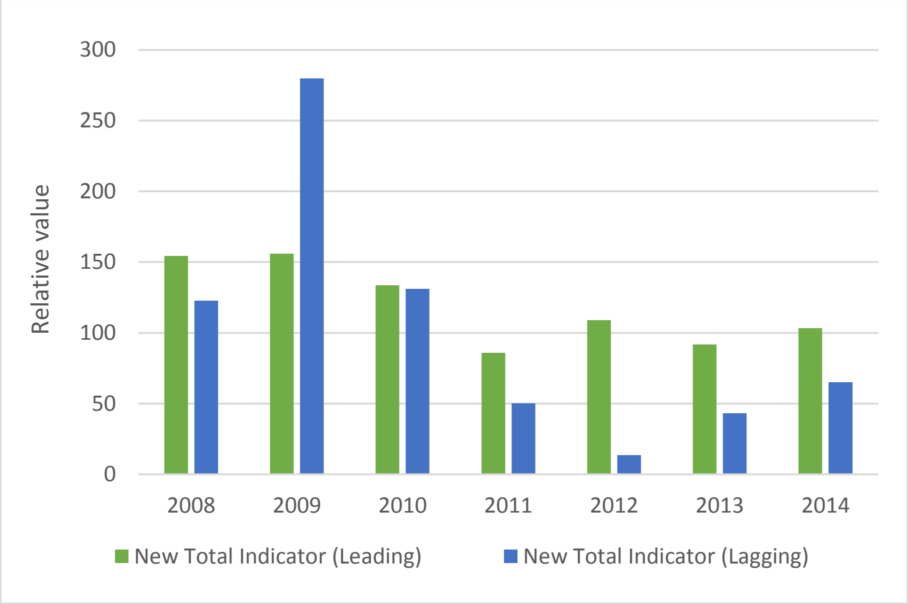


Figure 35: New Total Indicator Results (Relative value) Fixed Production Installations, 2008-2014

7.1 Further work

The methodology developed in this thesis can be seen as an ambitious and intriguing proposal for the further development of RNNP. As mentioned, the developed methodology is not recommended for implementation at this stage. There are however several areas and topics suitable for further work.

In order to properly assess the quality of the developed methodology the methodology should be tested by using RNNP data for all installations and all survey results. This would give better New Total Indicator results, which would be more comparable with current total indicator results. This would better assess the overall quality of the New Total Indicator.

It should be investigated if the indicator contributions should be weighted differently than what has been done in this thesis. For the proposed methodology the average values of two indicators is usually used to establish one indicator value e.g. the maintenance indicator which is the average value of the PM and CM relative values. A more thorough evaluation of the indicator contributions could enhance method quality and improve the mathematical foundation of the New Total Indicator.

The assumed DFU 12 weights are deemed satisfactory, but a complete helicopter risk assessment could reduce uncertainty and give more correct DFU 12 weights. For further work a DFU 12 risk assessment is recommended.

For further work it is suggested to evaluate New Total Indicator results up against safety performance results. This would evaluate the goodness of the New Total Indicator methodology, but most important analyze if there is an interdependency between the leading and lagging New Total Indicator. If a leading and lagging indicator relation could be established, then this would substantiate the New Total Indicator considerably. To analyze New Total Indicator results up against safety performance results is considered one of the most important and interesting areas of further work.

Undoubtedly there will be other areas of further work for the developed methodology and case study. The proposed areas of further work highlights the most evident and important areas for further development.

8. References

9. Abrahamsen, Heide, Vinnem, & Gelyani. (2015). *An improved method to express risk level and detect trends in risks in the Norwegian petroleum industry*. Article submitted for approval. Stavanger.

10. Almeida, A. G. d. (2013). *Identification of Global Indicators for Regulatory Risk Management in Production Platforms - Case study of Brazilian Industry*. Prepared for Presentation at Maerican Institute of Chemical engineers 5th Latin american Conference on Processs Safety. Safety and Environmental Dept. ANP. UNPUBLISHED.

11. Aven, T. (2012). The risk concept—historical and recent development trends. *Reliability Engineering & System Safety, 99*, 33-44. doi:http://dx.doi.org/10.1016/j.ress.2011.11.006

12. Aven, T. (2013a). On the meaning of a black swan in a risk context. *Safety Science, 57*, 44-51. doi:10.1016/j.ssci.2013.01.016

13. Aven, T. (2013b). Practical implications of the new risk perspectives. *Reliability Engineering & System Safety, 115*, 136-145. doi:http://dx.doi.org/10.1016/j.ress.2013.02.020

14. Aven, T., & Krohn, B. S. (2014). A new perspective on how to understand, assess and manage risk and the unforeseen. *Reliability Engineering & System Safety, 121*, 1-10. doi:http://dx.doi.org/10.1016/j.ress.2013.07.005

15. Bye, R., & Lamvik, G. M. (2007). Professional culture and risk perception: Coping with danger on board small fishing boats and offshore service vessels. *Reliability Engineering and System Safety, 92*(12), 1756-1763. doi:10.1016/j.ress.2007.03.024

16. Dammen, T., & Ekle, R. (2015, Sept. 29, 2015) *Personal Communication Safetec, Sept. 29, 2015/Interviewer: E. Andreassen*.

