UNIVERSITY OF TROMSØ UIT

Faculty of Science and Technology
Department of Engineering and Safety

Barrier management

Influence from the human factor in the arctic

TEK-3900 Master’s Thesis in Technology and Safety in the High North

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Master Thesis - TEK-3900 Master's Thesis in Technology and Safety in the High North

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In recent years several serious near-misses with major hazard accident potential have happened on the Norwegian Continental Shelf, many of them hydrocarbon leaks. Research has shown that many of these are caused by manual intervention. Despite this fact, current focus in QRAs and have been for a long time, are on technical systems. This is despite recent trends showing no decline in risk level. A higher focus on barriers and operational conditions is encouraged by the government and with upcoming production installations in the Barents Sea and arctic waters where operational conditions can be much harder, this must be a priority. Due to the remoteness and lack of infrastructure, a major hazard accident in these areas will most likely have a higher consequence both in regards to environmental impact but also in regards to loss of lives.

Based on this, the work in this thesis is an effort to further the work on human factors and influences from an arctic operational environment, and how to use this in a barrier management perspective by using the quantitative Risk OMT method.

By using relevant theory on cold climate exposure and a few legislation demands, two new RIFs are suggested for cold climate operations. One for the weather exposure and named wind chill factor, and one representing other cold climate factors and exposures named fitness for duty. Risk reducing measures by using sensors and Ex-safe screens are also tested. The thesis also suggests how to incorporate the result from Risk OMT into a barrier display, but further suggestions are made towards a more real-time version. This is due to the rapidly changing nature of the risk influences. It also addresses the shortcomings within the field of human, operational, and organizational performance standards and performance requirements.

The work in the thesis shows that there is a risk increase induced by the new RIFs based on the arctic operational environment and Risk OMT appears suitable to measure the human factor under such conditions. By use of importance measure and other output from the Risk OMT, good decision support for implementation of risk reducing measures could be provided.

Keywords:	**Supervisor:**
Barrier management, Risk OMT, arctic, human factor, barrier display, risk management, operational factors, organizational factors, and risk influencing factors (RIF)	Professor Per-Arne Sundsbø – Narvik University College Professor Jan Erik Vinnem – University of Stavanger

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Terms, definitions, abbreviations, and nomenclature

Terms and definitions

Barrier block diagram	Block diagram that outlines arrangement of barrier elements/functions designed to prevent an unwanted event (Vinnem(c), 2007).
Barrier element	(no: barriereelement) – Technical, operational, or organizational solutions that is included in the realization of a barrier function (Ptil, 2011). It is according to Z-013 a physical, technical, or operational component in a barrier system (Standards Norway, 2010).
Barrier management	(no: barrierestyring) – Coordinated activities done to establish and maintain the barriers, so that they may at any given time perform its function (Standards Norway, 2010).
Barrier function	(no: barrierefunksjon) – This is the task or role of the barrier system. Examples of this are: prevent leaks, prevent ignition, reduce fireloads, and ensure safe evacuation (Ptil, 2011). Z-013 defines it as a function planned to prevent, control, or mitigate undesired or accidental events (Standards Norway, 2010).
Barrier system	(no: barriere) – technical, operational, and/or organizational elements that either scattered or combined shall prevent a specific course of events from occurring, or affect it in an intentional direction by confining the damages and/or loss (Ptil, 2011). Z-013 defines it as a system designed and implemented to perform one or more barrier function (Standards Norway, 2010).
Basic event	An event that can by itself or in combination with others lead to a top event
Climate	The average weather condition in a place over a longer period of time. It is not the same as weather (Wergeland, 2009).
Cognitive	Mental capacity regarding information processing (Flin, O'Connor, & Crichton, 2008).
Deicing	Physical action of removing ice after being formed. This can be either manual or non-manual.
Execution	Completion of task at hand, like opening of flanges and connections, replacement and remaking of connections (Vinnem(a), 2013).
Execution failure	The task is completed, but erronous. Example: a control is performed, but it does not detect the error med in the work task (Vinnem(a), 2013). In Risk OMT failure of execution is seen as a result of human error or violations (Vinnem, et al., 2012).
Event tree	A risk analysis method – see ETA.
Ex-safe	Electronic equipment safe to use in hazardous areas in regards to ignition source control – intrinsically safe equipment.
Fault tree	A risk analysis method – see FTA.
Hazards	Events in the QRA that potetially can cause a major accident like: process leaks, blowouts, riser and pipeline accidents, structural collapse, loss of stability/position and riser accidents, and helicopter accidents (Skogdalen &

	Vinnem, 2011).
Human error	Risk OMT defines it as a reason for failure of execution (Vinnem, et al., 2012). Reason defines it as: *"occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some change agency"* (Reason, 1990, s. 10).
Human and operational factors	The definition used in the thesis: *"There are three areas of influence on people at work, namely: (a) the organization, (b) the job (c) personal factors. These are directly affected by: (a) the system for communication within the organization and (b) the training systems and procedures in operation; all of which are directed at preventing human error"* (Skogdalen & Vinnem, 2011, s. 470).
Initiating event	In the Risk OMT project it is defined as a technical or operational occurrence which may lead to leaks from the process system (Vinnem, et al., 2012). It is also a significant deviation that under given circumstances can lead to an unwanted event (Aven, Sklet, & Vinnem, 2006).
Installation	In this case it refers to a production platform or vessel.
Isolated equipment	Closed off from introduction of hydrocarbons.
Latent errors	Defined as an outcome not yet manifested, but certain. The only uncertainty is the point in time when it is manifested (Skogdalen & Vinnem, 2011).
Maintenance	The act of restoring (repairing or servicing) a component/module/system from a degraded state. This could be either corrective or preventive.
Major hazard accident	Is often in the offshore industry defined as action sequence out of control with the potential to cause five or more fatalities (Skogdalen & Vinnem, 2011).
Mistakes	*"…involve actions that are based on failure of interpretation of procedures, and/or failures of judgemental/inferential processes involved in the prescribed activity. This category does not distinguish between whether or not the actions directed by this judgement activities run according to the actor's plan. Typical mistakes are inadequate judgement/conclusion due to intrinsic conditions such as competence, fatigue, mode etc, and extrinsic conditions such as communication, information, workload, time pressure etc."* (Vinnem, et al., 2012, s. 280).
Omission failure	A task is forgotten, overlooked, or not performed. Example: the control is not carried out (Vinnem(a), 2013).
Operational barriers	As defined in Risk OMT, a operational barrier is a physical or mental actions taken by operators to carry out work or verification tasks according to procedures and/or instructions (Vinnem(a), 2013).
Performance requirement	Established set of testable requirements/demands for a barrier element to ensure that they perform their function to retain the barrier function (Ptil, 2011).
Performance shaping factors	Conditions that can affect the barrier function or elements ability to perform according to predefined requirements (Ptil, 2011).
Performance standard	Sets performance requirements for barrier elements, show bordering barrier systems/functions, and describe how they are followed up (Vinnem(c), 2007).
Planning	Includes long and short term planning, overall schedules, safe job analysis, etc.

	(Vinnem(a), 2013).
Post initiating event	In the nuclear industry it means after the unwanted event.
Precursor event	Incidents and near-misses – DFU (translated to "defined situations of hazard and accidents") in Norwegian (Vinnem j. E., 2010).
Preparation	Implies shut down, isolation, and depressurization, etc. (Vinnem(a), 2013).
Proactive	Probability reducing.
Reactive	Consequence reducing.
Reinstatement	The act of resetting of valves and controls, and also includes starting up (Vinnem(a), 2013).
Reliability	The ability a technical unit has to perform a specific function in a given environment and operating conditions over a given period of time (Rausand & Utne, 2009).
Risk	Usually defined as the combination of the probability of occurrence of harm and the severity of the harm (Standards Norway, 2010). A more elaborate definition is to include uncertainty of the consequences (or outcomes) given available knowledge.
Risk influence diagrams	A BBN for basic or top event.
Risk influencing factors	An aspect of a system or activity that affects the risk level of said system or activity (Vinnem, et al., 2012).
Shall	A verbal form indicating something that requirement must be strictly followed and no deviations are permitted, unless all parties agree (Standards Norway, 2010).
Should	A verbal form used to indicate a particularly suited alternative among several other possibilities. Indicates a preferred course of action, but not necessarily required (Standards Norway, 2010).
Slips and lapses	"Slips and lapses involve actions that represent unintended deviation from those practiced represented in the formal procedures. This is deviation due to error in execution and/or the storage stage of an action sequence. For our purpose, this category represents only actions where there is no intended violation, failure of interpretation of procedures and judgement failures prior to the action carried out." (Vinnem, et al., 2012, s. 280).
Top event	An unwanted event.
Validity	Refers to whether or not it measures what it is supposed to measure (Aven, Sklet, & Vinnem, 2006).
Verification	Act of verifying correct performance of previous task (Vinnem(a), 2013).
Violations	"Deliberate - but not necessarily reprehensible - deviation from those practices deemed necessary (by designers, managers and regulatory agencies) to maintain the safe operation of a potentially hazardous system" (Reason, 1990, s. 195). Reason makes three major distictions: routine, optimizing, and necessary violations. Corner-cutting and shortcuts make up routine violations. Atempt to

	realize unofficial goals as a part of the performed activity, make up optimizing violations. A necessary violation comes as a failure at the work site, of tools, or equipment (Vinnem, et al., 2012).
Winterization	Measures implemented to ensure safe operations of all systems and equipment, and in turn ensure safety of personnel. This can be in regards to temperature, wind, visibility, snow, and PPE restrictions.

Abbreviations

ALARP	As Low As Reasonably Practicable
BBN	Bayesian Belief Network
BORA	Barrier and Operational Risk Analysis
CCR	Centralized Control Room
CPT	Conditional Probability Table
CSE	Concept Safety Evaluation
DNV	Det Norske Veritas
EER	Escape, Evacuation, and Rescue
EOR	Enhanced Oil Recovery
ETA	Event Tree Analysis
Ffd	Fitness for duty
FTA	Fault Tree Analysis
HCL	Hybrid Causal Logic
HEP	Human Error Probability
HES	Health, Environment, and Safety
HMI	Human Machine Interface
HOF	Human and Organizational Factor – see terms and definitions
HRA	Human Reliability Analysis
HSE	Health and Safety Executive – UK equivalent of PSA
IEC	International Electrotechnical Commission
IFE	Institute for Energy Technology
IM	Importance Measure
ISO	International Organization for Standardization
MTO	Man, Technology, and Organization
NCS	Norwegian Continental Shelf
NORSOK	Norsk Sokkels Konkurranseposisjon
NTNU	Norwegian University of Science and Technology
OHC	Occupational Health and Safety
OREDA	Offshore Reliability Data Handbook
OTS	Operational Condition Safety
PDA	Personal Digital Assistant
PR	Performance Requirement
PS	Performance Standard
PRA	Probabilistic Risk Assessment
PSA	Petroleum Safety Authority
QRA	Quantitative Risk Assessment/Analysis

RIF	Risk Influencing Factor – see terms and definitions
Risk OMT	Risk modelling – Integration of Organizational, Human, and Technical factors
RNNP	Risk Level on the Norwegian Continental Shelf
SINTEF	Selskap for INDustriell og Teknisk Forskning ved norges tekniske hoegskole
SPAR-H	Standardized Plant Analysis Risk-Human Reliability
TRA	Total Risk Analysis
TTS	Teknisk Tilstand Sikkerhet
UIT	University of Tromsø
WCI	Wind Chill Index

Nomenclature

^oC	Temperature – degrees centigrade
ΔE_j	Change in expected value as an effect of a “small change”
κ	Von Kármán’s constant
π_j	Posterior distribution
π_j^Δ	Modified posterior distribution
ρ	Air density
τ_w	Shear stress of air
E1	Expected value before a “small change”
E2	Expected value after a “small change”
$F(\pi_j)$	Frequency of critical end consequence dependent on posterior distribution
$F(\pi_j^\Delta)$	Frequency of critical end consequence dependent on modified posterior distribution
$I^B(j)$	Birnbaums importance measure for RIF j
kg/s	Kilogram per second
m/s	Speed – meters per second
$P_{ave}(A)$	Industry average probability/frequency for event A
$P_{rev}(A)$	Installation specific probability/frequency for event A
Q_i	A measure for the status of RIF i
t_{2m}	Ambient air temperature at 2 meters above ground
t_a	Ambient air temperature
t_{WC}	Wind chill temperature, temperature related to the cooling effect on a local skin segment (Standard Norge, 2007)
u_*	Vertical velocity gradient
u_{10m}	Wind speed at 10 meters above ground
u_{ar}	Wind speed
w_i	Weight for RIF i
W/m^2	Effect – Watts per square meter
X_i	Random variable to represent a state (0 or 1 usually)
Z	Height
Z_0	Height of surface roughness
Risk OMT:	
B1-B6	Scenarios related to human intervention introducing latent error
C1-C3	Scenarios related to human intervention introducing immediate release
_A	Planning, belongs under B1

_B and _C	Different execution activities
_1	Same activity, but different teams

Figure and table lists

Figures

Tables

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Preface

This thesis is the culmination of the two year master's degree program Technology and Safety in the High North, at the University of Tromsø. The topic came during my summer job in the summer of 2012 for ENI Norway AS. It was during this job that I was properly introduced and became interested in the topic of barrier management. One of the topics was that the company was starting to discuss ways to monitor the human factor as a barrier in regards to ongoing barrier management projects. The topic sort of stuck, and an earlier project on risk management that a group of students and I had performed on applying a simplified version of the BORA method came to mind. This method looked like a potential candidate for the job and its descriptive nature promising. During the fall of 2012 I attended a course in applied risk analysis for offshore application at the University of Stavanger, and the lecturer was Professor Jan Erik Vinnem. When the method was addressed during a lecture it was unknown to me that Vinnem had participated in the development of the BORA method. The idea of using this method to look at the influence from an arctic operational environment would be a reality if a suitable advisor for applying the method was available, and by request Vinnem agreed to do this. It was unknown to me that the method had been revised and developed into a much more complicated method and a longer than expected period went into learning this new tool. In the end the result became this thesis, a cross-breed of my fascination for cold climate technology and winterization, the arctic, operational psychology, and barrier management. Hopefully this thesis can raise awareness on the issue of work performance in an arctic operational environment from a major hazard perspective.

During the course of this thesis and preliminary work a few people have made significant contributions, and a few acknowledgements are in order. First of all a great acknowledgement to my thesis advisors are in order, Professors Per-Arne Sundsbø and Jan Erik Vinnem. To Professor Per-Arne Sundsbø at Narvik University College for spiking my interest for cold climate technology and winterization and perhaps the final nudge in my decision to take my master's degree. A great resource this spring semester has been Professor Jan Erik Vinnem, and without his guidance this project would most likely not be the way it is today. All the people at ENI Norway, and especially Eirik Holand, HSEQ Manager District Operations for giving me a very inspirational summer and creative freedom, and support throughout this year. A big gratitude to Bjørn Aksel Gran, Olav Brautaset, and Jorunn Seljelid at Safetec Nordic AS for help with software and myriads of questions. To Georg Elvebakk at the Department of Mathematics and Statistics, thank you for advice in regards to the importance measure calculations. A big thank you goes to my class for all the good experiences, friendships, and hardships prevailed together, you know who you are. I must also thank my girlfriend who came into my life at the most hectic of times and decided to stay.

Tromsø 29th of May 2013

Ole Kristian Madsen

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Summary

Since 2005 several major offshore accidents have occurred worldwide. In Norway several serious near-misses have happened, and many of these have been serious hydrocarbon leaks with catastrophic potential. Many years' research and earlier studies shows that manual intervention is the main source for the majority of leaks (Vinnem(a), 2013). This aspect of human error is also supported by major accident investigations that show human, operational, and organizational factors influence the accident sequence. In spite of these results, the focus in QRAs and associated risk analyses for offshore petroleum facilities, are on technical safety systems. These past ten years the Norwegian offshore petroleum industry has had a high fraction of leak incidents without any significant improvement, giving way for the argument that the recent focus for improvement has been misguided in regards to areas with higher potential for improvement (Vinnem, et al., 2012). A higher focus on barriers and operational conditions is encouraged by the government and with upcoming production installations in the Barents Sea and arctic waters where operational conditions can be much harder, this must be a priority. Due to the remoteness and lack of infrastructure, a major hazard accident in these areas will most likely have a higher consequence both in regards to environmental impact but also in regards to loss of lives.

The Petroleum Safety Authority Norway (PSA) or Petroleumstilsynet (Ptil) in Norwegian has in their document from 2011 on barrier management principles, expressed a need for a higher focus on operational and organizational barrier elements (Ptil, 2011).

Through this request for higher focus on operational and organizational barrier elements, a specific barrier stands out, the human barrier. The main objective of the thesis will be to see how operational and organizational factors can be included in a tool that will give a result for how well the human barrier is functioning. A method that may be able to do this is the Risk OMT (Risk modelling – Integration of Organizational, Human, and Technical factors) method. It is both a qualitative and quantitative method and designed to take into account operational and organizational factors during an operational phase. It also has a high focus on proactive barriers as well as reactive barriers. By using the Risk OMT method a quantitative result is produced, representing the human condition on an oil and gas installation. If this method is applicable can this method also take into consideration an arctic operational environment? The main task is to look at possiblities to develop systems and adapt tools to analyze and set performance requirements to the human factor in an operational setting? This gives a thesis problem looking like this:

By using the Risk OMT method this thesis will explore the methods potential to be used to chart the operational condition of the human factor on an oil and gas installation located in the arctic, and how this factor as a barrier can be measured.