17. Denzin, N. K. (1989). *The research act : a theoretical introduction to sociological methods* (3rd ed. ed.). Englewood Cliffs, N.J: Prentice Hall.

18. Flage, R. (2016, 04.04). [Skype Interview/Conversation].

19. Haugen, S., & Vinnem, J. E. (2015). Perspectives on risk and the unforeseen. *Reliability Engineering & System Safety, 137*, 1-5. doi:http://dx.doi.org/10.1016/j.ress.2014.12.009

20. Haukelid, K. (1998). *En historie om risiko : antropologiske betraktninger om sikkerhet, bedriftskulturog ledelse i norsk oljevirksomhet.* (nr 32, 1998), Senter for teknologi og menneskelige verdier, Oslo.

21. Heide, B. (2009). *Monitoring major hazard risk for industrial sectors.* (no. 66), University of Stavanger, Faculty of Science and Technology, Stavanger.

22. Heide, B. (2015, 23.11.2015). [Mail correspondance].

23. Heide, B. (2016, 01.03.2016). [E-mail correspondance].

24. Heide, B., & Hallan, B. (2016, 04.04.2016). [PSA Master's thesis meeting].

25. Heide, B., & Lootz, E. (2015, 25.09.2015) *Personal Communication Petroleumstilsynet, Sept. 25, 2015/Interviewer: E. Andreassen*.

26. Henningsgård, S. (2013). Operational Risk in the Norwegian Barents Sea: Institutt for marin teknikk.

27. Ims, B. (2013). Emergency preparedness in Arctic oil and gas exploration: Institutt for marin teknikk.

28. ISO:31000. (2009). ISO Guide 73:2002 - Risk Management: ISO.

29. J.E.Vinnem (2016, 04.06.2016). [Mail Correspondance].

30. Jakobsen, M. F., & Ehlers, S. (2015). Assessment of Helicopter Emergency Response Capacity in the Barents Sea: NTNU.

31. Johannessen, A. (2009). *Introduksjon til SPSS : versjon 17* (4. utg. ed.). Oslo: Abstrakt forl.

32. Kilskar, S. S., & Øien, K. (2015). *Indikatorer på HMS i Høyrisikoindustri*. Retrieved from

33. Knardahl, S. (2015, Oct. 8.2015) *Personal Communication STAMI, Oct. 8, 2015/Interviewer: E. Andreassen*.

34. Kongsvik, T. (2016, 14.03.2016) *Meeting regarding the master's thesis, with particular emphasis on safety climate as an indicator./Interviewer: E. Andreassen*.

35. Kongsvik, T., Kjøs Johnsen, S. Å., & Sklet, S. (2011). Safety climate and hydrocarbon leaks: An empirical contribution to the leading-lagging indicator discussion. *Journal of Loss Prevention in the Process Industries, 24*(4), 405-411. doi:10.1016/j.jlp.2011.02.004

36. Mearns, K., Flin, R., Gordon, R., & Fleming, M. (1998). Measuring safety climate on offshore installations. *An International Journal of Work, Health & Organisations, 12*(3), 238-254. doi:10.1080/02678379808256864

37. Nielsen, M. B., Mearns, K., Matthiesen, S. B., & Eid, J. (2011). Using the Job Demands–Resources model to investigate risk perception, safety climate and job satisfaction in safety critical organizations. *Scandinavian Journal of Psychology, 52*(5), 465-475. doi:10.1111/j.1467-9450.2011.00885.x

38. NPD. (2015, 04.02.2016). Havområder på norsk kontinentalsokkel. Retrieved from http://www.norskpetroleum.no/kart/havomrader-pa-norsk-kontinentalsokkel/

39. NRK (Writer). (2016). Risikonivå i Norsk Petroleumsvirksomhet 2015 - Tv-sending [online broadcasting via nrk.no]: NRK.

40. Olsen, E. (2009). *Safety climate and safety culture in health care and the petroleum industry : psychometric quality, longitudinal change, and structural models.* (no. 74), University of Stavanger, Faculty of Social Sciences, Stavanger.

41. Petroleumstilsynet. (2015). Hydrocarbon leaks and fires. Retrieved from http://www.psa.no/process-integrity/hydrocarbon-leaks-and-fires-article4162-902.html

42. PSA. (2014a, 16.12.2014). Guidelines regarding the framework regulations.

43. PSA. (2014b). *Risikonivå i Norsk Petroleumsvirksomhet - Hovedrapport - Utviklingstrekk 2013 Norsk Sokkel*. Retrieved from Stavanger:

44. PSA. (2015a). *Risikonivå i Norsk Petroleumsvirksomhet - Hovedrapport - Utviklingstrekk 2014 Norsk Sokkel*. Retrieved from Stavanger:

45. PSA. (2015b). *Risikonivå i Norsk Petroleumsvirksomhet - Metoderapport - Utviklingstrekk 2014 Norsk Sokkel*. Retrieved from Stavanger:

46. PSA. (2015c). *RNNP Summary Report*. Retrieved from Stavanger:
47. Rausand, M. (2011). *Risk assessment theory, methods, and applications*. Hoboken, N.J.: Hoboken, N.J. : John Wiley & Sons.

48. Rausand, M., & Utne, I. B. (2009). *Risikoanalyse : teori og metoder*. Trondheim: Tapir akademisk forl.

49. Reason, J. (1997). *Managing the risks of organizational accidents*. Aldershot: Ashgate.

50. Rosness, R., & Forseth, U. (2015). *Boxing and dancing tripartite collaboration as an integral part of a regulatory regime*.

51. SINTEF. (2010). *Helicopter Safety Study (HSS-3)*. Retrieved from Trondheim:

52. Stensland, M. (2013). Combined Risk Indicator for Major Accident Precursors and Barriers in the Trends in Risk Level Project. Trondheim: Norwegian University of Science and Technology.

53. Taleb, N. N. (2010). *The black swan : the impact of the highly improbable* (2nd ed. ed.). New York: Random House Trade Paperbacks.

54. Tharaldsen, J. E., Olsen, E., & Rundmo, T. (2008). A longitudinal study of safety climate on the Norwegian continental shelf. *Safety Science, 46*(3), 427-439. doi:10.1016/j.ssci.2007.05.006

55. Ulleberg, P., & Nordvik, H. (2001). *Faktoranalyse*. Trondheim: Tapir.

56. Vinnem, J. E. (2010). Risk indicators for major hazards on offshore installations. *Safety Science, 48*(6), 770-787. doi:http://dx.doi.org/10.1016/j.ssci.2010.02.015

57. Vinnem, J. E. (2014). *Offshore risk assessment : principles, modelling and applications of QRA studies* (3rd ed. ed.). London: Springer.

58. Vinnem, J. E. (2015, 08.09.2015) *Counceling session/Interviewer: E. Andreassen*. NTNU, Trondheim.

59. Vinnem, J. E. (2016, 13.04.2016). [Counseling session].

60. Vinnem, J. E., Aven, T., Husebø, T., Seljelid, J., & Tveit, O. J. (2006). Major hazard risk indicators for monitoring of trends in the Norwegian offshore petroleum sector. *Reliability Engineering & System Safety, 91*(7), 778-791. doi:http://dx.doi.org/10.1016/j.ress.2005.07.004

61. Vinnem, J. E., & Ravdal, B. (2006). *Analysis of Barrier indicators*. Paper presented at the European Safety and Reliability Conference 2006, Portugal.

62. Vinnem, J. E., & Røed, W. (2015). Root causes of hydrocarbon leaks on offshore petroleum installations. *Journal of Loss Prevention in the Process Industries, 36*, 54-62. doi:http://dx.doi.org/10.1016/j.jlp.2015.05.014

63. Zohar, D. (1980). Safety climate in industrial organizations: Theoretical and applied implications. *Journal of Applied Psychology, 65*(1), 96-102. doi:10.1037/0021-9010.65.1.96

Appendices

Appendix I Complete DFU list

DFU	**Description**
1	Unignited hydrocarbon leak
2	Ignited hydrocarbon leak
3	Well incident/loss of well control
4	Fire/explosion in other areas, combustible liquid
5	Ship on collision course (headed toward installation)
6	Drifting object (Headed toward installation)
7	Collision with other field-related vessel/installation
8	Construction damage (positioning-/anchoring and stability)
9	Leak from pipes and subsea production installations
10	Damage pipes and subsea production installations
11	Evacuation
12	Helicopter incident
13	Man over board
14	Personal injury
15	Work-related illness
16	Full loss of power
18	Diving accident
19	H_2S emission
21	Falling object

(PSA, 2015b)

Appendix II DFU Weights (Fixed Production Installations)