The following sub-tasks will be answered:

- Determine if the Risk OMT method is a suitable tool and can it be adapted to the purpose of charting influence of the human factor in the arctic.
- Look at how the human factor be measured through performance standards, and see how this human factor can be implemented in a barrier display.
- Assess if this risk management tool can have a positive effect on the risk level on an oil and gas installation.

Based on available articles and material on QRAs, current QRA practice, human factor, BORA, and Risk OMT, a literature review was performed in regards to content and purpose of the QRA, current practice and focus of QRAs, along with how the human factor is and should be inserted into this tool. Available methods for analyzing the human factor are mentioned, and current ongoing projects with relevance for the work are also emphasized. After this a thorough description and explanation is

made of the eight steps of the BORA method and how this model and its weaknesses are improved in the Risk OMT method.

By using relevant theory on cold climate exposure and a few legislation demands, two new RIFs are suggested for cold climate operations. One for the weather exposure and named wind chill factor, and one representing other cold climate factors and exposures named fitness for duty. The WCI factor is based around different levels of exposure similar to the restrictions set in regards to wind chill exposure set in NORSOK S-002. The topic of wind chill also addresses the need and ideas around the subject of screening, locally, globally, and in regards to demands for ventilation. Fitness for duty is a collection of different factors relevant for arctic operations, but not all of them are due to arctic exposure. The shared attribute is that they all have an aspect of giving cognitive reduction and a combination of these should have the potential for increased risk in regards to intervention errors. Risk influencing factors addressed in the RIF is absence of daylight and consequences like depression and sleep deprivation, the cold exposure effect that might be increased if the operator is not acclimated at the start of work rotation, and nausea due to seasickness. This RIF can also include if the operator is slightly chilly and represent a level of discomfort. These factors represented in the fitness for duty RIF are subjected to extreme variations from person to person and are highly individual. A risk reducing measure is also included to check the effects of risk reducing measures in regards to the risk increase from the arctic RIFs. The measure is the use of programmable Ex-safe screens and sensors to verify the isolation plan and verifying if valves and gauges are in correct position. This can improve execution and verification activities in regards to isolation and reinstatement. Both the risk inducing scenarios and the risk reducing scenarios were simulated in the Risk OMT tool. Results gave a potentially high risk increase and a rather low risk reduction, but importance measure results verify the cause of this.

The topic of performance standard and performance requirements are addressed and explained, both in regards to content and demands in regards to legislations. It is addressed by the PSA that there is a need for proper performance standards and requirements as well as good risk indicators for measuring elements important for the human factor, be it operational or organizational. This will be crucial for the further development and attention on the topic of human and organizational factors, especially in a barrier management perspective.

Barrier panels, a system to display lagging and leading indicators for major accident hazards are defined according to Vinnem (2010) and discussed. Here the barrier panel is defined as a system established for periodic reporting and follow-up of the performance of major hazard barriers. The intention of the system is to give attention to the follow-up of barrier performance to the management and operational personnel. A barrier display should present the status of the barrier, but also the recent trend (Vinnem j. E., 2010). The thesis also suggests how to incorporate the result from OMT into a barrier display, but further suggestions are made towards a more real-time version, due to the rapidly changing nature of the risk influences. In that sense a suggestion is made towards the idea of a pure operational panel.

The work in the thesis shows that there is a risk increase induced by the new RIFs based on the arctic operational environment, and Risk OMT appears to be a suitable method to measure the human factor under such conditions. By using importance measure and other output from the Risk OMT, good decision support for implementation of risk reducing measures could be provided. Risk reducing measures can also be simulated in Risk OMT. The Risk OMT and suggestions for use presented in the thesis is also a very good step in the direction of having a more daily use and monitoring of risk levels by using QRA and risk management tools. This is also a step towards addressing QRAs on a level 4 in regards to HOFs, a level not yet reached on the NCS.

Content

1. Introduction

This master thesis is the culmination of a two year master program in Technology and Safety in the High North at the University of Tromsø. The thesis is an individual project and is equivalent to 30 ECTS. The goal is for the student to gain in-depth knowledge and competence within a selected area in the field of technology and safety, relevant for the high north. Learning outcome through the project is to improve the student's ability to do independent engineering and research work, and provide training in planning of projects, systematic processing of information and report writing.

In this chapter the thesis background will be presented along with the objective(s), aim, sub-tasks, limitations, and thesis outline.

1.1 Background information

Since 2005 several major offshore accidents have occurred worldwide. In Norway several serious near-misses have happened, and many of these have been serious hydrocarbon leaks with catastrophic potential. Many years' research and earlier studies shows that manual intervention is the main source for the majority of leaks (Vinnem(a), 2013). This aspect of human error is also supported by major accident investigations that show human, operational, and organizational factors influence the accident sequence. In spite of these results, the focus in QRAs and associated risk analyses for offshore petroleum facilities, are on technical safety systems. These past ten years the Norwegian offshore petroleum industry has had a high fraction of leak incidents without any significant improvement, giving way for the argument that the recent focus for improvement has been misguided in regards to areas with higher potential for improvement (Vinnem, et al., 2012). A higher focus on barriers and operational conditions is encouraged by the government and with upcoming production installations in the Barents Sea and arctic waters where operational conditions can be much harder, this must be a priority. Due to the remoteness and lack of infrastructure, a major hazard accident in these areas will most likely have a higher consequence both in regards to environmental impact but also in regards to loss of lives.

The Petroleum Safety Authority Norway (PSA) or Petroleumstilsynet (Ptil) in Norwegian has in their document from 2011 on barrier management principles, expressed a need for a higher focus on operational and organizational barrier elements.

Through this request for higher focus on operational and organizational barrier elements, a specific barrier stands out, the human barrier. In the article, on the analysis of hydrocarbon leaks in the Norwegian offshore industry, Vinnem(b) (2012) challenges the common misconception that the execution of the maintenance and modification tasks produces the highest risk for hydrocarbon leaks, also known as precursor events that may cause a major accident. The article gives a picture of how the main elements of the work process like planning, preparation, execution, and resetting and start-up, of a system are all risk inducing factors that contribute to major hazard precursors independent from the execution. The article shows that major contributors to the risk is that planning, preparation, and reinstatement are more hazardous than the execution itself and may explain why the leak rate offshore have not been significantly improved after a great deal of focus in the industry has been on the execution of modification tasks. Another factor important to this kind of work is to work actively with safety issues, because when you no longer work actively with these issues one will experience deterioration of routines, procedures, and the good work put into place (Vinnem(b), 2012).

1.2 Problem Description

In this sub-chapter the main objective(s), task, and sub-tasks, that the thesis will answer is presented here.

1.2.1 Aim - Main objective(s)

The main objective of the thesis will be to see how operational and organizational factors can be included in a tool that will give a result for how well the human barrier is functioning. A method that may be able to do this is the Risk OMT (Risk modelling – Integration of Organizational, Human, and Technical factors) method. It is both a qualitative and quantitative method and designed to take into account operational and organizational factors during an operational phase. It also has a high focus on proactive barriers as well as reactive barriers. By using the Risk OMT method a quantitative result is produced, representing the human condition on an oil and gas installation. If this method is applicable can this method also take into consideration an arctic operational environment?

1.2.3 Aim – Main task

The PSA say in their document on barrier management, that it is not the label put on the different barrier element, but identifying and establishing performance requirements for all the elements necessary to perform a barrier function that is more important. Some barriers will have emphasis on technical barrier elements, like emergency shutdown and pressure relief systems, while others will have an emphasis on operational elements (Ptil, 2011).

With this statement in mind, is it possible to develop systems and adapt tools to analyze and set performance requirements to the human factor in an operational setting? This gives a thesis problem looking like this:

By using the Risk OMT method this thesis will explore the methods potential to be used to chart the operational condition of the human factor on an oil and gas installation located in the arctic, and how this factor as a barrier can be measured.

1.2.4 Research questions – Sub-tasks

The thesis will try to answer the main task by answering the questions listed below:

- Determine if the Risk OMT method is a suitable tool and can it be adapted to the purpose of charting influence of the human factor in the arctic.
- Look at how the human factor be measured through performance standards, and see how this human factor can be implemented in a barrier display.
- Assess if this risk management tool can have a positive effect on the risk level on an oil and gas installation.

1.3 Limitations

The author has limited knowledge about factual offshore conditions and work practices on the Norwegian Continental Shelf (NCS). This is a limitation and will affect the assumptions made in the thesis, as they are based on guesswork and simulated “ideal states”. Assumptions are also made in regards to what are required according legislations, and deviations from factual conditions on offshore installations.

The thesis is limited in regards to available information presented in published articles on the BORA and Risk OMT projects. A few extra sources of information are available in the Risk OMT simulation tool and research paper, but mainly only relevant for the execution of simulations.

Risk OMT is limited to leak probability and predefined scenarios B1-B6 and C1-C3 regarding loss of containment, and the thesis follows that limitation. That means that the thesis is limited to the maintenance of hydrocarbon containing equipment on an oil and gas installation with focus on major hazard accidents from a proactive standpoint in avoiding leaks. The human factor will be related to tasks associated with the above mentioned activities, and with the inclusion of arctic risk influencing factors in the operational environment. The Risk OMT modelling will be described, but the simulation tool will be only partly described and due to company and third party sensitivity for the data contained in the tool, only brief descriptions will be given in regards to its use.

In general this thesis will not look at specific technical details for the maintenance work, but suggestions are made that may be too simplified or not reflecting the technical state of a process module.

The thesis is as mentioned focused towards major hazard risk and will not address HSE related issues, unless they overlap with aspects related to major hazard risk. This will also apply to environmental factors, where only exposure to personnel are evaluated. Here only a limited exposure factors have been given focus in regards to arctic exposure and simplifications made may be debated.

Different winterization solutions will be mentioned, but not necessary further explained unless relevant for use in the thesis.

All of these aspects mentioned above are related to topside activity and subsea activity is therefore not addressed.

The Risk OMT Exel database is a restricted and company confidential tool and its content, apart from the authors contributions is restricted from publication in this thesis. The database is verified and tested in accordance with Safetec quality assurance procedures. Documentation of this can be found in appendix A.

Due to limited knowledge, available information, and use of a new simulation model, the author have been forced to make certain academic “leaps” or assumptions in regards to the importance measure calculations that may be erronous.

1.4 Thesis outline

In this sub chapter an outline of the thesis is presented. Chapter 1 contains sub chapters containing background information relevant for the thesis and problem description, containing separate sub-chapters with thesis objective, aim and sub tasks, and limitations, and thesis outline are separate sub-chapters. After that chapter 2 follows with method and material used in the thesis, along with sub-chapters containing literature review, presentations of the methods BORA and Risk OMT, and a small section on use of software in the thesis. Chapter 3 contains the added emphasis of operating in an arctic/cold environment and the challenges faced under such exposure. Here basic introduction to the arctic and cold climate exposure is presented with what current legislations sets in regards to mitigation of exposure. The following two sub-chapters contain suggestions to new risk influencing factors (RIFs) to be included in the Risk OMT model and one risk reducing measure by improving barriers, and how these changes can be implemented based on theory and application of the model. In chapter 4, an introduction to what performance standards and performance requirements are and contain is given. Chapter 5 contains theory on barrier displays and suggestions to how the human factor can be measured in such an arrangement. Simulation results and assumptions are presented in chapter 6. Here several simulations have been performed and are presented in separate sub-chapters. First is a sub-chapter on the risk increase due to introduction of new RIFs measured against a baseline case without arctic RIFs. Second a sub-chapter on the risk reducing effect from the risk reducing implementation is presented. Last is a sub-chapter containing four scenarios where importance measure is performed to rank the RIFs with the highest risk influencing potential. Chapter 7 is a discussion of the findings and an assessment of the sub tasks presented in chapter 1.2.4. Conclusions to the thesis are presented in chapter 8, along with suggestions for further research. In the end there are chapters on references and appendixes.

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2. Material and method – Methodology and research approach

In this chapter there will be a description of the methods used in this thesis along with a thorough description of the literature pertaining to this field of research and the BORA and Risk OMT method. A few points on the software used is also made.

This thesis is mainly a literature study based on the use of research articles, manuals, and available literature on the topics in question. Elements from both natural and social sciences are used since the topic deals with human, technical, and organizational risk influencing factors. This thesis will not develop any new method, but rather try to use an existing method and introduce already established knowledge from a different field to create a new result based on this. If this could be categorized as a new application area could be debated since it is still an operational environment on an oil and gas installation. On the other hand, the application of the result is different. How often updates will be done is also different, so arguments for new application areas are definitely present. The work is mainly an individual effort, but with good input and training in the use of software from thesis advisors and external sources.

The methodology used in the thesis is the methods applied to represent reality. The choice of strategy is usually divided between induction and deduction. Deduction is based on the principle "from theory to cut-and-try", where the usual steps are to create an opinion or expectation of reality and then go out and try to gather data and see how the expectations reflects reality. The expectations are in most cases based on earlier findings and previously formed theories (Jacobsen, 2005). This thesis is based on the method of deduction. The aim and objectives are based on former theories about higher risk exposure in the operational environment and simulations and theories to prove this are applied. Risk OMT is also based on former research, and the adaption of the model and evaluation are just a way of showing that the method is still applicable. All the data generated through simulations are also based on preconceptions. Induction is the opposite of deduction and is based on using data to create theory. It is founded on the principle that the researcher is to have a completely open mind and gather information and then retreat and put data into the system and evaluate the collected data, before theories are formed. The idea is to have no preconceptions before gathering data to avoid contamination and bias in collected data (Jacobsen, 2005). The thesis is based previous research and no data is collected and therefore induction is not a method used. There is a third method, a crossing between induction and deduction but closer to induction, called abduction. It is based around looking for a pattern and the forming of a hypothesis. Based on the absence of data to support any other explanation a "best explanation" is formed, but may just as easily be false. A common example is the wet lawn, a circumstance. A hypothetical explanation is formed, like it rained last night. Now, if it rained last night it is unsurprising that the lawn is wet, and by abductive reasoning it is a reasonable possibility. When abducting a false conclusion can be formed, since in this case dew, lawn sprinklers, etc., may be the reason, but no data is available to support this (Douven, 2011). From this there are some cases in the thesis that uses abductive reasoning. To follow the legislations is an abduced hypothetical explanation to the circumstance of having an industry standard, but the industry standard may not be sufficient with just following the legislations. This is an example of abductive reasoning used in the thesis.

2.1 Literature review – State of the art

A Quantified Risk Assessment or Quantitative Risk Analysis (QRA) is the more frequent terms for the type of risk assessment applied for offshore operations. In this wording assessment includes analysis, but also an evaluation of the result. Quantitative risk assessment is often referred to as: Total Risk Analysis (TRA), Concept Safety Evaluation (CSE), Probabilistic Risk Assessment (PRA), and many more. QRA and TRA are more frequently used. QRAs have been applied in the Norwegian petroleum industry since 1981 and Norway were one of the first countries to use it systematically for new offshore installations in the conceptual design phase. Accidents like the Piper Alpha in 1988 and others after that, along with major research programs have lead to upgrades of the standards and extended the scope of the studies. The latest change was made to fully integrate the regulations for both offshore and onshore activity (Vinnem(c), 2007). The need for extensive risk analyses is defined in the Norwegian HES management regulations, and demands quantitative risk analyses to identify contributors to major hazard accidents, and to give a balanced and comprehensive picture of the risk with the necessary sensitivity calculations and evaluations of uncertainty (Vinnem(c), 2007) (PSA, 2013).

The QRA is a tool used by both the authorities for developing regulations and the operators to base their design upon. All operators have to perform a QRA according to legislations, NORSOK Z-013, ISO/IEC 31000, and others, and it is a requirement in all phases from project planning, to project execution, to operation, and finally decommissioning. When the operators perform a QRA the purpose is to determine which safety barriers are needed, as well as what the dimensioning loads and requirements should be. Early on the focus was on improving the incorporation of safety in design. This was due to the fact that a high number of accidents had their root in the design process. This came as a reaction to the fact that the first decade focused only the engineering phases, after the installation type and concept had been decided. That meant an absence of a thorough concept evaluation for fulfilling the system objectives, and the contractor had to design safety measures around these choices and there was little reason to question these high-level decisions. With this increased scope of the QRAs and the increased boundaries came the inclusion of the operational phase. In this phase the human and organizational factors (HOFs) plays an even greater role than in the previous phases. Several factors were updated like: experience, modifications, model improvements, changes in criteria, operational mode, manning level, and maintenance philosophy. The safety systems implemented was usually addressed separately and dependencies and common mode/cause failures was not identified. Release statistics in the 1990s showed that half the leaks from hydrocarbon production systems on the NCS were caused by manual intervention (Skogdalen & Vinnem, 2011) and later studies have shown that differentiation of the work phases is important, as shown by Vinnem(b) (2012) that 40% of major accident precursors come from preparation and reinstatement (33% and 7% respectively). Engineering defenses are often partially deactivated during these manual interventions to avoid production stops. This showed that safety barriers related to containment of leaks did not function sufficiently, and proves that better understanding of both technical and non-technical barriers are crucial. The introduction of latent errors are often from the design phase and introduced by a separate company than during the operational phase, showing that HOFs must be addressed in all stages to reduce latent errors and increase durability, serviceability, and compatibility. This is due to the fact that HOFs dominates the major hazard precursors in the various lifecycles after installation. Decisions made in the design phase should reflect this aspect (Skogdalen & Vinnem, 2011).