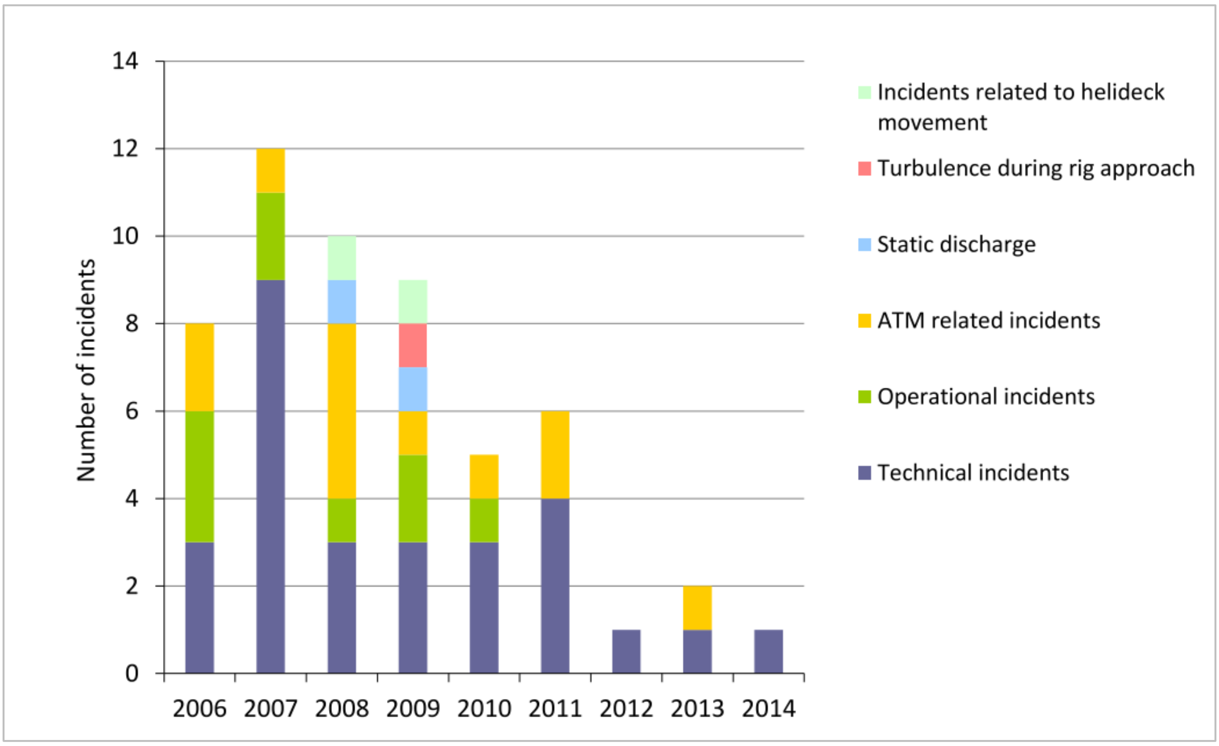
DFU	Description	Weight (PLL)
1	Unignited hydrocarbon leak Small Medium Large	 0,0013 0,009 0,12
2	Ignited hydrocarbon leak	Individually established
3	Well incident/loss of well control Level 3 Level 2 (except level 2.3) Level 1 (except level 1.3 and 1.1) Level 2.3 Level 1.1 Level 1.3	 0,0035 0,017 0,087 0,087 Individually established 0,87
4	Fire/explosion in other areas, combustible liquid	0,021
5	Ship on collision course (headed toward installation)	0,0081
6	Drifting object (Headed toward installation)	0,0009
7	Collision with other field-related vessel/installation	0,0021
8	Construction damage (positioning-/anchoring and stability) Major Supermajor	 0,01 N/A
9	Leak from pipes and subsea production installations	0,48
10	Damage pipes and subsea production installations	0,096
11	Evacuation	Incorporated in the other weight estimations
12	Helicopter incident	

(PSA, 2015b)

Appendix III – Key tables and figures, DFU 12

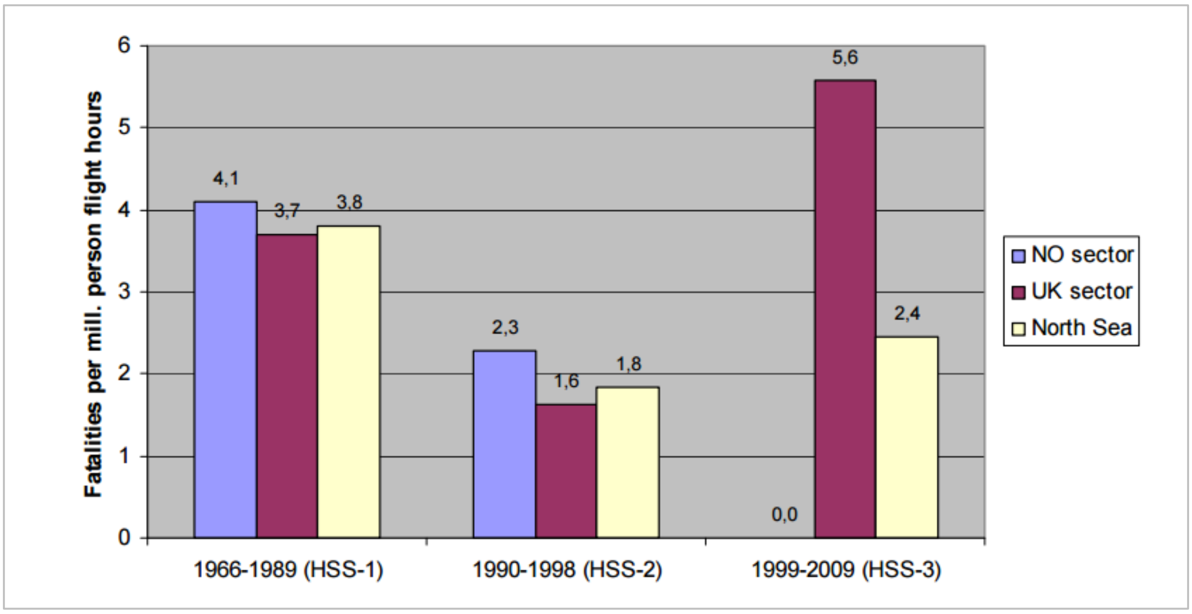
Year	Number of incidents with medium remaining safety margin against fatal accident (1 barrier)	Number of incidents with small remaining safety margin against fatal accident (0 barriers)
2006	7	1
2007	12	1
2008	8	2
2009	9	0
2010	5	0
2011	6	0
2012	1	0
2013	2	0
2014	0	1

(PSA, 2015a)



(PSA, 2015c)

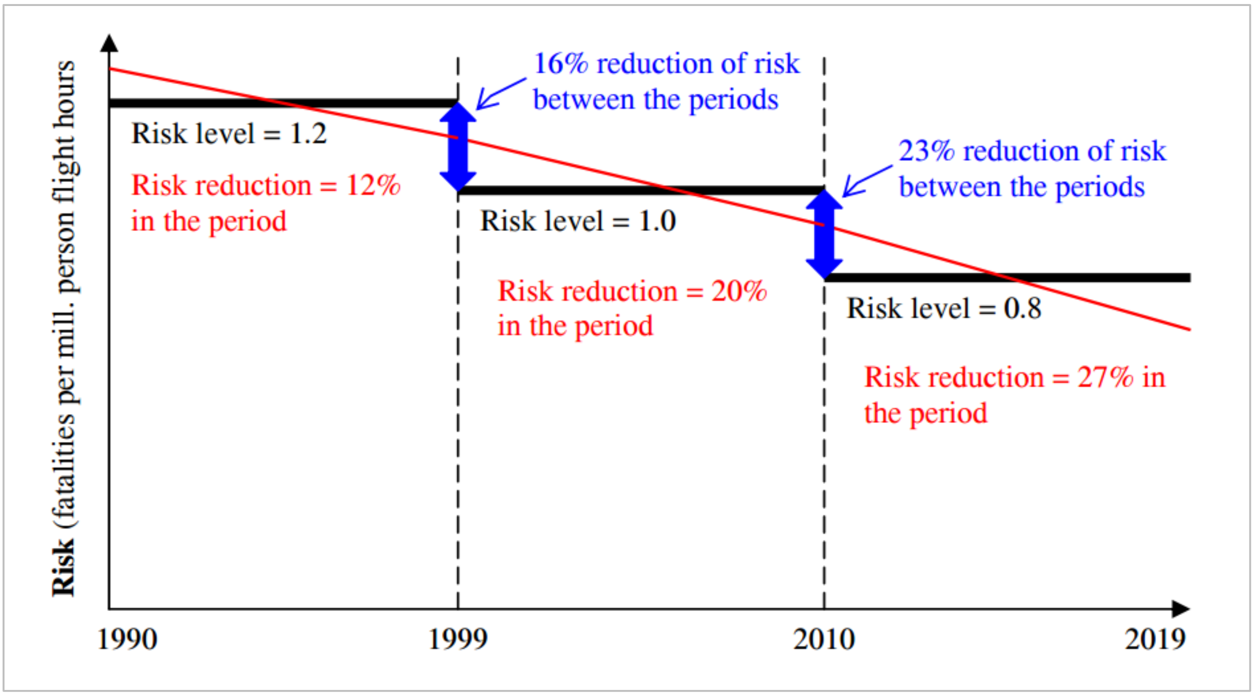
Appendix IV Results - SINTEF Helicopter Safety Study (HSS-3)



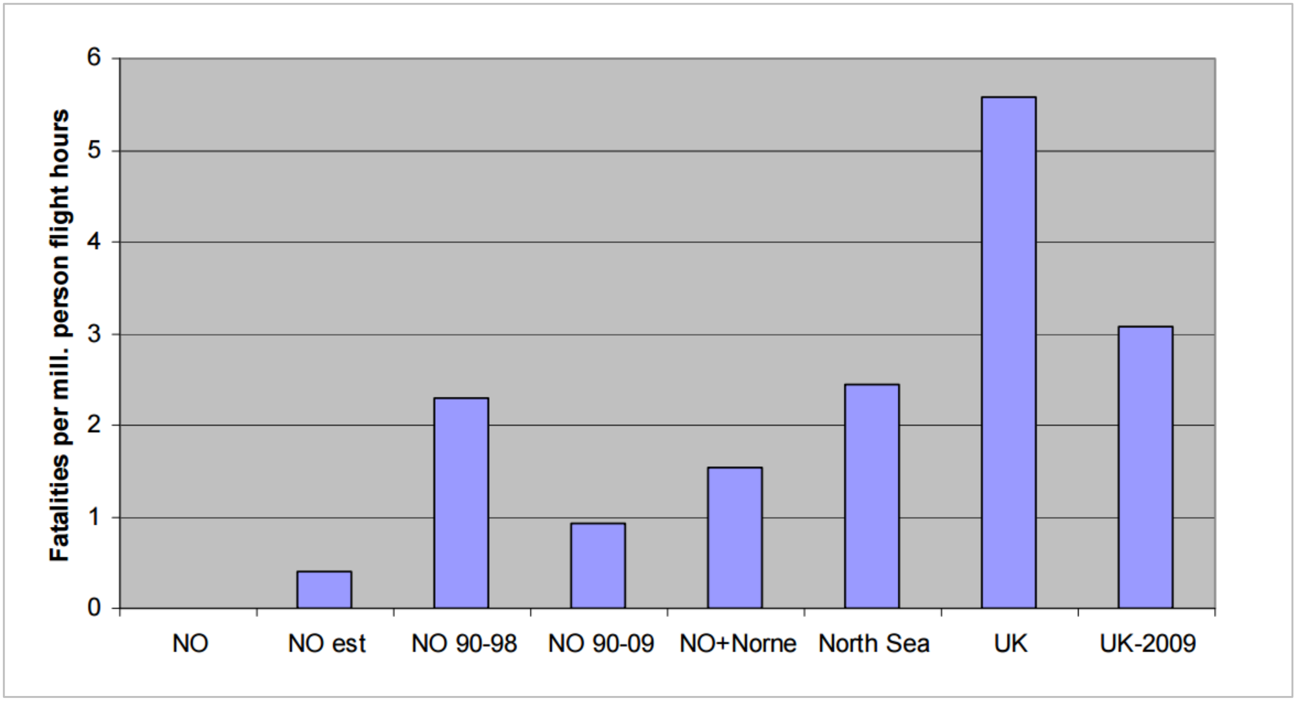
(SINTEF, 2010)