The last fifteen years have brought a higher focus on the operational phase of an installation. This is also the case for QRAs, which have gone from using the analysis like it was in the design phase with no regard to the vast difference between the design phase to the operational phase. This is seen in a major hazard risk perspective. The practice today reflects the important differences between the phases (Vinnem(c), 2007). With all these changes and the lessons learned from major hazard investigations like: the process accident at Longford, Piper Alpha, BP Texas City, the Macondo blowout, the space shuttles Challenger and Columbia, railway accident like Åsta, and many others including accidents on the NCS show technical, operational, and organizational factors have influenced the accident, the main focus of the QRAs are still only on the technical systems (Aven, Sklet, & Vinnem, 2006). This is emphasized in the barrier and operational risk analysis (BORA) project, and will be further explained in chapter 2.2. In regards to offshore QRAs there is a need for more detailed analysis for all of these aspects in regards to safety barriers (Vinnem, Aven, Hundseid, Vassmyr, Vollen, & Øien, 2003). In addition to this the government has increased the focus on enhanced oil recovery (EOR), extension of operational life for existing installations, and tie-ins of new subsea templates, which implies that operational safety is receiving more and more attention in contrast to design safety. This also increases the focus on reduction of risk in the operational phase (Vinnem(d), NA).

In the article Quantitative risk analysis offshore – Human and organizational factors by Skogdalen and Vinnem (2011) they analyze how various QRAs include HOFs. The Norwegian authorities demand in accordance with the faculty regulations (section 10 especially) that the *"installations, systems and equipment shall be designed in the most robust and simple manner possible and such that the possibility for human error is limited"* (PSA, 2013). This shall be done for all phases of the petroleum activities. The operator shall when conduction risk reducing measures, secure that the technical, operational, or organizational solutions that offers the best results, according to individual harm and overall evaluation for present and future use, provided that the associated costs are not significantly disproportionate to the risk reduction achieved (ALARP-principle). The Management regulation addresses important factors like the need for quantitative risk analyses to identify major hazard risks and that the result is balanced and gives a comprehensible picture of the risk. Section 18 states that the operator shall carry out analyses that shall ensure a sound working environment and provide support for the technical, operational and organizational solutions, so that safety is preserved and measures to improve the risk are addressed for: (a) mistakes that can result in hazards and accident situations, (b) exposure and physical or physiological effects, are addressed (PSA, 2013) (Skogdalen & Vinnem, 2011).

Based on these requirements, Skogdalen and Vinnem (2011) analyzed how fifteen different QRAs address HOFs. The authors created a scale with four levels and related requirements for addressing HOFs in regards to how well they are addressed. The levels are shown in table 1. Use of BORA, Operational Condition Safety (OTS), Risk OMT, or other similar way of addressing HOFs will qualify as a level 3 QRA. HOFs can be addressed in many ways, and the methods mentioned are not a demand. When published there was no QRA that qualified for a level 4. Of the fifteen QRAs, only two qualified for as a level 3. This way of conducting QRAs will show that the risk analysts have a thorough understanding of the system and performance, are accurately representing the world, precisely describing the quantities observed, and understanding the risk and associated uncertainties and treating them consistently, with a good documentation of the background information for the assessments. Still with HOFs being a vital factor for all QRAs and a legislative demand, there is no demand for how thorough HOFs should be addressed. This is reflected in the industry with their varying approach to applying the QRA (Skogdalen & Vinnem, 2011).

Table 1: Level and requirements for HOFs. Adapted: (Skogdalen & Vinnem, 2011, s. 476).

Level	Requirements
Level 4	• The QRA is an integrated part of the safety and risk management system • Results from the QRA form the basis for the daily risk management • The QRA is known and accepted at all levels of the organization • QRA is combined with risk indicators to reveal the status of the safety barriers
Level 3	• Systemativ collection of data related to HOF • QRA-models are adjusted according to findings from HOF • Identifies causes of errors to support devolopment of preventive or migitating measures
Level 2	• Explains the improtance of HOF • The HOF-factors' influence on different part of the system are partly described • Human error is calculated separately • Interviews with parts of the crew. The results are revealed but the models and calculation are not adjusted
Level 1	• Analysis of technical and operational factors. Technical factors are valves, flanges, bends, instrument connections, water depth, pressure, hydrocarbon composition. Operational factors are number of flights, number of shipping arrivals, etc. • Risk-reducing measures are technical; for example, passive fire protection and riser bumper protection. They can also be operational, like fewer shipping arrivals

The BORA, OTS, and Risk OMT projects were developed to create a better understanding of safety barriers, their failure mechanisms, and their dependencies in a QRA perspective. The Risk OMT project has been taken further and is still an ongoing project under the same name. A lot of research has been done on the field of incorporating organizational factors into QRAs and several models and methods have been produced. Among these is the I-Risk project which was an inspiration for the BORA method. There are several other models and methods described and developed over the past 15 years like: Manager, MACHINE (Model of Accident Causation using Hierarchical Influence Network), ISM (Integrated Safety Method), WPAM (The Work Process Analysis Model), the ω-factor model, SAM (System Action Management), ORIM (Organizational Risk Influence Model), and ARAMIS. None of these have been used as an integrated part of offshore QRAs before (Aven, Sklet, & Vinnem, 2006). It is important to mention that most methods and models for human reliability analysis (HRA) were developed for use in the nuclear industry.

Karin Laumann and other researchers at the Institute for Energy Technology (IFE), SINTEF, NTNU, and Idaho National lab (the institution that developed SPAR-H), in cooperation with the industry partners Statoil and DNV, are currently developing a method to chart human factor and organizational influence based on the Standardized Plant Analysis Risk-Human Reliability (SPAR-H) methodology. A method developed for human reliability analysis and applied in the nuclear industry. The project is named Analysis of human action as barriers in major accidents in the petroleum industry, application of human reliability analysis methods. The SPAR-H method is a simplified and fast HRA method (compared to SPAR PRA) and is used in conjunction with SPAR Probabilistic Risk Assessment (PRA) and assumes that human error can be identified, modelled, and then quantified. The method was developed out of early cognitive science approaches and is the development and testing of general information processing models of human performance (Gertman, Blackman, J, Byers, & Smith, 2005). Calculation of human error probabilities (HEP) are straightforward, and are based on predefined error rates for cognitive versus action oriented tasks. The calculations also incorporate performance shaping factors (not very different from RIFs), that corresponds to different levels of degradation. The method is widely used in the nuclear industry by both operators and regulators (Boring & Blackman, 2007). The SPAR-H can be applied before the pre-initiating event (the same as initiating event in the oil industry) and after the initiating event (the same as the unwanted event in the oil industry). The new method being developed is focusing on post initiating event and consequence reducing barriers, opposite to the BORA and Risk OMT that focuses on initiating events and barriers leading up to the unwanted events. The method was selected due to its flexibility to be introduced to numerous systems without significant adaptation. Project goals include creating guidelines for the entire HRA process: qualitative data collection, task analysis, expert judgment/assessment, and quantification (that is a part of HRA). The new method might include a few elements from the ATEANA method, but it is emphasized that ATHEANA is a very complex method to use in its entirety (Laumann, 2013).

The BORA project initiated a literature review in order to identify existing methods for incorporating the effect of organizational factors in QRAs. The models and methods mentioned earlier for incorporating organizational factors into QRAs were reviewed and compared against the nine criteria set for the BORA method. The reviews showed that none of the models and methods could be directly applied to analyze platform specific release frequencies, effect of safety barriers introduced to prevent release, and how platform specific conditions of RIFs influence the barrier performance. These reviews did however result in increased knowledge about existing methods and were used as a basis for the development of the BORA method. When this was done, an assessment was done on already well known modeling techniques in order to select an approach for analyzing the already predefined twenty leak scenarios. The techniques that were assessed are the current practice in QRAs, fault analysis, barrier block/event tree diagrams, and overall influence diagram. The assessment consisted of discussion of advantages and disadvantages, and “scoring” in accordance with the predefined criteria. The assessment is presented below in table 2. The score 1 indicates "not suitable" and a score of 5 indicates "very suitable" (Aven, Sklet, & Vinnem, 2006).

Table 2: The comparison of various modelling techniques from the BORA project. Adapted: (Aven, Sklet, & Vinnem, 2006, s. 683).

No.	Criteria	Current QRA	Fault Tree	Barrier block diagram	Overall influence diagram
1	Facilitate identification and illustration of safety barriers	1	3	5	2
2	Contribute to an understanding of which factors that influence the performance of the barrier functions	1	3	4	3
3	Reflect different causes of hydrocarbon release	1	4	4	4
4	Be suitable for quantification of the frequency of initiating events and the performance of safety barriers	5	3	3	2
5	Allow use of relevant data	5	3	3	2
6	Allow consideration of different activities, phases, and conditions	2	3	4	2
7	Enable identification of common causes and dependencies	1	4	5	5
8	Be practically applicable regarding use of resources	5	2	3	2
9	Provides "re-use" of the generic model	1	3	5	4
	Total score of modelling approach	**22**	**28**	**36**	**26**

As seen in table 2, the result clearly shows that barrier block diagrams and fault tree analysis (FTA) have very good qualities in regards to the predefined criteria. Barrier block diagrams was decided to be the most suited method to model the hydrocarbon release scenarios and the fault tree analysis to model the performance of the different barrier functions. The method was reviewed and adjusted before it was tested through a case study and adjusted again before it became the model presented in the literature (Aven, Sklet, & Vinnem, 2006). The case studies performed and the feedback from the industry during the BORA project confirmed that the barrier block diagram and the generic risk model illustrates the barriers in a good way, that gives a more detailed risk picture than current QRA practice, and that the result of the model is trustworthy. The method also has the ability to analyze causal factors from hydrocarbon releases compared to the current QRA practice. Testing of the model was done and a lot of sensitivity analyses were made, and assessed reasonable. The ability to test and study separate barriers and the effect of barrier performance is also a great strength. One of the few draw downs were the RIF scoring that was assessed to be an area of improvement (Sklet(a), Vinnem, & Aven, 2006). This was further developed in the OTS and Risk OMT projects.

The intention with the Risk OMT was to further develop the work done in the BORA and OTS projects. The emphasis in the Risk OMT is to further the work of RIF modelling and how these affect the performance of operational barriers. A lot of research was made into finding models to find a new framework to improve the RIF modelling. The project looked outside the Norwegian offshore industry in search of an approach. Several frameworks were found. One of these frameworks was the hybrid causal logic (HCL) and proved to have many great features. This framework was also tested alongside the Bayesian Belief Network (BBN) approach in the HUGIN software. At almost the same time as the HCL surfaced another framework appeared for validating and developing models of organizational influence, and formed the basis for the safety risk framework named Socio-Technical Risk Analysis (SoTeRiA). Issues with this model could be solved through the BBN approach and its ability to solve multi-dimensional measurements (Vinnem, et al., 2012). The model shows that the Risk OMT method using either the BBN or the hybrid approach gives a clear improvement compared to the previous BORA method.

In the following chapter there will be an introduction to the risk analysis methods BORA-release and Risk OMT, and how this is connected to other risk analysis methods and current legislation by reviewing available material on the topic. Several articles and handbooks have been used to gather information on the use and applicability of the methods. In the following sub-chapters there will be an introduction and results presented about the methods and their adjoining projects. The two methods explored in this thesis are the culmination of research into operational barrier performance since 2003, and considerable research and studies have been made, and are still ongoing.

2.2 The BORA method

In Norway the Petroleum Safety Authority has high demands to the risk analyses and safety barriers of an oil and gas installation. Current practise is that the quantitative and qualitative risk analyses being performed (for QRAs and other purposes) mainly focus on the consequence reducing (reactive) barriers, and that the probability reducing (proactive) barriers receive less focus. The need for proactive risk analysis tools spurred the BORA project, and the BORA-release method was developed (Rausand & Utne, 2009).

The BORA-release method (in the future referred to as BORA or BORA method) is both a quantitative and qualitative tool for analyzing the performance of safety barriers. The method incorporates operational conditions, human and organizational factors, as well as technical conditions. This is one of the few tools that manage to incorporate all of these factors that influence the accident sequence. This also makes the method somewhat complex and requires that the user have extensive knowledge of the different risk analysis tools included. The BORA method is mainly a tool developed for the operational phase of oil and gas installations. The purpose is to calculate how changes in activity have on the risk for hydrocarbon leaks, and in turn major accident hazard (Rausand & Utne, 2009). Since the method introduces a way to incorporate operational conditions, human factors, and organizational factors, one can also study how these platform specific factors influence the barrier performance. The BORA method comprises of eight steps that will be elaborated below (Aven, Sklet, & Vinnem, 2006). The project did a thorough evaluation of twenty of the most exposed release scenarios that represents potential for a major hazard accident. The scenarios were selected based on accident statistics, incident reports, and literature concerning loss of containment (Sklet(b), 2005).

The eight steps follow a certain work flow. The work flow presented in the BORA method can be illustrated by separating the need for quantitative and qualitative modelling, as seen in figure 1.

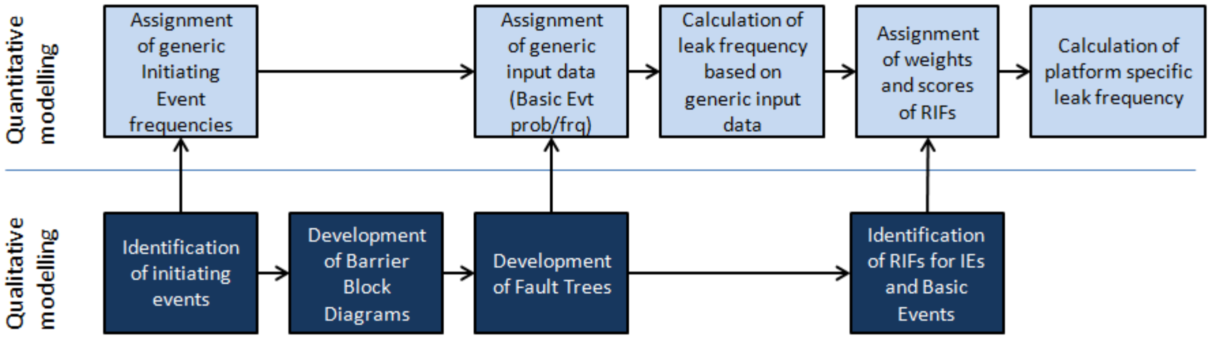


Figure 1: An overview of the main steps in the BORA method. Adapted: (Seljelid, Haugen, Sklet, & Vinnem, 2007, s. 4).

Step 1 – Development of basic risk model, including release scenarios

The first step in the model is to develop a basic risk model that incorporate and display the representative set of hydrocarbon release scenarios. With the purpose of identifying, illustrate, and describe the scenarios, the barrier block diagram was chosen as the best tool to illustrate barrier interaction to prevent hydrocarbon release (Aven, Sklet, & Vinnem, 2006).
The barrier block diagram consists of an initiating event, barrier functions and arrows to show the event sequences, and possible end events or outcomes. In the diagram a horizontal arrow indicates that the barrier fulfils its function, and a vertical arrow indicates that the barrier fails to fulfil its function. According to the project and the hydrocarbon release scenarios, a gas and/or oil release (including condensate) from the process flow, well flow or flexible risers with a rate bigger than 0,1 kg/s defines the minimum rate that can be defined as a release. Minor release and diffuse discharge defines the leaks smaller than 0,1 kg/s. The barrier diagram also corresponds to an event tree and can therefore be used to make a quantitative analysis (Aven, Sklet, & Vinnem, 2006).

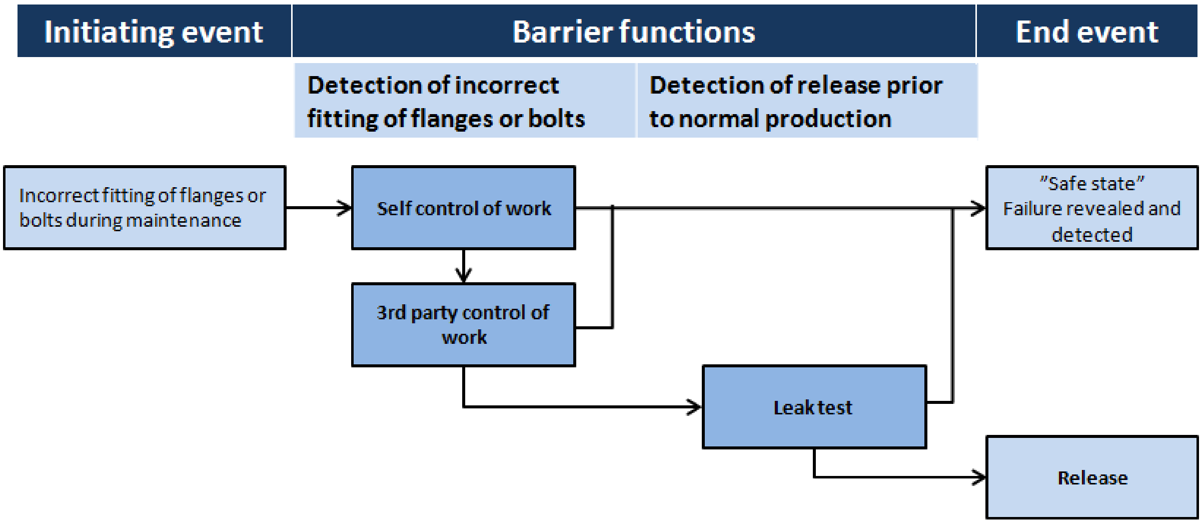


Figure 2: Example of a barrier block diagram; scenario "Release due to incorrect fitting of flanges or bolts during maintenance. Adapted: (Aven, Sklet, & Vinnem, 2006, s. 683).