Parameter	**1990–1998**			**1999–2009**			**1990–2009**		
	NO	UK	North Sea	NO1)	UK2)	North Sea3)	NO	UK	North Sea
Million person flight hours	5.2	10.5	15.7	*7.8*	*6.1*	*13.9*	*13.1*	*16.6*	*29.7*
Number of accidents	4	11	15	1	11	12	5	22	27
Number of fatal accidents	1	2	3	0	3	3	1	5	6
Percentage fatal accidents	0.25	0.18	0.20	0	0.27	0.25	0.20	0.23	0.22
Number of fatalities	12	17	29	0	34	34	12	51	63
Accidents per million person flight hours (accident rate)	0.76	1.05	0.95	0.13	1.81	0.86	0.38	1.33	0.91
Number of fatalities per accident	3.0	1.5	1.9	0	3.1	2.8	2.4	2.3	2.3
Number of fatalities per million person flight hours	**2.3**	**1.6**	**1.8**	***0***	***5.6***	***2.4***	***0.9***	***3.1***	***2.1***
FAR	230	160	180	*0*	*560*	*240*	*90*	*310*	*210*

(SINTEF, 2010)



(SINTEF, 2010)



Alternative risk estimates based on UK and NCS incident statistics 1999-2009

(SINTEF, 2010)

Appendix V Uncertainty rating

Score	**Knowledge Strength classification**	**Classification description**
5	Very strong	▪ Assumptions are very reasonable ▪ Practically all relevant information/data is available ▪ Broad agreement amongst the great majority of experts ▪ Phenomena is very well understood ▪ Models provide results with high accuracy
4	High	• Assumptions appear reasonable • Large amount of relevant information/data is available • Broad agreement amongst experts • Phenomena is understood • Models provide results with satisfactory/ required accuracy
3	Medium	• Assumptions are satisfactory or less than satisfactory • Information/data is available • Agreement/disagreement amongst experts • Phenomena is partly understood • Models provide results which are neither accurate or inaccurate
2	Low	• The chosen assumptions represent simplifications • Data/information is to some extent limited, unreliable or irrelevant • Disagreement among experts • Phenomena could be poorly understood/interpreted • Models are believed to give poor predictions
1	Poor	• The chosen assumptions represent very strong simplifications • Data/information is non-existent, limited, unreliable or irrelevant • Strong disagreement among experts • Phenomena is poorly understood/interpreted • Models are non-existent or believed to give highly inaccurate predictions(Abrahamsen et al., 2015)

Score	Robustness classification	Classification description
5	Highly significant	• Changes in indicator values are practically never seen to lead to changes in results/conclusions. (Robustness is not significant if one fault more or less may alter the results/conclusions)
4	Considerable	• Changes in indicator values are rarely seen to lead to changes in results/conclusions. (Robustness is not significant if one fault more or less may alter the results/conclusions)
3	Moderate	• Changes in indicator values are occasionally seen to lead to changes in results/conclusions. (Robustness is not significant if one fault more or less may alter the results/conclusions)
2	Low	• Changes in indicator values can be seen some years, often leading to changing results/conclusions.
1	Minor	• Changes in indicator values can be practically all years, leading to changing results/conclusions.

Appendix VI DFU Weights incl. DFU 12 weight estimates

DFU	Description	Weight (PLL)
1	Unignited hydrocarbon leak Small Medium Large	 0,0013 0,009 0,12
2	Ignited hydrocarbon leak	Individually established
3	Well incident/loss of well control Level 3 Level 2 (except level 2.3) Level 1 (except level 1.3 and 1.1) Level 2.3 Level 1.1 Level 1.3	 0,0035 0,017 0,087 0,087 Individually established 0,87
4	Fire/explosion in other areas, combustible liquid	0,021
5	Ship on collision course (headed toward installation)	0,0081
6	Drifting object (Headed toward installation)	0,0009
7	Collision with other field-related vessel/installation	0,0021
8	Construction damage (positioning-/anchoring and stability) Major Supermajor	 0,01 N/A
9	Leak from pipes and subsea production installations	0,48
10	Damage pipes and subsea production installations	0,096
11	Evacuation	Incorporated in the other weight estimations
12	Helicopter incident 0 remaining barriers – High risk event 1 remaining barrier – High risk event 0 remaining barriers – Medium risk event 1 remaining barrier – Medium risk event 0 remaining barriers – Low risk event 1 remaining barrier – Low risk event	 0,02795 0,01505 0,01659 0,00891 0,01106 0,00584

(PSA, 2015b)

Appendix VII Uncertainty Rating Fixed Production Installations (2008-2014)

		UNCERTAINTY VARIABLE 1 : NEW INSTALLATION DESIGNS													
DFU INDICATOR UNCERTAINTY		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
1	**Unignited Hydrocarbon leak**														
2	**Ignited Hydrocarbon leak**														
3	**Well Incident**														
4	Fire/Explosion in other areas	4	3	4	3	4	3	4	3	4	3	4	3	3	3
5	**Ship on collision course**														
6	**Drifting object**														
7	**Collision with other field related vessel**														
8	Construction damage	4	4	4	4	4	4	4	4	4	4	4	4	4	4
9	**Leak from pipes/subsea installations**														
10	**Damage on pipes/subsea installations**														
11	Evacuation	5	3	5	4	4	3	5	3	5	4	5	3	5	3
12	**Helicopter incident**														
	Sum	**13**	**10**	**13**	**11**	**12**	**10**	**13**	**10**	**13**	**11**	**13**	**10**	**12**	**10**
	Overall Score	**0,87**	**0,67**	**0,87**	**0,73**	**0,80**	**0,67**	**0,87**	**0,67**	**0,87**	**0,73**	**0,87**	**0,67**	**0,80**	**0,67**
	Relative level of uncertainty UV1	**87**	**67**	**87**	**73**	**80**	**67**	**87**	**67**	**87**	**73**	**87**	**67**	**80**	**67**

UNCERTAINTY VARIABLE 2 : NEW FIELD DEVELOPMENTS

DFU INDICATOR UNCERTAINTY		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
1	**Unignited Hydrocarbon leak**														
2	**Ignited Hydrocarbon leak**														
3	**Well Incident**														
4	**Fire/Explosion in other areas**														
5	**Ship on collision course**														
6	Drifting object	4	4	4	4	4	4	3	4	3	3	2	3	2	3
7	**Collision with other field related vessel**														
8	Construction damage	5	4	5	4	5	4	5	4	5	4	5	4	4	3
9	Leak from pipes/subsea installations	4	5	4	5	4	5	4	5	4	5	4	5	3	5
10	**Damage on pipes/subsea installations**														
11	Evacuation	4	3	4	3	4	3	5	3	5	3	5	3	3	3
12	Helicopter incident	4	4	4	4	4	4	4	4	4	4	4	4	3	3
	Sum	**21**	**20**	**21**	**20**	**21**	**20**	**21**	**20**	**21**	**19**	**20**	**19**	**15**	**17**
	Overall Score	**0,84**	**0,8**	**0,84**	**0,8**	**0,84**	**0,8**	**0,84**	**0,8**	**0,84**	**0,76**	**0,8**	**0,76**	**0,6**	**0,68**
	Relative level of uncertainty UV2	**84**	**80**	**84**	**80**	**84**	**80**	**84**	**80**	**84**	**76**	**80**	**76**	**60**	**68**

UNCERTAINTY VARIABLE 3 : Changes in operational structure (Integrated operations, work rotations etc.)

DFU INDICATOR UNCERTAINTY		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
1	Unignited Hydrocarbon leak	5	4	5	4	5	4	5	4	5	4	5	4	2	2
2	**Ignited Hydrocarbon leak**														
3	Well Incident	4	4	4	4	4	4	4	4	4	4	4	4	3	3
4	**Fire/Explosion in other areas**														
5	Ship on collision course	2	3	2	3	3	3	3	3	4	4	5	5	5	5
6	**Drifting object**														
7	**Collision with other field related vessel**														
8	**Construction damage**														
9	**Leak from pipes/subsea installations**														
10	**Damage on pipes/subsea installations**														
11	**Evacuation**														
12	**Helicopter incident**														
	Sum	11	11	11	11	12	11	12	11	13	12	14	13	10	10
	Overall Score	0,73	0,73	0,73	0,73	0,80	0,73	0,80	0,73	0,87	0,80	0,93	0,87	0,67	0,67
	Relative level of uncertainty UV3	73	73	73	73	80	73	80	73	87	80	93	87	67	67

UNCERTAINTY VARIABLE 4 : Interpretation and follow up of guidelines and regulations

DFU INDICATOR UNCERTAINTY

Indicator	Description	2008		2009		2010		2011		2012		2013		2014	
		Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
1	Unignited Hydrocarbon leak	4	4	4	3	4	3	4	4	4	4	4	4	4	4
2	**Ignited Hydrocarbon leak**														
3	Well Incident	3	3	4	3	2	2	4	3	4	3	4	3	4	3
4	Fire/Explosion in other areas	3	3	3	2	2	2	4	3	4	3	4	3	4	3
5	**Ship on collision course**														
6	**Drifting object**														
7	**Collision with other field related vessel**														
8	Construction damage	4	3	4	3	4	4	4	3	3	2	4	3	4	
9	**Leak from pipes/subsea installations**														
10	**Damage on pipes/subsea installations**														
11	**Evacuation**														
12	**Helicopter incident**														
	Sum	**14**	**13**	**15**	**11**	**12**	**11**	**16**	**13**	**15**	**12**	**16**	**13**	**16**	**10**
	Overall Score	**0,7**	**0,65**	**0,75**	**0,55**	**0,6**	**0,55**	**0,8**	**0,65**	**0,75**	**0,6**	**0,8**	**0,65**	**0,8**	**0,5**
	Relative level of uncertainty UV 4	**70**	**65**	**75**	**55**	**60**	**55**	**80**	**65**	**75**	**60**	**80**	**65**	**80**	**50**