Step 2 – Modelling the performance of safety barriers

This step is to analyze the plant specific barrier performance. To model the safety barriers performance, considerations must be made in regards to the platform specific conditions concerning human, operational, organizational, and technical factors. A number of attributes are key to barrier performance and taken into the analysis. Highly relevant factors are: functionality or effectiveness, reliability/availability, response time, robustness, and the triggering event or condition (Aven, Sklet, & Vinnem, 2006).
In the BORA method fault tree analysis is used to analyze the barrier performance. The method sets a generic top event in the fault tree analysis to "Failure of a barrier system to perform the specified barrier function". This generic top event is adapted to each specific barrier in the different scenarios, like "Mechanician fails to detect an incorrect fitted flange or bolt by self control" for the first barrier, seen in figure 2. From this modelling, the qualitative results from the fault tree analysis are a list of basic events and an overview of (minimal) cut sets (Aven, Sklet, & Vinnem, 2006).

At the start of chapter 2.1 it is explained that the BORA method contains certain elements that gives it an advantage over the current QRA practise. These advantages can work as an extension to current practise. Due to the broad view on safety barriers, the BORA method can incorporate performance of operational barriers like the performance of the shutdown system, 3rd party control of work, and the inspection program. Therefore systems like these must be analysed. The use of the barrier block diagram creates a link between the fault tree analysis and the performance of the safety barriers since they are directly linked to the event tree in one common risk model. Surely the fault tree analysis cannot cover all aspects necessary to chart the barrier performance, other analyses like human reliability analysis (HRA), analysis of fire and explosion loads, impairment analysis, qualitative assessments of barrier funtionality, or others, may be necessary. This solution with the barrier block diagram and fault trees creates the possibilty to show the barriers represented in a way that gives a clear an consistent image of the barriers, their connections, and their occurence in the system or in time, along with a seperate analysis of each barrier with a desired level of detail. The use of these tools provides a possibility to provide a generic tool since many platform will have a similar set-up, and while the detailed analysis of the seperate safety barriers may be platform specific (Aven, Sklet, & Vinnem, 2006).

Step 3 – Assignment of industry average/frequencies and risk quantification based on these probabilities/frequencies

Step 3 is where one assigns probabilities/frequencies to the initiating events and the basic events found in the fault trees. These probabilities/frequencies are used to perform a quantitative analysis for the risk of hydrocarbon release (for both the event trees and fault trees). These calculations apply plant specific data if possible to reflect local conditions, but in practise extensive use of industry averages will be necessary to perform the quantitative analysis. The plant specific data is usually found in the incident databases, log data, and maintenance databases. There are several databases available like OREDA for equipment reliability, and many more found at the ROSS website (ROSS, NA). A few databases exist for human reliability as well. When performing analyses such as these, a discovery is quickly made that neither plant specific nor generic data is available. In these cases the use of expert judgment to assign probabilities will be necessary (Aven, Sklet, & Vinnem, 2006).

To assign industry average probabilities/frequencies may cause some headache. Many industry averages may be found in generic databases and platform specific information on operational conditions can be collected. On the other hand it can be extensive work to recover data from internal sources since these data are not adapted to the method, and will often require much interpretation. The novelty aspect of the method creates an information shortage for certain barriers, since data has never been recorded for these before. This will to some degree apply to human reliability data which is scarce and in need to be collected for the barriers in question. The lack of data will create the need for expert judgement sessions to be able to generate relevent data (Aven, Sklet, & Vinnem, 2006).

Step 4 – Development of risk influencing diagrams

The purpose of this step is to develop risk influence diagrams that incorporate the effect of the plant specific conditions of the human, operational, organizational, and technical RIFs, on the occurrences of the initiating events and the barrier performance. It may in many cases be necessary to develop risk influencing diagrams for each basic event (Aven, Sklet, & Vinnem, 2006). An example of a risk influence diagram can be seen in figure 3 and is the same as the top event exemplified in figure 2.

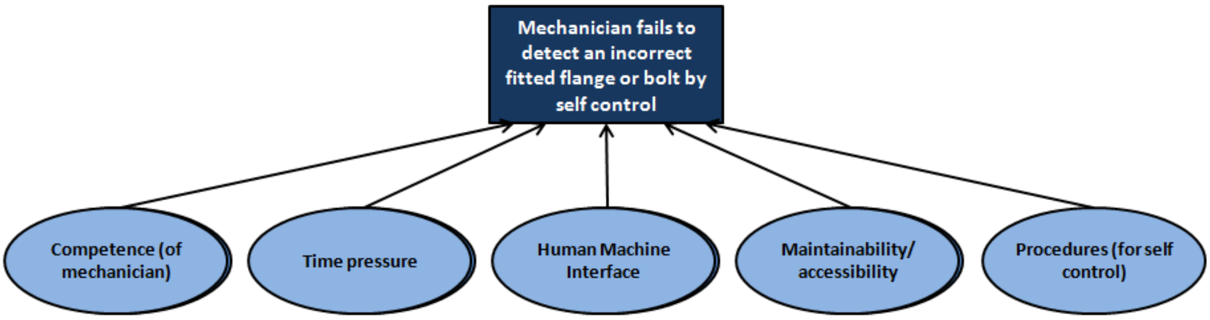


Figure 3: Risk influence diagram; basic event "Mechanician fails to detect an incorrect fitted flange or bolt by self control". Adapted: (Haugen, Seljelid, Sklet, Vinnem, & Aven, 2006, s. A.1.12).

The types of events considered may vary extensively along with the degree of complexity. Therefore a combined approach was preferred when the method was developed. The approach is to identify RIFs based on a top-down approach where a generic list of RIFs are used as a basis, and a bottom-up approach where the events are chosen as a starting point. This means that one will identify specific RIFs for each initiating event and use the list to identify the *basic events*. The list of generic RIFs may be supplemented with new ones when necessary (Aven, Sklet, & Vinnem, 2006). New RIFs for cold climate operations will be addressed later in chapter 3.2 and tested in chapter 6.2.

A framework has been developed for identification of RIFs. The framework has five main groups:

- Characteristics of the personnel performing the tasks.
- Characteristics of the tasks being performed.
- Characteristics of the technical system.
- Administrative control (procedures and disposable work description).
- Organizational factors/operational philosophy.

The experience with the BORA case studies has along with review, comparison and synthesis of several schemes of classification of human, technical, and organizational (MTO) factors, have given a proposed RIF framework. The framework is presented in table 3 and includes a column describing the separate RIFs (Aven, Sklet, & Vinnem, 2006).

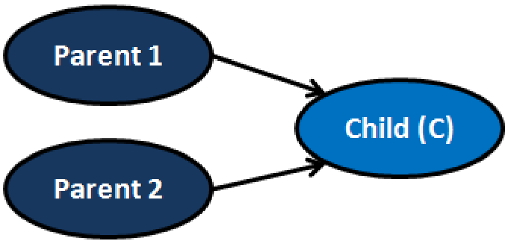
Table 3: Description of RIFs used in the BORA project. Adapted: (Aven, Sklet, & Vinnem, 2006, s. 685).

RIF group	RIF	RIF description
Personal characteristics	Competence	Cover aspects related to the competence, experience, system knowledge and training of personnel
	Work load/stress	Cover aspects related to the general working load of persons (the sum of all the tasks and activities)
	Fatigue	Cover aspects related to fatigue of the person, e.g. due to night shift and extensive use of overtime
	Work environment	Cover aspects related to the physical working environment like noise, light, vibration, use of chemical substances, etc.
Task characteristics	Methodology	Cover aspects related to the methodology used to carry out a specific task
	Task supervision	Cover aspects related to supervision of specific tasks by a supervisor (e.g. by operations manager or mechanical supervisor)
	Task complexity	Cover aspects related to the complexity of a specific task
	Time pressure	Cover aspects related to the time pressure in the planning, execution and finishing of a specific task
	Tools	Cover aspects related to the availability and operability of necessary tools in the order to perform a task
	Spares	Cover aspects related to the availability of the spares needed to perform the task
Characteristics of the technical system	Equipment design	Cover aspects related to the design of equipment and systems such as flange type (ANSI or compact), valve type, etc.
	Material properties	Cover aspects related to properties of the selected material with respect to corrosion, erosion, fatigue, gasket material properties, etc.
	Process complexity	Cover aspects related to the general complexity of the process plant as a whole
	HMI	Cover aspects related to the human-machine interface such as ergonomic factors, labelling of equipment, position feedback from valves, alarms, etc.
	Maintainability/accessability	Cover aspects related to the maintainability of equipment and systems like accessability to valves and flanges, space to use necessary tools, etc.
	System feedback	Cover aspects related to how errors and failures are instantaneously detected, due to alarm, failure to start, etc.
	Technical condition	Cover aspects related to the condition of the technical system
Administrative control	Procedures	Cover aspects related to the quality and availability of permanent procedures and job/task description
	Work permit	Cover aspects related to the system for work permits, like application, review, approval, follow-up, and control
	Disposable work description	Cover aspects related to the quality and availability of disposable work description like safe job analysis (SJA) and isolation plans
Organizational factors/operational philosophy	Programs	Cover aspects related to the extent and quality of programs for preventive maintenance (PM), condition monitoring (CM), inspection, 3rd party control of work, use of self control/checklists, etc. One important aspect is whether PM, CM, etc. is specified
	Work practice	Cover aspects related to common practice during accomplishment of work activities. Factors like whether procedures and checklists are used and followed, whether shortcuts are accepted, focus on time before quality, etc.
	Supervision	Cover aspects related to the supervision of the platform like follow-up of plans, deadlines, etc.
	Communication	Cover aspects related to communication between different actors like area platform manager, supervisors, area technician, maintenance contractors, CCR technicians, etc.
	Acceptance criteria	Cover aspects related to the definitions of specific acceptance criteria related to for instance condition monitoring, inspection, etc.
	Simultaneous activities	Cover aspects related to amount of simultaneous activities, either planned (like maintenances and modifications) and unplanned (like shutdown)
	Management of changes	Cover aspects related to the changes and modifications

The top-down approach when developing the risk influence diagrams gives the opportunity to define the RIFs in the same manner for different analyses, and the bottom-up approach ensures that new/unique RIFs may be discovered and assessed for platform specific conditions. The RIF framework presented in this sub-chapter, includes factors influencing hardware failure events. This seperates the BORA method from traditional performance influencing factors that mainly focuses on factors influencing human failure events. The case studies have determined that the main RIF groups are adequate for identifying RIFs, but the list in table 3 may be supplemented. This is to be able to cover all the basic events included in the analyses of barrier performance. This creates a "living" list that may be revised in the future when higher user experience is achieved (Aven, Sklet, & Vinnem, 2006).

To develop the risk influencing diagram the method uses *Bayesian Belief Networks (BBN)* to illustrate how the different RIFs influence the barrier function. For simple barriers the BBN can show directly how the RIFs influence the barrier. Most barriers in the oil and gas industry are complex and will demand that a fault tree is constructed and then one may assign RIFs to the basic events and initiating events (Rausand & Utne, 2009).

When performing quantitative analysis of a BBN, a random variable like X_i is attached to each node and usually given a number like 0 and 1 to represent the state. The node is assumed to have two or more states, like on/off, functioning/non-functioning, etc. It is advised to limit the amount of states since it easily increases the amount of calculations drastically. For each node a conditional probability table (CPT) must be made. For the nodes that do not have a parent node, an estimate of the probability distribution has to be made for the variables X_i. This could be from available data or expert assessment. For the nodes with parent nodes the probability distribution has to be made for all the different combinations that the parent nodes can be found in (Rausand & Utne, 2009).



Parent nodes		Child [P(C|parent)]	
Parent 1	Parent 2	True	Wrong
Wrong	Wrong	0,10	0,90
Wrong	True	0,25	0,75
True	Wrong	0,50	0,50
True	True	0,95	0,05

Figure 4: An example of a simple BBN and adjoining CPT. Adapted: (Rausand & Utne, 2009, s. 190).

As seen in figure 4, the sum of the CPT in each line is equal to 1, and all conditions are present. This can also be done for fault trees where all the minimum cut sets have to be used. It is important to remember that parent nodes are nodes with direct influence on the child node. The probability of the child's condition is calculated by using Bayes formula. The bigger the BBN, the bigger and more complicated this will be to calculate, and the complexity increases rapidly from simple diagrams to bigger ones. A condition for using Bayes formula is that two nodes will be independent given that all the conditions for the parent nodes are known, also known as conditional independence (Rausand & Utne, 2009).

Step 5 – Scoring of risk influencing factors

In this step the platform specific condition of the RIFs are assessed. The aim is to assign a score to each identified RIF in the risk influence diagrams. The RIFs will be given a score from A to F, where A corresponds to the best standard in the industry, C corresponds to industry average, and F corresponds to worst practice in the industry (Aven, Sklet, & Vinnem, 2006). The scoring can be found in table 4.

Table 4: The generic scheme for scoring of RIFs. Adapted: (Aven, Sklet, & Vinnem, 2006, s. 686).

Score	Explanation
A	Status corresponds to the best standard in the industry
B	Status corresponds to a level better than industry average
C	Status corresponds to the industry average
D	Status corresponds to a level slightly worse than the industry average
E	Status corresponds to a level considerably worse than the industry average
F	Status corresponds to the worst practice in the industry

Three methods are emphasised in the literature for scoring of RIFs. The first is through direct assessment of the RIF status. A RIF audit is done for the RIFs in the risk influence diagrams, and is carried out through structured interviews of key personnel on the plant and observation of work performance. Surveys may in addition be used as a part of the RIF audit and as supplement to other techniques.

The second method for scoring is through a review method from Statoil's technical safety and barrier management project, the TTS project. This project was developed to map and monitor safety critical barriers. The condition of the barriers are measured through a review technique and measured up against predefined performance standards (PS). Several techniques are available to check the performance requirement. The six-point scoring scheme can be directly transferred to the scores found in table 4.

The third method is based on the data from the bi-annual questionnaire in the RNNS project, the RNNS project, and accident investigations. The RNNS questionnaire is broad and addresses general health, environmental, and safety (HSE) aspects, risk perception, and safety culture. From the questionnaire and project, industry averages and platform specific data can be extracted. To follow the scoring scheme, further analysis will be required. Results from accident investigations are used more as a supplement to the RNNS data (Aven, Sklet, & Vinnem, 2006). The RNNS project is developed to monitor the trends and conditions of the safety level and HES levels on the NCS.

The six-point scoring scheme used in step 5 to assign a score to the RIFs are misaligned. With a score of C representing the industry average, there are two scores above average and three for below average scores. This is due to the already high level of safety in the industry, and the assumption that there is as a consequence a higher potential for decline in safety than improvement. For the three methods mentioned for scoring of RIFs, the methods may be used seperately or combined. The first method with RIF auditing is by far the most resource demanding, but it gives a direct assessment and can ensure a high validity. Here there is a demand for better aids for the execution of the RIF scoring. Useful aids like the behavioural checklists and behavioural anchored rating scales (BARS), and tools like this can help create consistency in the scoring process. The second approach, the TTS requires some carefull assessment before use. The TTS data have a similar six-point scale, but is measured against a PS and not an industry average that can be transformed to BORA scores. The TTS data is from a project conducted on several platforms on the NCS, so the data is relatively easy to use. There are some disadvantages to this approach since the project revolved around status of technical aspects of the consequence reducing barriers, and therefore little is known of the organizational factors. The assessments are carried out several years in advance and may be outdated from a time aspect, and finally the data may be lacking in relevance since the original data and assessments was performed for another purpose. The third approach, is the use of data from the RNNS survey and accident investigations. There is one main advantage with the RNNS data, and that is platform specific data are available. On the other side there are several disadvantages. The biggest is the low validity since the questions in the survey are not developed for this purpose, and rather general and not specific for the specific RIFs. Another important aspect is the bi-annual nature of the survey, where the result from the last survey may not be up to date when applied. The last point is that the answers may be influenced by other factors, like general dissatisfaction with the working conditions. This may affect the data and render them irrelevant for the analysed RIF (Aven, Sklet, & Vinnem, 2006). The approach to scoring of RIFs have a clear data deficiency as seen above, but have other very good resources available for the scoring. Future data and questionnaires may bridge this gap and create more applicable data.

A rule of thumb has been proposed to preserve the credibility of the assessment when scoring the RIFs and selecting approach. The rule is that, the more detailed, specific, and resource demanding the assessment is, the more credible the result will be. This must be evaluated and balanced against how much resources are available and excisting data to minimize the use of resources. This will be an argument from the oil companies, where the use of resources will always be an important factor (Aven, Sklet, & Vinnem, 2006).

Step 6 – Weighting of the risk influencing factors

The purpose of this step is to assess the effect of the RIFs and the importance RIFs has on the frequency of occurrence of the basic events. The weights correspond to the relative difference in the frequency of occurrence of an event if the status of the RIF is changed from best standard A, to worst practice F. The weighting is done by expert judgement through discussion with platform personnel and analysts where the following principles are applied (Aven, Sklet, & Vinnem, 2006, s. 686):

1. Determine the most important RIF based on general discussions.
2. Give this RIF a relative weight equal to 10.
3. Compare the importance of the other RIFs with the most important one, and give them relative weights on the scale 10-8-6-4-2.
4. Evaluate if the results are reasonable.

The weighting of the RIFs are normalized as the sum should be equal to 1 (Aven, Sklet, & Vinnem, 2006).

A simple technique for weighting of RIFs is proposed through the use of expert judgement. Several factors speaks to its advantage. The process of weighting is easy to carry out in practice. The result is unambigious and provides good traceability. Another key aspect is the involvement of operational personell working on the platform for the identification, scoring, and weighting of the RIFs. This is argumented by the fact that nobody is as competent to perform these steps as the operational personnel itself. It is also crucial that a risk analyst should guide the operational personnel through the weighting process (Aven, Sklet, & Vinnem, 2006).

Step 7 – Adjustment of industry average probabilities/frequencies

In this step, by using industry average probabilities/frequencies, the purpose is to assign platform specific values to the input probabilities/frequencies allowing for platform specific conditions of the RIFs. This will be an adjustment to the quantitative analysis of the industry average probabilities/frequencies. The adjustment is made through an assessment of the weights and the status of the RIFs (Aven, Sklet, & Vinnem, 2006). The BORA method proposes the following method for the adjustment of the industry average probabilities/frequencies:
By defining $P_{rev}(A)$ to be the "installation specific" probability/frequency of occurrence of event A. The probability $P_{rev}(A)$ is determined through the following formula (Aven, Sklet, & Vinnem, 2006):

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

Where $P_{ave}(A)$ denote the industry average probability of occurrence of event A, w_i denotes the weight or importance of RIF number *i* for event A, Q_i is a measure of the status of RIF number *i*, and *n* is the number of RIFs. Like step 6 mentions (Aven, Sklet, & Vinnem, 2006):

$$\sum_{i=1}^{n} w_i = 1 \qquad (2)$$

The next challenge is to determine appropriate values for Q_i and w_i. In order to do that a proposed method to determine the Q_i's looks like this (Aven, Sklet, & Vinnem, 2006):

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

$$Q_i(s) = \begin{cases} P_{low}/P_{ave} & if\ s = A \\ 1 & if\ s = C \\ P_{high}/P_{ave} & if\ s = F \end{cases} \qquad (3)$$

Where s denotes the score or status of RIF number i (Aven, Sklet, & Vinnem, 2006).

To explain how to set the values of Q_i a couple of rules have been made. If the score s is A, and $P_{low}(A)$ is 10% of $P_{ave}(A)$, then Q_i is equal to 0,1. The other way around we have if the score s i F, and $P_{high}(A)$ is 10 times higher than $P_{ave}(A)$, then Q_i is equal to 10. If the score s is C, then Q_i is equal to 1. Furthermore, if all RIFs have the same score, A, C, or F, then $P_{rev}(A)$ is equal to $P_{low}(A)$, $P_{ave}(A)$, or $P_{high}(A)$ (Aven, Sklet, & Vinnem, 2006).

To set values for Q_i when s=B, s=D, and s=E, there is assumed a linear relationship between $Q_i(A)$ and $Q_i(C)$, and between $Q_i(C)$ and $Q_i(D \text{ or } E)$. By using $s_A=1$. $S_B=2$, $s_C=3$, $s_D=4$, $s_E=5$, and $s_F=6$, the values for s=B, S=D, and s=E are calculated like this (Aven, Sklet, & Vinnem, 2006):

$$Q_i(B) = \frac{P_{low}}{P_{ave}} + \frac{(s_B - s_A)(1-(P_{low}/P_{ave}))}{s_C - s_A} \qquad (4)$$

$$Q_i(D) = 1 + \frac{(s_D - s_C)((P_{high}/P_{ave})-1)}{s_F - s_C} \qquad (5)$$

The score for $Q_i(E)$ is calculated the same way as $Q_i(D)$, but s_D is exchanged for s_E in formula (5) (Aven, Sklet, & Vinnem, 2006).

In this step the use of upper (P_{high}) and lower (P_{low}) values act as anchor values and contribute to give credability to the result. The range size in the probability will obviously affect the final result. A wide range in the probability will imply a possibility for major change in the risk level, and a small range will imply a minor change in the risk level. The limits are established by expert judgement, and if possible supported by experience data. There is another approach that can be used to determine the upper and lower values. Through the use of failure rates and upper and lower bounds presented in generic databases like OREDA, etc, ranges can be set. There is an assumed linear relationship between $Q_i(A)$ and $Q_i(C)$, and $Q_i(C)$ and $Q_i(F)$ respectively, but other relationships may be assumed. These linear relationships shows that the risk improvement potential is less than the risk worsening potential. This may be explained by the already low risk level in the industry due to high safety focus for several years (Aven, Sklet, & Vinnem, 2006).

Step 8 – Recalculation of the risk in order to determine the platform specific risk related to hydrocarbon release

The last step in the BORA method is to apply all the platform specific input probabilities/frequencies, $P_{rev}(A)$, and insert them for all the events in the risk model. Then the platform specific risk of hydrocarbon release can be calculated. By using these revised probabilities the result is an updated risk picture that includes an analysis of the performance of the safety barriers introduced to prevent hydrocarbon release. This revised risk picture takes the platform specific conditions of human, operational, technical, and organizational RIFs into consideration (Aven, Sklet, & Vinnem, 2006).
Recalculation of the risk is the final step in the BORA-release method. The new platform specific risk calculated through revised probabilities is fairly straightforward as long as the previous steps have been carried out (Aven, Sklet, & Vinnem, 2006).

The new and recalculated risk picture by using the BORA method will give valuable input to the decisionmakers. Improved knowledge is obtained about existing and non-existing safety barriers and better understanding of the influence of the RIFs. The increase in knowledge about qualitative aspects are important results in itself, aside from the quantitative results. As for all other risk analyses the quantitative results from the method will rely on a set of assumtions, and a slight change or adjustment in the scaling or input data will affect the final numerical results. The decision-makers using the method should take into account the assumptions and not rely solely on the numerical result of the analysis. This will make the decision-makers look at the result in a broader context and take limitations and constraints of the analysis into account (Aven, Sklet, & Vinnem, 2006).

2.3 The Risk OMT project

The Risk OMT (Risk modelling – Integration of Organizational, Human and Technical factors) program is a further development of the BORA project and the OTS project with the intention to develop more representative models for the calculation of leak frequencies as a function of the volume of manual interventions. The Risk OMT program has a higher emphasis on making more comprehensive modelling of RIFs and how these affect the performance of operational barriers. In general the approach will be the same as in the previous projects but more developed. The objective of the program is to provide new knowledge and tools through improved understanding of the influence factors (human, technical and organizational) for the major risk management of plants and platforms. The quantitative model developed in the project can take both “soft” and “hard” RIFs into account and is very much suited to assess the effects of improving the status of the RIFs. Both of these factors were the research objectives for the project (Vinnem, et al., 2012).

The BORA project was concluded in 2006 and the result was a generalized, but relatively course methodology. This was based both on the initial methodology formulation as well as the experience gained from the case studies. The RIF structure in the BORA method is structured in one layer where all the RIFs were given the same structural importance. In the method the scores from the RIFs were used together with the weights of the RIFs to calculate the adjustment factors for the HEP. The OTS project was based on the BORA project and gave the opportunity to study the human and organizational factors in more detail. The project objective was to have a system to assess the operational safety condition on a plant/platform. The project had a special emphasis on how the operational barriers contribute to prevent major hazard accidents and how organizational and human factors affect the barrier performance. As described earlier there was a need for dedicated surveys questionnaire against work practice for interventions and associated functions, and this was developed in the OTS project. This survey may be used as a main basis for the scoring of RIFs, and seven performance standards were created (Vinnem, et al., 2012, s. 276):

1. Work practice
2. Competence

3. Procedures and documentation
4. Communication
5. Workload and physical working environment
6. Management
7. Management of change

There are various types of human failures that can cause process leaks during maintenance operations. Both BORA and Risk OMT categorize equipment as either hydrocarbon containing equipment or other (this group of equipment can only lead to a leak through indirect actions, like dropped or swinging objects). Focus is mainly on the first category since it may lead directly to a leak. Errors that may lead to a leak for the hydrocarbon containing equipment is split in three with respect to the execution of maintenance work (Vinnem, et al., 2012, s. 277):

- Work on pressurized, hydrocarbon containing equipment
- Work on isolated and depressurized, hydrocarbon containing equipment
- Work on other equipment and structures

In the Risk OMT project the main focus is on human failures connected to maintenance work and the main group of initiating event or scenarios are: B: Human intervention introducing latent error, or C: Human intervention causing immediate release (Vinnem, et al., 2012). These scenarios contain work on equipment containing hydrocarbons and will also be used for the simulations in this thesis. The initiating events can be found in table 5. The overall model in the Risk OMT project takes contributions to risk by the model previously explained using barrier block diagrams/event trees, fault trees, and risk influence diagrams (simplified BBN model). This approach is very similar to the BORA approach. The B1 scenario was used in the project for model testing, verification, and validation, to confirm all the building blocks of the total model (Vinnem, et al., 2012).

Table 5: Overview over work operations and initiating events used in the Risk OMT project. Adapted: (Vinnem, et al., 2012, s. 278).

Type of initiating event	Type of operation							
	Pressurized equipment				Depressurized equipment		Other work in process area	Quantity of equipment
	Normal operation	Preventive maintenance/ inspection	Sampling	External	Major unit	Small unit		
A1 Degradation of valve sealing								X
A2 Degradation of flange gasket								X
A3 Loss of bolt tensioning								X
A4 Fatigue								X
A5 Internal corrosion								X
A6 External corrosion								X
A7 Erosion								X
A8 Other								X
B1 Incorrect blinding/isolation					X	X		
B2 Incorrect fitting of flanges or bolts during maintenance					X	X		
B3 Valve(s) in incorrect position after maintenance		X			X	X		
B4 Erroneous choice of installation of sealing device					X	X		
B5 Maloperation of valve(s) during manual operations	X	X			X	X		
B6 Maloperation of temporary hoses	X				X	X		
C1 Breakdown of isolation system during maintenance (technical)					X	X		
C2 Maloperation of valve(s) during manual operations	X	X	X		X	X		
C3 Work on wrong equipment (not known to be pressurized)					X	X	X	
D1 Overpressure	X							
D2 Overflow/over filling	X							
E1 Design related failures								X
F1 Impact from falling object				X	X	X	X	
F2 Impact from bumping/collision				X	X	X	X	

The project has further developed the model presented in figure 19 to include the work operations and connect them with the initiating events that can be produced from deviations caused in the operation. From this there is now an opportunity to take into consideration activity that will require coincident planning for several tasks, and take into account coordination during the planning and execution phases. This gives the analyst the possibility to assess activities that may take place at the same time, and incorporate how to incorporate such circumstances for the RIF influence modelling in order to enable consideration of dependencies. This gives the new model the ability to calculate the risk from each scenario through using the amount of maintenance activity as input in the overall model. The model developed assumed maintenance activity on a major unit containing depressurized equipment (Vinnem, et al., 2012).

This new way of modelling gives a starting point where a set of work operations are defined as seen to the left in figure 20. As defined in the project, the various types of human intervention causing initiating events that can cause a leak scenario comes next. Further there will be barriers in place to prevent the the IE from causing the leak, and the performance of the barriers and IE will be modelled using FTA. Last there is the modelling of the RIFs and how the human and organizational factors affect the basic events. In figure 20 the scenario caused by IE B1-B4 are modelled together. The work operation "Work on isolated depressurized equipment" is shown in figure 5 with the tasks and sequencing as an event tree (Vinnem, et al., 2012).

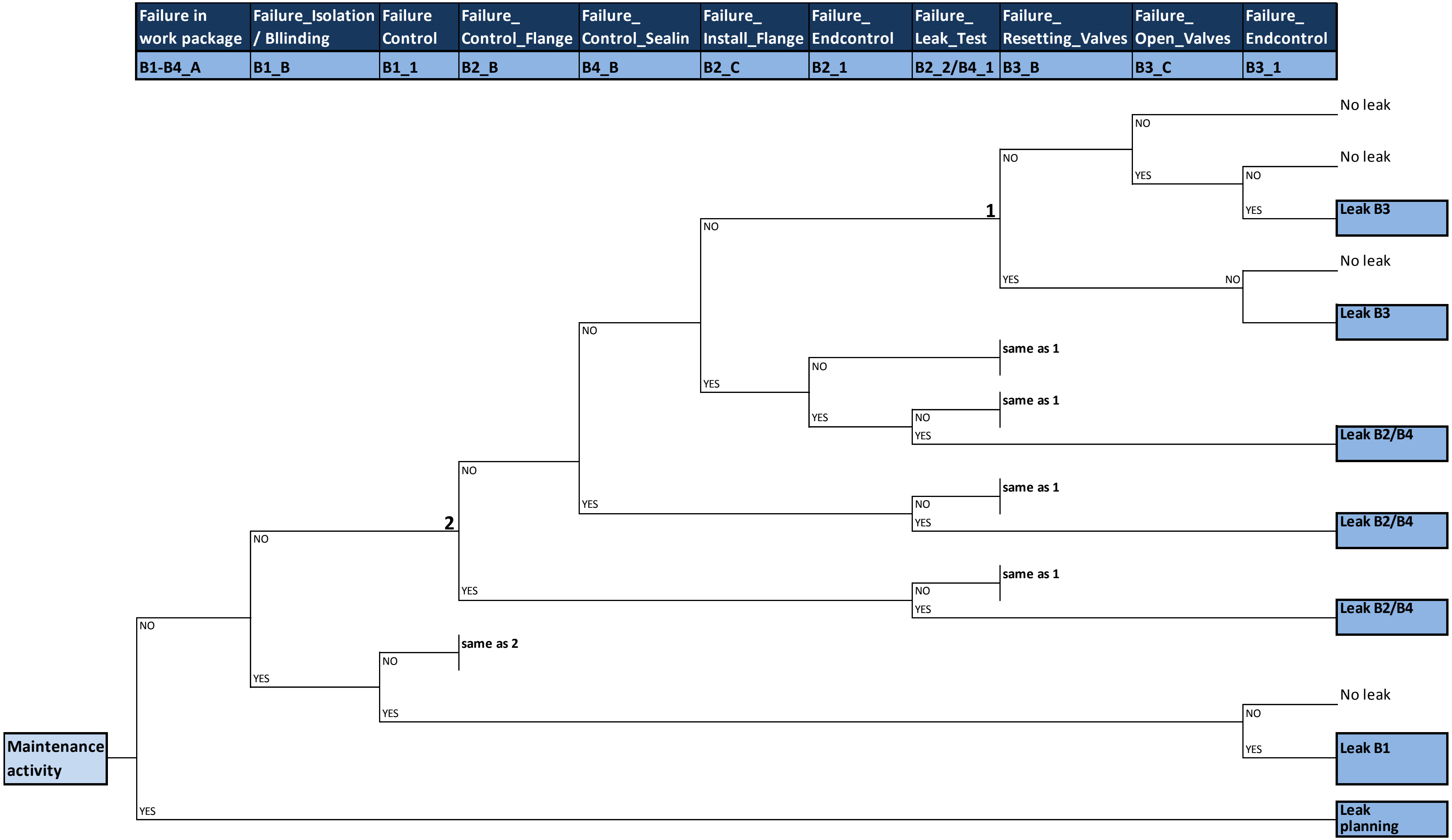


Figure 5: The leak scenario work on isolated pressurized equipment illustrated by an event tree from the Risk OMT database. Adapted: (Vinnem, et al., 2012, s. 279).

As seen in figure 6 leaks can occur if the barriers fail (the correct performance of a task is considered a barrier). These barriers and IE are modelled by FTA and the top events are often categorized as a failure to perform the task, etc. This relates to the failure to detect an error introduced in the system. The project divides the cause for a top event into two groups, the first is an inadequate or insufficient "functionality" of the work task or barrier system. This can be that the barrier system is not specified or not used. This is described as a "failure of omission". The second one is human failure and cover "violations"and human errors, these are categorized into "mistakes" and "slips and lapses" related to preparation and performance of the work. The tree types of failures are described as "Error of execution". The updated fault tree model for B1-B4_A "Failure in work package" can be seen in figure 6. The figure shows that the failure in the work package is caused by both a failure in the planning (B1-B4_Aa) and a failure in the control of the planning (B1-B4_Ab). The probability of the top event is distributed between between the events in each layer and then again within each branch (Vinnem, et al., 2012).

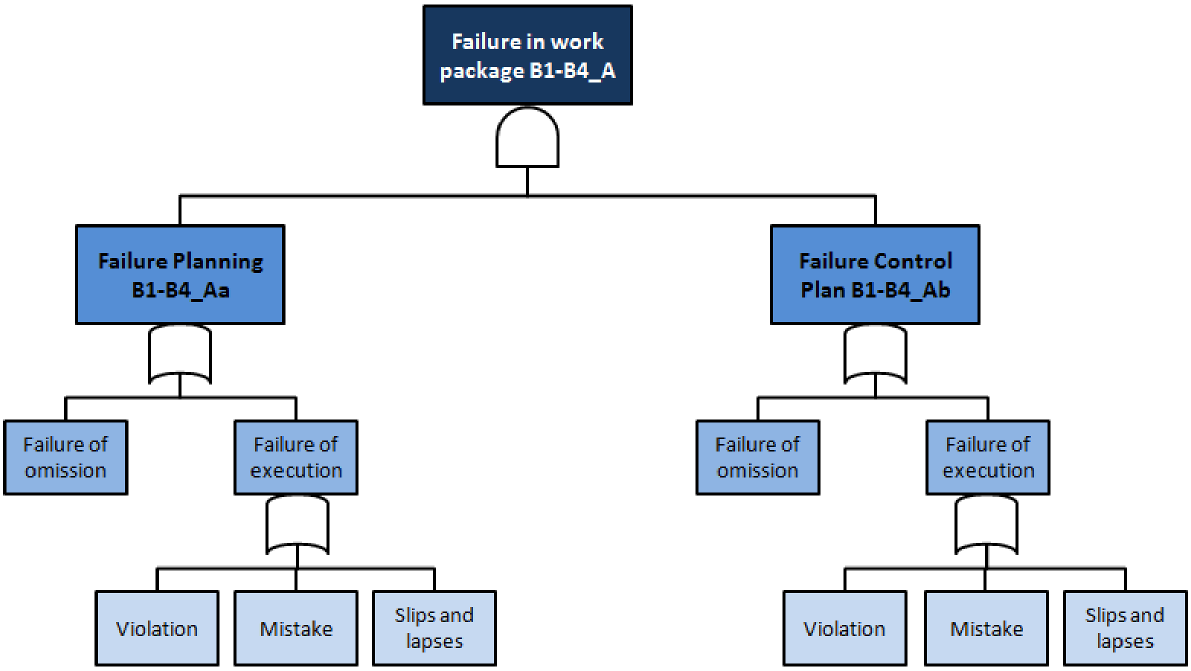


Figure 6: Basic event; a failure in work package. A fault tree model for B1-B4.A. Adapted: (Vinnem, et al., 2012, s. 280).