Uncertainty variable 5: Component Technology

BARRIER INDICATOR UNCERTAINTY		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
	Barrier Elements	2	1	2	1	3	1	3	1	3	1	4	1	4	1
	Maintenance					1	1	2	2	2	2	2	2	2	2
	Sum	**2**	**1**	**2**	**1**	**4**	**2**	**5**	**3**	**5**	**3**	**6**	**3**	**6**	**3**
	Overall Score	**0,2**	**0,1**	**0,2**	**0,1**	**0,4**	**0,2**	**0,5**	**0,3**	**0,5**	**0,3**	**0,6**	**0,3**	**0,6**	**0,3**
	Relative level of uncertainty UV2	**20**	**10**	**20**	**10**	**40**	**20**	**50**	**30**	**50**	**30**	**60**	**30**	**60**	**30**

Uncertainty variable 6: Test Procedures

BARRIER INDICATOR UNCERTAINTY		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
	Barrier Elements	1	2	1	2	1	2	1	2	1	2	1	2	1	2
	Maintenance	2	1	2	1	2	1	3	2	4	2	4	2	4	2
	Sum	**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**	**5**	**4**	**5**	**4**	**5**	**4**
	Overall Score	**0,3**	**0,3**	**0,3**	**0,3**	**0,3**	**0,3**	**0,4**	**0,4**	**0,5**	**0,4**	**0,5**	**0,4**	**0,5**	**0,4**
	Relative level of uncertainty UV2	**30**	**30**	**30**	**30**	**30**	**30**	**40**	**40**	**50**	**40**	**50**	**40**	**50**	**40**

BARRIER INDICATOR UNCERTAINTY		Uncertainty variable 7: Changes in definitions/criteria													
		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
	Barrier Elements	2	2	2	2	2	2	2	2	3	3	3	3	3	3
	Maintenance	1	1	1	1	1	1	2	2	2	2	2	2	2	2
	Sum	**3**	**3**	**3**	**3**	**3**	**3**	**4**	**4**	**5**	**5**	**5**	**5**	**5**	**5**
	Overall Score	**0,3**	**0,3**	**0,3**	**0,3**	**0,3**	**0,3**	**0,4**	**0,4**	**0,5**	**0,5**	**0,5**	**0,5**	**0,5**	**0,5**
	Relative level of uncertainty UV2	**30**	**30**	**30**	**30**	**30**	**30**	**40**	**40**	**50**	**50**	**50**	**50**	**50**	**50**

SURVEY RESULTS UNCERTAINTY		Uncertainty variable 8: Survey respondent percentage													
		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
	Safety climate indicator	4	2	4	2	4	2	4	2	4	2	4	2	4	2
	Sum	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**
	Overall Score	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**
	Relative level of uncertainty UV2	**80**	**40**	**80**	**40**	**80**	**40**	**80**	**40**	**80**	**40**	**80**	**40**	**80**	**40**

SURVEY RESULTS UNCERTAINTY		Uncertainty variable 9: Survey respondent representativeness													
		2008		2009		2010		2011		2012		2013		2014	
Indicator	Description	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness	Knowledge strength	Robustness
	Safety climate indicator	2	4	2	4	2	4	2	4	2	4	2	4	2	4
	Sum	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**	**2**	**4**
	Overall Score	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**	**0,4**	**0,8**
	Relative level of uncertainty UV2	**40**	**80**	**40**	**80**	**40**	**80**	**40**	**80**	**40**	**80**	**40**	**80**	**40**	**80**

THE UNCERTAINTY INDICATOR

Relative values

	Knowledge Strength							Robustness						
	2008	2009	2010	2011	2012	2013	2014	2008	2009	2010	2011	2012	2013	2014
Uncertainty Variable 1	87	87	80	87	87	87	80	67	73	67	67	73	67	67
Uncertainty Variable 2	84	84	84	84	84	80	60	80	80	80	80	76	76	68
Uncertainty Variable 3	73	73	80	80	87	93	67	73	73	73	73	80	87	67
Uncertainty Variable 4	70	75	60	80	75	80	80	65	55	55	65	60	65	50
Uncertainty Variable 5	20	20	40	50	50	60	60	10	10	20	30	30	30	30
Uncertainty Variable 6	12	12	12	16	20	20	20	12	12	12	16	16	16	16
Uncertainty Variable 7	30	30	30	50	60	60	60	30	30	30	40	50	50	50
Uncertainty Variable 8	80	80	80	80	80	80	80	40	40	40	40	40	40	40
Uncertainty Variable 9	40	40	40	40	40	40	40	80	80	80	80	80	80	80
DFU Uncertainty (VAR 1-3)	19	19	19	16	14	13	31	27	24	27	27	24	24	33
Barrier Uncertainty (VAR 4-7)	67	66	65	51	49	45	45	71	73	71	62	61	60	64
Survey results Uncertainty (VAR 8-9)	40	40	40	40	40	40	40	40	40	40	40	40	40	40
DFU Uncertainty (VAR 1-3) (COMBINED)	23	22	23	22	19	18	32							
Barrier Uncertainty (VAR 4-7) (COMBINED)	69	70	68	57	55	52	54							
Survey results Uncertainty (VAR 8-9) (COMBINED)	40	40	40	40	40	40	40							