As seen above in the basic event model, failure of an activity is divided into the categories, failure of omission and failure of execution. The research in the project showed that execution errors were more important for leaks and therefore omission failures will only be based on historical data, but future versions wants to have a more thorough analysis of omission failures. Here failure of omission will describe some prescribed activity that is left out or not performed. Failure of execution aims at inadequate actions that can cause a failure, this can be a series of actions in wrong sequence, at the wrong time, without the right precision, etc. The taxanomy of human failure that the project does, enables a differentiation between violations and human error, and a differentiation between different mistakes and slips and lapses. By using this taxanomy the project could find the most predominant execution failures in each activity that may generate an IE (B1-B5 and C1-C3), based on the relationship of the RIFs and the failure of a given activity. After this the project identified possible RIF groups that could have impact on execution failures in the subcategories, and these RIF groups are presented in table 6 (Vinnem, et al., 2012).

Table 6: Description of the generic RIFs used in the Risk OMT project. Adapted: (Vinnem, et al., 2012, s. 291).

RIF	Description	RIF level
Competence	Knowledge, skills and abilities that can contribute to adequate work performance and/or problem solving related to a specific work operation	1
Disposable work description	The availability and readability of the "work package" generated for a specific work operation	1
Governing documents	Written and electronic documents that gives superior guidelines regarding a performance of a specific work operation	1
Technical documentation	Written and electronic aids that describe the design and status of the plant	1
Design	Accessibility and physical working environment, with relevance for correct performance of a work specific work operation	1
HMI	Tagging of equipment and availability of tools, with relevance for correct performance of a specific work operation	1
Communication	Dissemination of information and knowledge with relevance for correct performance of a specific work operation	1
Supervision	Planning, coordination, monitoring, follow-up and improvement of daily work operation, with contribution to safety	1
Time pressure	Perceived time pressure to perform a specific work operation that challenges accuracy and safety	1
Workload	The proportion between work and rest	1
Work motivation	A product of multiple factors regarding the psychological working environment (e.g. cooperation , social support)	1
Management_competence	Management concerning the development and maintenance of relevant competence among staff	2
Management_information	Management concerning the development and maintenance of relevant documentation	2
Management_technical	Management concerning design and HMI	2
Management_task	Management concerning small scale planning, coordination, monitoring, follow-up and improvement	2
Management_general	Management concerning all general aspects not specified in other management categories	2

The examination of the scenarios B1-B5 and C1-C3 scenarios and associated activities lead to the creation of two generic RIF structures for the activity specific RIF structures. The RIF structures are divided into planning activities, and execution and control activities. The RIF identification process in the project resulted in a two level RIF structure. Level 1 represents RIFs that have a theoretical and empirical justifiable direct influence on one or more of the error types. Level 2 consists of different management aspects that have a theoretical and empirical justifiable direct influence on the RIFs on level 1. The purpose of this two level structure is to emphasise and elucidate how underlying impacts from managerial decisions can have on the probabilities of human failure. In the model only the RIFs on level 1 are considered to have a direct influence on the basic events. The RIFs on level 2 are only considered to have influence on level 1 with the prospect of reducing uncertainties for RIFs on level 1 with associated scores. The generic RIF models for both the planning, and execution and control activities are presented in figure 7 and 8. In the planning activities it is assumed that there are some of the same RIFs influencing the error types, but no additional RIFs are introduced.

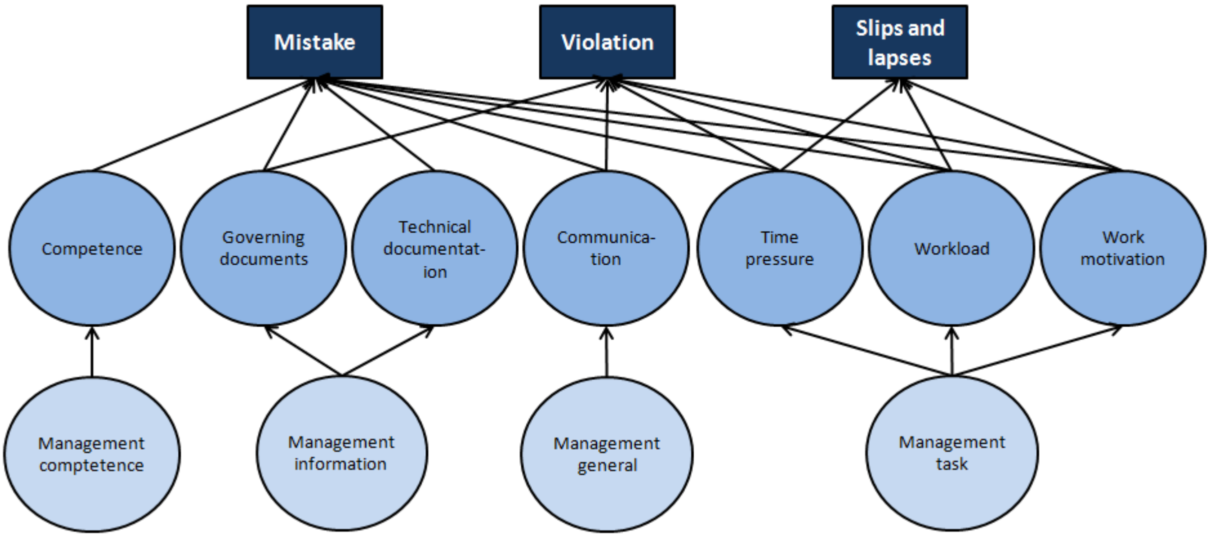


Figure 7: Generic RIF model for planning activities. Adapted: (Vinnem, et al., 2012, s. 281).

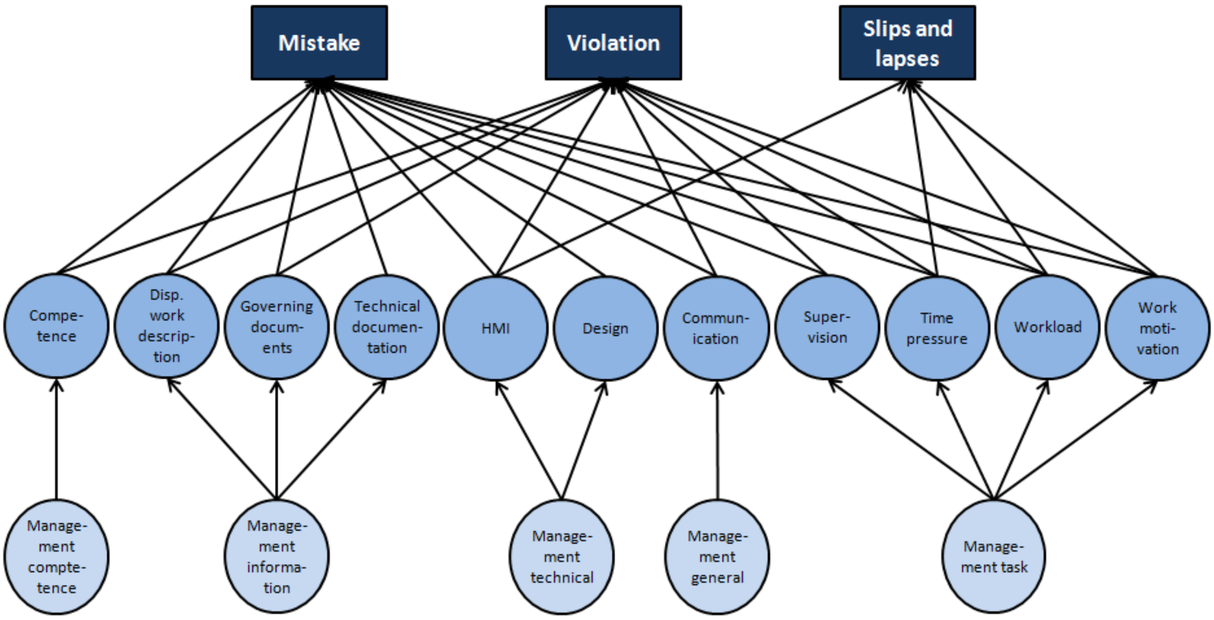


Figure 8: Generic RIF model for execution and control activities. Adapted: (Vinnem, et al., 2012, s. 282).

The structure presented in figure 7 and 8 is the generic RIF model, but will not apply to all the scenarios in question. There has been a need to spilt some of the RIFs in sub categories in some scenarios to differentiate the impact certain RIFs have on some parts of the organization. This can be exemplified through the competence of the process operators versus the mechanics. A split like this was in the project only made when there was significant emphirical basis (Vinnem, et al., 2012).

After the relevant RIFs are identified for each scenario their relevance will be assessed and weighed. The weighing will follow the same principles as stated in step 6 in chapter 2.2, but with some changes. The weights are now categorized as High (H), Medium (M), and Low (L) and will follow the same weighting processes with expert judgement as previously in the BORA project. In addition if there is no relationship identified between an error type and a RIF for a certain scenario then the weight is set to 0. The error type violations will for some scenarios be the same as sabotage which is not modelled, and will not be applicable (NA) and the weight set to 0. The weight are now given the quantitative scale of 5 – 3 – 1, and finalized by normalizing the sum to 1. The condition of the RIFs are still assessed on the scale from A to F representing the score. A score is treated as an observation of the true underlying RIF. In the BBN this will correspond with an arrow from the RIF to the corresponding score. In some cases there will be no available observation of the RIF, in those cases a value equal to the industry average is used (Vinnem, et al., 2012).

Integrating these new aspects into the BBN

In this section there will be a description of how the project models the fault trees and event trees as integral parts of the BBN structure. Each IE and scenario B1-B5 has been implemented into a BBN, but separate. All the nodes are modelled as “labelled nodes” with the states failed/not failed, or A-F as described in the previous section. The upper part of the BBN represents the fault tree and the lower part represents the RIFs and their scoring (Vinnem, et al., 2012).

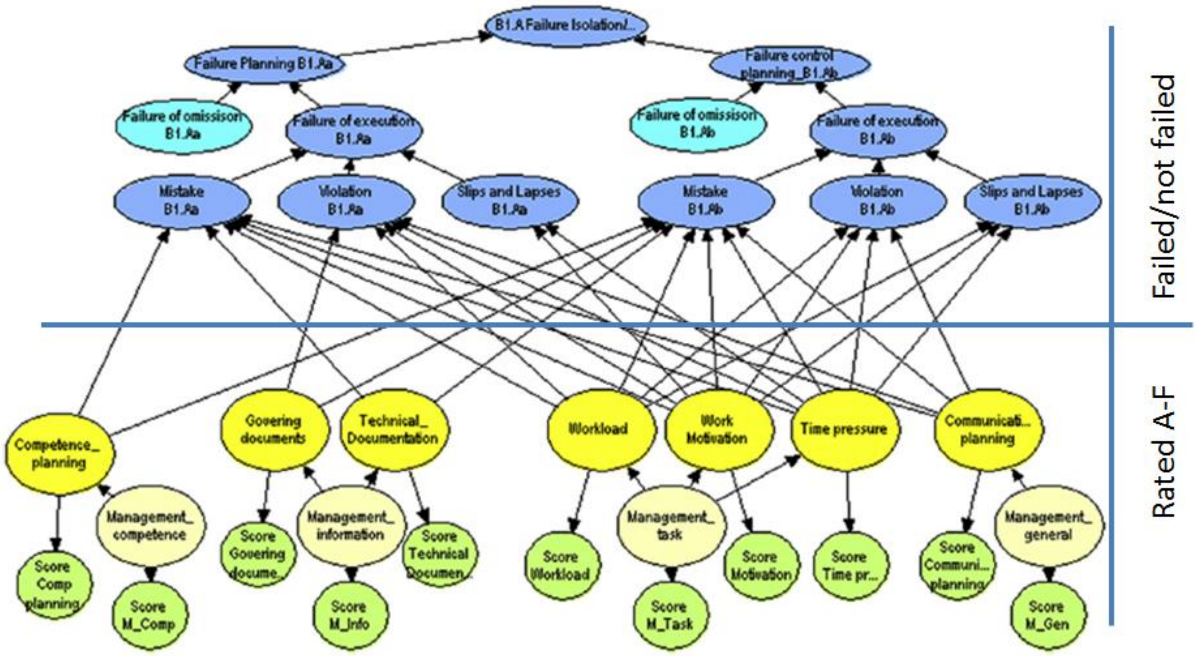


Figure 9: A BBN for the IE B1_A with labelled nodes and states (Vinnem, et al., 2012, s. 282).

The project deals with the conditional probability tables (CPT) by using 0's and 1's in accordance with the structure of the fault tree. Representation of the fault trees AND or OR-gates are in the BBN represented by the 1's and 0's, this can be seen in table 7. As seen in figure 9, the basic events are connected to the RIFs that have a score A-F. The user of the model have to decide how the HEP is to be associated with the characters. The six-point scale used, is adapted from the OTS project and is based on observed values. By using this scale, the HEP data can not be collected as a single probability or average, but the user also has to have access to the spread of the value (be it error fractions or quintiles). From this one has to decide how to apply the average and the spread. The project considered it most appropriate to assign the average HEP to the character C hand, and by using collected error fractions to represent the spread from character C to B and E, and from B to A, and from D to F. With a HEP value of 0,01 would yield a result as seen in table 8 (Vinnem, et al., 2012).

Table 7: Example of how a parent AND-gate and OR-gate with two child nodes are arranged in a BBN CPT. Adapted: (Vinnem, et al., 2012, s. 283).

Child 1	**True**		**False**		
Child 2	True	False	True	False	
True	1	0	0	0	AND
False	0	1	1	1	
Child 1	**True**		**False**		
Child 2	True	False	True	False	
True	1	1	1	0	OR
False	0	0	0	1	

Table 8: Interpretation of a HEP=0,01 value for different error fractions (EF). Adapted: (Vinnem, et al., 2012, s. 283).

Error Fractions	A	B	C	D	E	F
3	0,0011	0,0033	0,0100	0,0173	0,0300	0,0520
5	0,0004	0,0020	0,0100	0,0224	0,0500	0,1118
10	0,0001	0,0001	0,0100	0,0316	0,1000	0,3162

The scoring of the RIFs are based on the approach used in the OTS project and utilizing an questionnaire directly focusing on work practice during manual intervention, and an comprehensive interview scheme with an interview guide. How important the RIF are or how strongly it influence the basic event was modelled by using the assigned weights. The RIFs in the BBN without a parent node is a top node in accordance with BBN theory and is referred to as a RIF on level 2.

The project have used a triangular distribution modal expected value at the "character C" to describe the expected prior in the BBN. The character C still refers to an industry average. By using the triangular distribution the project could fit the entire range of A to F to be covered by significant probability values. In addition to this the expected value for the CPT was equal to the value it was conditioned upon (for example E(RIF|RIF level 2=B)=B). When the RIFs on level 2 are given, the RIFs on level 1 must be assigned given the RIFs at level 2. Based on the underlying documentation from the BORA project it was clear that the CPTs were not the same for each RIF. The structural importance signifying the relationship has been divided into three categories: "low", "medium", and "high". This will show how much weight the parent node on level 2 will have on the child node on level 1. Two distributions were used to ensure that the CPTs covered the entire range from A to F with a significant probability. The condition that the CPT is conditioned upon set the modals of the triangular distributions, like seen earlier. One distribution has a variance that goes over the whole interval (0-6), while the other has a narrow variance around the modal value or a wider variance by introducing a floor. The resulting distribution created is a sum of the two distributions. The weights in the distributions are set by expert judgement (Vinnem, et al., 2012). The results of these distributions can be seen in figure 10. This means that an influence on the underlying RIF categorized as "low" will have a high variance, and "high" influence will yield a low variance (Gran, et al., 2012). A third set of CPTs are also made. This is created given the incoming RIFs scores. These CPTs gives a description of how important the score is to the RIF. Here the relationship between a score and a RIF are also categorized into "low", "medium", and "high" and the CPTs are as previous a combination of two triangular distributions (Vinnem, et al., 2012).

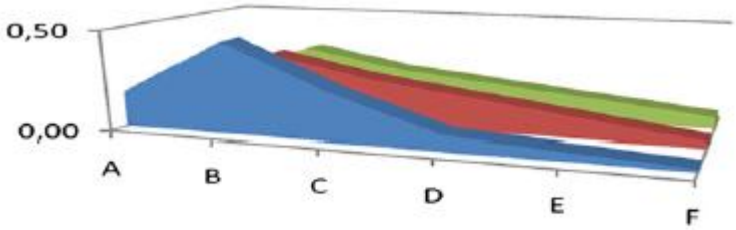


Figure 10: The CPTs for a RIF given "RIF level 2 in state-B" for the cases that the dependency is low (green), medium (red), and high (blue) (Vinnem, et al., 2012, s. 283).

The BBN approach used in the project is believed to have strength in fact that it allows the same RIFs to have a connection to different barriers in the model. A downside is the BBN dependency for memory to perform the calculations. By having the two different implementations to analyze the risk, provides a mean for verification by comparing the results and also support different visualization needs (Gran, et al., 2012).

The use of importance measure

Importance measurement is a helpful tool for identification of candidates for system improvement. This will also be the case for fault tree analysis, and is also the aim of the importance analysis in the Risk OMT model. Literature involving importance measure is vast and the Birnbaum's measure of reliability importance is one of the most important. When using the Birnbaum measure, $I^B(i)$, in fault trees the measure will be defined as a change in the top event probability, Q_0, as a function of the change in unreliability, q_i, for component i. The formula is thus $I^B(i)=\partial Q_0/\partial q_i$. In the case of event trees this is more complicated due to the fact that there may be more than one "critical" end consequence, in this case leak scenarios. However, the project has revealed that there is only one leak scenario for each event tree in question. This gives us the opportunity to use the ordinary definition of Birnbaum's importance measure. The Risk OMT project has also developed a level below the basic event again with the RIFs structure, and the project had to develop a Birnbaum measure on this level. Since the RIFs are random variables and not parameters compared to normal fault trees and event trees, there is no longer a deterministic relationship between the RIF, like RIF number j and the unreliability of component i, and a new definition of a "small change" is needed for the value of the RIF. To deal with this change the Risk OMT project proposes to define a change in the RIF in terms of a shift in the expected value of the RIF. By establishing π_j as the posterior distribution of RIF j, and have a (small) change in the expected value of the RIF be ΔE_j. Further the project makes an assumption that it is straight forward to establish a modified posterior distribution π_j^{Δ}, given the shift in expectation. Next establish F as the frequency of the critical end consequence, in this case a leak, where F depends on the posterior distribution of the RIFs, and particularly RIF j. The Birnbaum like importance measure for RIF j is then given by the expression (Vinnem, et al., 2012):

$$I_{RIF}^{B}(j) = \frac{\left[F(\pi_j^{\Delta}-F(\pi_j)\right]}{\Delta E_j} \qquad (6)$$

To be able to implement the measures in equation 6, a few aspects have to be considered. To shift a posterior distribution is not straight forward. Here the simplest situation is when one is considering first level RIFs, the RIFs directly influencing the basic events. The posterior distribution π_j is rather easy to find from the BBN structure over the RIFs. The project proposes to approximate a beta distribution to, and with some parameters a new beta distribution may be found and can represent π_j^{Δ}. This is done and a ΔE_j is obtained, and the variance is maintained in the distribution (Vinnem, et al., 2012).

Dependency modelling and modelling of interactions between RIFs

The Risk OMT project addresses dependencies by using dependence levels like zero, low, moderate, high and complete, based on common practice in the field of assessing human reliability analysis dependence. Each level corresponds to a β-factor which is the conditional probability of a subsequent failure given a first failure. It is noted by the project that common cause failures appear more a more important issue *after* a critical event and is often addressed in combination with mitigation of consequences compared to this project where the modelling is prior to the leak. Because of that the project assumed a lower common cause influence than the ones used in the literature. Closeness in time, similarity of crew/performer(s), stress, and complexity was considered most important in the project. The project introduced a simplification in form of a scoring regime for each of the factors (Vinnem, et al., 2012). More information on how this was executed can be found in Vinnem, et al. (2012) and Gran, et al. (2012).

The common cause effects affect the basic events in the model. To add such an effect can be done in two ways, and both have been discussed in the project but the Risk OMT model does not include these factors in the model. If it to be included an assessment of the common cause size must be made (Gran, et al., 2012).

In the basic Risk OMT model the RIFs have an assumed independence from each other in regards to the basic event probabilities. In many situations a RIF with a low score can have a negative influence on other RIFs with a low score and vice versa if the scores are good. In some cases neutralization of low scores with good scores can be considered. The Risk OMT project has only focused on negative effects that strengthened the negative influence on the basic events. In the model only influences between level 1 RIF was assessed since level 1 RIFs are only affected by one RIF from level 2 (Vinnem, et al., 2012). Through the method described in Vinnem, et al. (2012) the negative effects of RIF interactions are discussed. The project have identified some candidate sets of RIFs, like work motivation and communication in regards to violations, and time pressure and workload in regards to slips and lapses (Gran, et al., 2012).

Case studies

Like in the BORA project the Risk OMT project constructed case studies to test and fine tune the model. Sensitivity studies were also performed to test the sensitivity of the model and assess if responses in parameter variation are logical and have reasonable amplitudes. The input of data when performing quantitative risk studies offshore and onshore should be able to use the installation-specific data produced from the audits, interviews, surveys, and expert sessions. A requirement to the method is that it is not prohibitive, meaning that the work put into performing the analysis can be regained from the result obtained through the analysis (Gran, et al., 2012).

An importance measure (IM) analysis and risk reduction measures was tested in the project. Those tests shows that risk reducing measures that affect the RIFs ranked high on the IM analysis had a greater impact on risk reduction, thus showing that the assessments appear to be in accordance with assumptions in the Risk OMT model (Gran, et al., 2012). This also shows that the model is a highly adaptive risk management tool. The different implementations in the BBN and hybrid model provide both a generalization and an improvement of the previous BORA model. The model has also proved capable of reflecting relative differences between alternative installations, and can show how human and organizational factors affect the risk level. This can also be simulated in combination with risk reducing measures to evaluate further improvement (Gran, et al., 2012).

2.4 Use of software – HUGIN and the Risk OMT database

The use of software is not in itself a focal point in this thesis, but its applicability will play a certain role. Therefore a quick introduction to the two different software applications are made, but no further detailed knowledge about how they work is made. How the different software work is company restricted information, but can also be considered not within the scope of the thesis.

The HUGIN software is provided by Hugin Expert A/S and is a tool for support in decision making. It offers compact, intuitive, and representation of dependencies between entities within a problem domain. This type of type of decision support is used in industries like medicine, software, information processing, industry, economy, military, and agriculture (Hugin Expert, NA).

The use of the HUGIN software in the Risk OMT project is documented in chapter 2.3, and gives a through explanation of its use. However a few advantages and disadvantages of the software should be emphasized here. Given the nature of “true” underlying RIF and the modelling, the HUGIN will create all the CPTs when the distributions for the RIFs and dependencies are given. A drawback is that the method requires a lot of memory and a series of simplification have to be made, and some parts have to be done in steps to complete the simulations (Vinnem, et al., 2012).

After the Risk OMT application with the HUGIN and the hybrid model, another implementation was created. This is a Microsoft Exel based database that does all the calculations given in regards to work packages, RIFs, HRA, tasks, etc, and gives an output without any stepwise solution. The application of this database has gone from the two level RIF structure implementation to a one level structure. This still considers the management aspect, but uses mixed distributions to join the distributions to one level before implementation. The new implementation is considered an easier method to use and has a simpler system for input of data, along with no memory restrictions, and an easier platform for performing simulations.

3. Added emphasis – Cold climate and challenges in an operational environment

In this chapter an introduction of the arctic will be given, along with potential consequences of an oil spill in these areas, and the topic of maintenance in the arctic is raised. How operational conditions in the arctic may affect the human factor is explained in a separate sub-chapter. Then a sub-chapter on the new RIFs for use in the Risk OMT model representing the arctic operational environment is followed by a sub-chapter on the topic of barriers and a suggestion for a risk reducing measure is made to be simulated in the Risk OMT model.

3.1 The arctic and environmental effects

A lot of published materials concerning cold climate operations are focused around the arctic and circum arctic areas. The topics in this thesis are concentrated around activities that are both ongoing and underway to these areas. Activity in these areas creates a lot of exposure and to exemplify and to set the premise for the arguments made in this thesis, a few aspects must be explained.

The arctic is usually defined through three or four of these definitions (Wergeland, 2009):

1. The areas north of the polar circle. These areas have midnight sun, and includes the areas Norway, Sweden, Finland, Iceland, Greenland, Russia, Alaska, Canada, and the Arctic Ocean.
2. The areas where the yearly mean temperature of the warmest month is below 10^{o}C. This is almost equal to the northernmost tree line. North of this there is mostly tundra.
3. Socially and political: the arctic is the northernmost parts of the eight countries presented in the first definition.
4. Socially and political: arctic is the marine ice cover in the Arctic Ocean.

Oil and gas activity in the arctic, both onshore and offshore, will be affected by the arctic parameters that will affect all activities here to a varying degree. These most common factors to include are (Gudmestad & Quale, 2011):

- The sea ice condition and its variation in severity throughout the season and possibility to vary tremendously from season to season.
- The conditions in regards to atmospheric and sea spray icing (seasonal variation and extremes).
- Low temperatures and the following wind chill exposure.
- Polar lows and extreme weather.
- Darkness and lack of daylight – available daylight through the season will vary.
- Distance to shore. Fuel stop may be necessary for helicopters.
- Water depth, currents, and waves.
- Permafrost onshore.

All these factors can be found to a varying degree in the Barents Sea. The Barents Sea is where most of the Norwegian oil and gas development in the arctic will be, and the development being done on the Norwegian side will be subjected to the legislation for both onshore and offshore activity. In regards to the increased activity in these areas the DNV research project Barents 2020 has suggested to divide the Barents Sea into eight sub-areas according to the physical characteristics of the area. An important factor is here the presence of sea ice. This is considered appropriate and the sub-areas and ice conditions looks like this (DNV, 2012):

I.	Spitsbergen	-Usually ice every winter
II.	Norwegian	-Generally ice free
III.	Franz Josef Land	- Usually ice every winter
IV.	North East Barents Sea	- Usually ice every winter
V.	Novozemelsky	-In between
VI.	Kola	-In between
VII.	Pechora	-Usually ice every winter
VIII.	White Sea	-Usually ice every winter

Figure 11: The generalized environmental climate zones in the Barents Sea (DNV, 2012, s. 105).

Sub-area II is at present the most relevant area for the PSA's jurisdiction and the area is generally ice free (Gudmestad & Quale, 2011), and this is also where Goliat is located, to the south-east of the coast of Finnmark. New fields under development like Skrugard and Havis is further north and in proximity of sub-areas that have ice, and these fields are inside the isotherm for possible ice cover every 2400 years (Helgesen, 2013). This means that the immediate challenges for operational activities will be in generally ice free waters, but that will in turn increase the exposure for marine sea spray icing.

3.2 Potential consequences of an oil spill in the arctic

Oil and gas activity in the arctic will introduce major challenges in regards to the consequences of a major oil spill. The Barents Sea in particular is considered one of Europe's largest and cleanest untouched marine ecosystems. The area has a high primary production and a rich biological diversity, including numerous seabird colonies. In addition, the area also has a unique variety of marine mammals like polar bears, walrus, and bowhead whales. Deep water corals reefs that are unique and numerous can also be found (WWF-Norge, 2003). This is also a vital point in many debates on the ongoing and future activity in the area. An oil spill in these areas would be catastrophic, both for the marine life and for the oil and gas industry and potential future activity. Especially vulnerable is the fall, winter, and early spring, since there is little daylight to conduct oil spill management and the possibility of polar lows to worsen the situation and work performance. Summer will in general not be such a exposed season and can even be considered more favourable than in the south since there is constant daylight. With activity in areas where one will face sea ice, an oil spill will present a very difficult scenario. Low oil viscosity can lead to oil being trapped under the ice and migration up brine channels produced in thick ice covers (usually with thickness above 10cm). In the melting season the channels can reach the surface and accelerate ice melting. Oil can also be frozen into the ice in droplets in colder seasons. Ice-drift and interaction is also important and can even trap the oil between broken floes and mix with the sludge, if there is any. Oil emulsion is possible in these cases and the ice can act as a barrier for the viscous oil types (Gudmestad, Løset, Alhimenko, Shkhinek, Tørum, & Jensen, 2007). These factors also creates major challenges when it comes to oil spill simulations, oil recovery, and oil spill barriers. Some of these challenges may prove to be impossible to solve in certain areas. This is just an illustration of how difficult and complex an oil spill can be in the arctic. The factors mentioned here is just the tip of the iceberg (so to speak), where other factors like platform integrity, potential loss of life, time until rescue/pick-up, and pollution and spill from the platform itself (mud, hydraulic fluids, and the hull/structure), present major hazards to health, safety, and environment. A leak scenario is an immediate threat that can cause such a grave situation as the one described here. Therefore measures must be implemented to minimize precursor events that can escalate into a leak.

3.3 Maintenance in the arctic

In regards to major hazard accidents, maintenance (intervention) will be the focal point in this thesis and the scenarios in question is described in the BORA method (chapter 2.2) and the Risk OMT method (chapter 2.3) as B1-B5 and C1-C3. There is limited research on performance of maintenance and operations in remote, harsh, and sensitive environments. Though there is experience with these activities in Alaska, Canada, Kazakhstan, and Russia, as well as onshore activities from the LNG plant Snøhvit, drilling activities in the Barents Sea, and activities from the preliminary phases of the Goliat oil and gas field. ENI Norway also has experience from production facilities in the Caspian Sea where there is heavy weather exposure (both hot and cold). The major difference in the experience from Russia, Alaska, and Canada, is that Norway represents an area with frequent changes in temperatures and will represent a challenge in regards to rapid temperature changes compared to the mentioned countries where there is a “stable” cold climate. Implications and consequences of the environmental factors is reduced reliability, more unplanned maintenance, leading to more error identification that may increase complexity of the task, more downtime, and possibly more exposure since maintenance will take more time. These are possible consequences that can cause complications and uncertainties in regards to production in untested conditions (Markeset(a), 2008). The weather exposure as mentioned can cause normal maintenance activities to take longer time than normal. There are several factors that can cause this, like heavy and cumbersome clothing, the cold exposure will demand more breaks, the darkness will reduce work speed, and the exposure will also demand more energy and reduce available energy for the task at hand (Markeset(b), 2008). An important aspect with production under these conditions is how exposed the equipment is and if there is winterization measures implemented. In some cases the enclosure of production areas to reduce weather exposure can also create conditions better than on other parts of the NCS and increased reliability may be experienced, though this is debated.

3.4 On arctic expoure in regards to work activity

There are not many demands to the operational environment in regards to arctic exposure. Even the new arctic ISO standard does not address operational environment apart from HSE demands in regards to Escape, Evacuation, and Rescue (EER) and that wind chill must be considered, along with a selection of appropriate physical operating parameters (ISO, 2010). One the few demands for outdoor work operations are from the NORSOK standard S-002 concerning work environment. Chapter 5.8 in S-002 states that the percentage of the time each worker is exposed to a wind chill index (WCI) above 1000 W/m^2 shall be reduced as much as reasonably practicable for work areas where work operations is performed frequently and exceeds 10 minutes or more. The unavailability should not exceed 2% on a yearly basis (Standard Norge, 2004). Table 9 and 10 exemplify the operational restrictions in regards to prevent damages due to wind chill on unprotected skin. The tables also contain additional information and illustration.

Table 9: Wind chill temperatures based on wind speed and ambient air temperature, including cold effects designations. Adapted: (Sundsbø(b), 2011).

Wind	**u_{10m}**		**Ambient air temp , t_{2m}**											
Beaufort classification (modified)	*[m/s]*	*[km/h]*	***5***	***0***	***-5***	***-10***	***-15***	***-20***	***-25***	***-30***	***-35***	***-40***	***-45***	***-50***
Light Breeze	*1,6*	**5,8**	4	-2	-8	-13	-19	-25	-31	-36	-42	-48	-54	-59
	3,4	**12,2**	2	-4	-10	-16	-22	-28	-34	-40	-46	-52	-58	-65
Gentle breeze	*5,5*	**19,8**	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
Moderate breeze	*8*	**28,8**	0	-6	-13	-19	-26	-32	-39	-45	-52	-58	-65	-71
Fresh breeze	*10,8*	**38,9**	-1	-7	-14	-21	-27	-34	-41	-47	-54	-61	-67	-74
Strong breeze	*13,9*	**50,0**	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
Moderate gale, near gale	*17,1*	**61,6**	-2	-9	-16	-23	-30	-37	-44	-51	-57	-64	-71	-78
Gale, fresh gale	*20,8*	**74,9**	-2	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
Strong gale	*24,5*	**88,2**	-3	-10	-17	-24	-32	-39	-46	-53	-60	-67	-75	-82
Storm, whole gale	*28,5*	**102,6**	-3	-11	-18	-25	-33	-40	-47	-54	-62	-69	-76	-83
Violent storm	*32,7*	**117,7**	-4	-11	-19	-26	-33	-41	-48	-55	-63	-70	-77	-85
Hurricane force	≥32,7	**≥117,7**												

Classification of risk	***t_{ch} [°C]***	**Effect of chill**
1	-10 to -24	Uncomfortably cold
2	-25 to -34	Very cold, risk of skin freezing
3	-35 to -59	Bitterly cold, exposed skin may freeze in 10 min
4	-60 and colder	Extremely cold, exposed skin may freeze within 2 min

Table 10: WCI exposure based on wind speed and ambient air temperature, including available outdoor work time per hour designations. Adapted: (Sundsbø(b), 2011).

u_{ar}	**Ambient air temp , t_a**											
[m/s]	***5***	***0***	***-5***	***-10***	***-15***	***-20***	***-25***	***-30***	***-35***	***-40***	***-45***	***-50***
0,5	553	652	750	849	948	1046	1145	1244	1343	1441	1540	**1639**
0,7	588	694	799	904	1009	1114	1219	1324	1429	1534	**1639**	**1744**
1	632	745	857	970	1083	1196	1309	1421	1534	**1647**	**1760**	**1873**
1,5	688	811	934	1057	1180	1303	1426	1549	**1672**	**1795**	**1918**	**2041**
3	805	948	1092	1236	1379	1523	**1667**	**1710**	**1954**	**2098**	**2241**	**2385**
5	903	1065	1226	1387	1548	**1710**	**1871**	**2032**	**2194**	**2355**	**2516**	**2678**
8	998	1177	1355	1533	**1711**	**1890**	**2068**	**2246**	**2424**	**2603**	**2781**	**2959**
10	1042	1228	1414	**1600**	**1786**	**1972**	**2158**	**2344**	**2530**	**2716**	**2902**	**3088**
12	1075	1267	1459	**1651**	**1843**	**2034**	**2226**	**2418**	**2610**	**2802**	**2994**	**3186**
15	1110	1308	1507	**1705**	**1903**	**2101**	**2300**	**2498**	**2696**	**2894**	**3093**	**3291**
20	1142	1346	1550	**1754**	**1958**	**2162**	**2366**	**2570**	**2774**	**2978**	**3182**	**3386**

WCI	**Chilling temperature**	**Consequence**
WCI>1600	t_{ch}<-30°C	No outdoor work to be performed
1600>WCI>1500	-30°C < t_{ch} <-25°C	Available working time 0 - 33 % linear per hour/person
1500>WCI>1000	-25°C < t_{ch} < -6°C	Available working time 33 - 100 % linear per hour/person
WCI<1000	t_{ch}> -6°C	Normally 100 % Available working time

The wind chill temperature displayed in table 9 is the cooling effect the wind have on the skin, based on the ambient air temperature and wind speed. The wind chill temperature as seen in NS-EN ISO 11079:2007 is the following formula, but slightly modified:

$$t_{WC} = 13{,}12 + 0{,}6215 \cdot t_a - 11{,}37 \cdot u_{10m}^{0{,}16} + 0{,}3965 \cdot t_a \cdot u_{10m}^{0{,}16} \tag{6}$$

The wind chill temperature t_{WC} is displayed in ^{o}C, the ambient air temperature t_a is usually measured 2 meters above ground level in Norway and often displayed as t_{2m} and also in ^{o}C, u_{10m} is the wind speed measured in m/s and at 10 meters above ground level, which is normal measurement height (Standard Norge, 2007).

The effective mechanical power of the wind speed and temperature, known as wind chill index (WCI) is measured in W/m^2, and the formula is:

$$WCI = 1{,}16 \cdot \left(10{,}45 + 10\sqrt{u_{ar}} - u_{ar}\right) \cdot (33 - t_a) \tag{7}$$

The ambient temperature is the same as stated in formula 6. The wind speed u_{ar} is in m/s, and is the logarithmic profile for turbulent mean flow for heights greater than 5cm or friction velocity, u(z):

$$u(z) = \frac{u_*}{\kappa} ln\left(\frac{z}{z_0}\right) \tag{8}$$

Where z is the height in question and z_0 is the aerodynamic surface roughness in meter, κ is the Von Kármán's constant which is approximately equal to 0,41, and u_* is the vertical velocity gradient (Sundsbø(a), 2011):

$$u_* = \sqrt{\tau_W/\rho} \tag{9}$$

Where τ_W is the shear stress and ρ is the air density (Sundsbø(a), 2011).

These formulas show that the wind profile is logarithmic and wind speed increases with the height. The profile can be displaced upwards on land in areas with obstacles like process facilities, and represent the surface roughness. Offshore there can be little surface roughness and wind speeds can escalate faster in the vertical direction than onshore (given obstacles). With the Goliat platform process decks are located approximately 15-20 meters above sea level and with a few degrees below zero and average wind speeds of around 10 m/s, the WCI will be 1228-1414 W/m^2. This is a rather heavy exposure and can show that considerations must be made in regards to what wind speeds one will face at certain heights. This can be a considerable contribution and create the necessity to screen outdoor work areas since exposure demands are exceeded even at low wind speeds and average seasonal temperatures. This is often a major challenge to combine with the demand for air circulation.

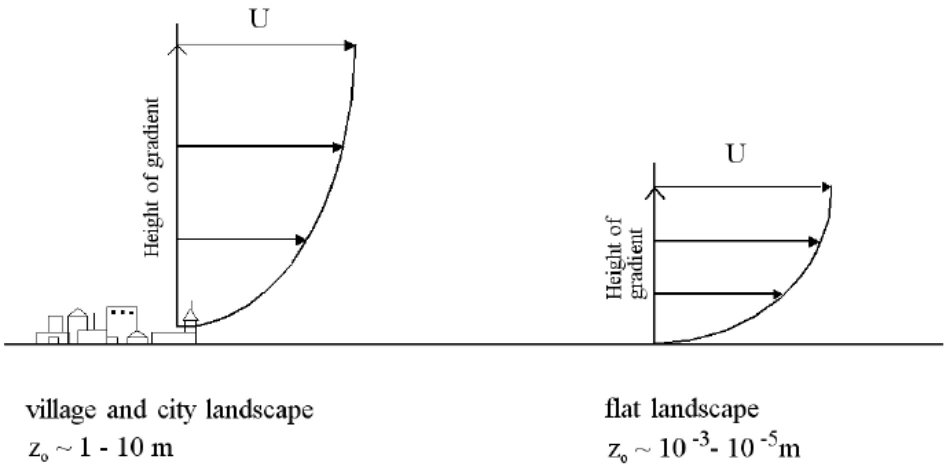


Figure 12: Illustration of the influence of surface roughness on the mean velocity profile (Sundsbø(a), 2011, s. 3).

S-002 also states that for installations in an arctic climate, outdoor work tasks must be identified and reduced to a minimum. It further states that if demands are in conflict with the limits for explosion loads or wind loads it is acceptable to compensate with appropriate enclosure in of other areas that is included in the operator's work environment, like utility areas. Frequently manned areas shall be sheltered without exceeding the permitted explosion risks. All outdoor handles, switches, etc, should be serviceable with gloves on. A heated shelter shall be located on the drill floor. This shall be in a safe place in regards to dropped objects (Standard Norge, 2004). These demands are essentially the only demands that are made in regards to exposure to snow, ice, and wind chill, in an HES perspective excluding falling ice as a hazard. The sheltering of the work environment must be a tradeoff in regards to demands for ventilation stated in NORSOK S-001, where there is a demand for minimum 12 air changes/hour in hazardous areas (Standards Norway, 2008), like process areas.

Other documents exists that focuses on assessing and managing the risk in cold workplaces like ISO 15743:2008, that can be very useful in reducing the effects of exposure and help giving the operator a full focus on the task at hand. The standard suggests the following model for risk assessment in cold workplaces (European Committee for standardization, 2008):

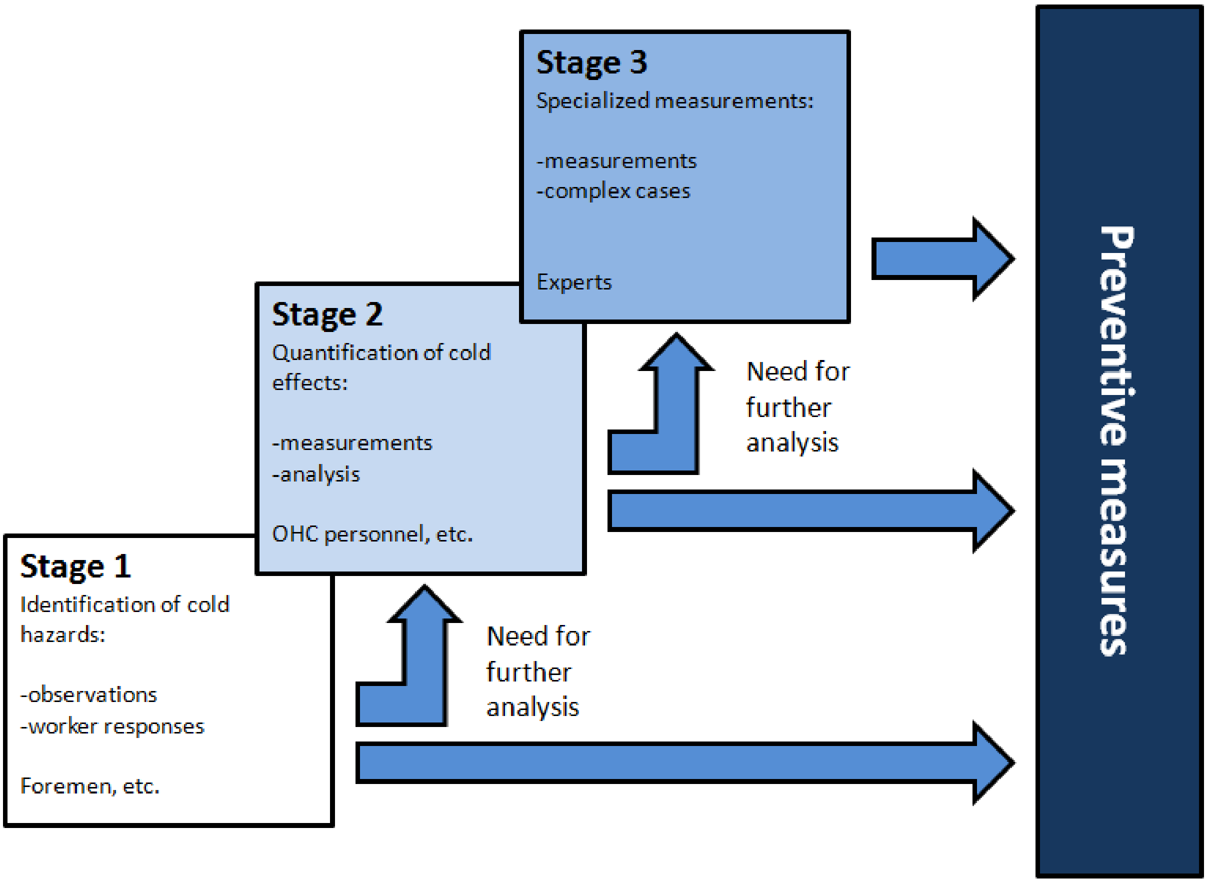


Figure 13: Model for cold risk assessment in the workplace. Adapted: (European Committee for standardization, 2008, s. 3).

This standard also contains some measures that can act as barriers against errors induced by the operator being exposed to wind chill and other effects from exposure.

3.5 The human factor in the arctic

There are several sources stating that cold and wind chill have adverse effects on the human body and error frequency will rise, along with reduced dexterity (fingers especially), precision and stamina is also reduced, sensation of pain is not uncommon, and severe reaction to the cold may occur after prolonged exposure, as stated in (Thelma, 2010), (Hassi, et al., NA), and (OLF, 2012). These factors are important when when working on equipment where a simple mistake can result in a potential leak and if conditions are present, the leak can result in a major hazard accident. One major risk when exposed to the cold is reduction in cognitive performance. Cognitive reduction as an effect of exposure is mentioned in all of the sources mentioned above, but there is a need to emphasize this aspect. This is because cognitive reduction can be seen as a RIF, creating a adverse effect on probability for leak scenarios presented in chapters 2.2 and 2.3, concerning the BORA and Risk OMT method.

The exposure of the cold can also be worsened by the absence of daylight in the darkest periods and have an additional psychological effect (reduced thyroid levels (Hassi, et al., NA)), and both sleep pattern and state of mind may be affected, causing additional effects. The lack of acclimation can cause a higher adverse effect since the operator is not adjusted to working under such exposure from cold, and a higher risk may be present until the operator has been acclimized.

This effect can also be added to if the operator experiences sea sickness. This will of course depend highly on platform or installation type, and if the operator gets seasick or not. In the Barents Sea there is a high probability that the platform or installation will be a floating device with some form of quick disconnect, and therefore will be subjected to some pitch, roll, and heave due to the motion of the ocean. The iso-curves for significant wave height in these areas are similar to the North Sea, but the periods appear longer up north, according to NORSOK N-003 (Standards Norway, 2007). It is not the authors opinion that there is a higher probability of sea sickness in the Barents Sea, but it could be an influencial factor in combination with others. The amount of strainious work in combination with PPE used will affect how exhausted the operator becomes, and this will also affect the cognitive performance. Recent research into cold exposure shows that a slight chill can increase cognitive performance, but several stresses put together can cause significant cognitive reduction (Thelma, 2010).

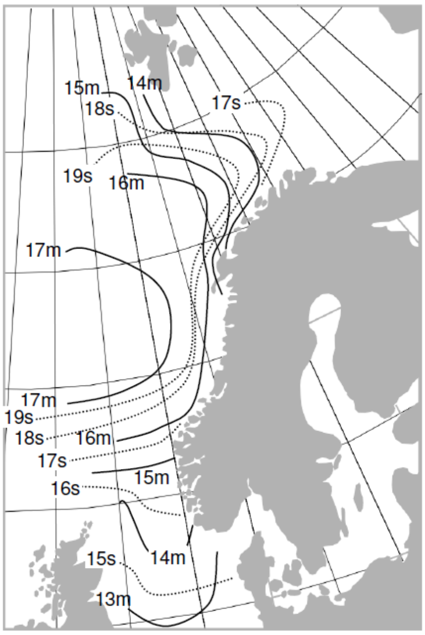


Figure 14: Significant wave height and related maximum peak period with annual probability of exceedance of 10^-2 for sea-states of 3 hour duration. Iso-curves for wave period are indicated with dotted lines and wave heights are solid (Standards Norway, 2007, s. 13).

As these factors shows us, is that exposure to cold and harsh working environments can possibly have a adverse effect on the probability of a hydrocarbon leak. This is one of the aspect that this thesis will look into, and try to both look at how and why the risk will increase, along with if risk reducing measures like barriers can reduce the increased risk. The new RIFs and improvement of barriers will be discussed in the two following sub-chapters, along with simulations of these factors in the Risk OMT model.

It is also very important to separate HSE related aspects and aspects related to major hazard risk in harsh climate. HSE related exposure will in this thesis include skin temperature, hand dexterity, numbness, and an increase in work related accidents, as stated in relevant literature (Thelma, 2010) (Hassi, et al., NA) (Oksa & Rintamäki, 1995) (Havenith, Heus, & Daanen, 1995). Long term effects of cold like cardiovascular illnesses, periphery circulation illnesses and Raynaulds syndrome, stroke, cold allergy, muscle and skeletal illnesses, and respiration illnesses, also short term effects like frost injuries and hypothermia (Thelma, 2010) (Hassi, et al., NA), are also not included as a risk towards major hazard events, but is a HSE issue in this case. It is in the author's opinion that factors that contribute to a poor work execution will be registered by the operator and rectified, otherwise it must be considered an act of sabotage, violation and neglecting of duty. Error caused by mistakes, and slips and lapses, would be more connected to cognitive reduction and stress from being exposed to the cold. This is also in combination with the other RIFs presented in chapter 2.2 and 2.3. Through this line of reasoning, factors like freezing and absence of daylight will be the main addition to the existing RIFs. Acclimation, nausea and sea sickness has been added to create an additional effect representing periods of adjustment when re-entering the operational environment after time away.

The reason reduced cognitive performance have been given such weight when working in cold environments is due to the fact that the operator's situational awareness is in essence a measure of level of concentration or attention, and there is plenty of good evidence about factors that can affect this. This theory is based that each person has a certain amout of capacity for picking up new information and maintaining a mental awareness of it. The amount of storage space can change drastically depending on conditions. This is often exemplified with a vessel filled with liquid. If the vessel is not full additional information can be added (more liquid) and be managed, but when the vessel is full, no more liquid can be added unless some of the existing liquid is removed or displaced. So the ideal state for operational personnel is to have some spare capacity if there is a rise in the information flow. Fatigue and stress are well known factors for reducing the quality of the situational awareness. Being tired can be compared to having a smaller vessel for the information "flow", and the capacity for processing new information is therefore reduced. Fatigue appears to reduce the operators ability to attend to new cues in the environment and holding information in conscious awareness, along with a reduced capacity for attention. Typical effects of reduced cognitive performance is an adverse effect on innovative thinking and flexible decision-making, reduced ability to cope with unforseen rapid changes, less able to adjust plans when new information becomes available, tendency to adopt more rigid thinking and previous solutions, and lower standards of performance becomes acceptable. Stress is often manifested as anxiety and has similar detrimental effects. This is probably since the operator is preoccupied with other problems (like freezing, nausea, or pain as a result from exposure) or worries (like depression due to the lack of daylight or sleep deprevation) that are taking up attentional resources. Typical cognitive indicators of acture stress is impairment of memory; prone to distraction, confirmation bias (tend to ignore information that does not support following a particular chosen course of action or model), information overload, and task shedding (the abandonment of certain tasks when stress or workload make it difficult to concentrate on all of the tasks simultaneously), reduced concentration; difficulty prioritising, preoccupation with trivia, and perceptual tunnelling (attention becomes narrowly focused on salient cues), difficulty in decision-making: availability bias (resort to familiar routines and not consider plans that are not immediately available in memory, and "stalling thinking" – mind blank. Research has also shown that offshore drill crews experience of work stress have affected their situational awareness and in turn led to unsafe behaviour (Flin, O'Connor, & Crichton, 2008).

3.6 New RIFs due to cold climate exposure

This sub-chapter will introduce two arctic RIFs and test them in chapter 6.2, in the Risk OMT model. These two RIFs are created to represent the exposure from the cold and environmental factors introduced in an arctic operational environment. The first RIF is named the WCI factor and a direct influence of the physical environment. The second RIF is named fitness for duty. Both RIFs are a combination of factors that are crucial to that specific RIF and assessments for how they should be weighed and scored must be made. The proposed RIFs with methodology for weighing and scoring are a suggestion from the author, with input from thesis advisors and other qualified personnel. These RIFs will be subjected only to activities performed outside; therefore planning activities will not be subjected to these factors (if they are not performed outside) according to the Risk OMT model.

The WCI factor

This RIF will revolve around the exposure factor in regards to the wind chill exposure and measures implemented to mitigate or reduce exposure.
In a weighing process it is important to separate between the different exposures. Having no wind or temperature to consider, like in summer, spring, autumn, or on a mild winter day, a score of 0 could be applied. Being exposed to a slight chill may not be a heavy exposure and will in many cases not affect the operator's performance, but it will most likely affect the cognitive performance since freezing just a little will draw away attention to this. A slight chill may receive a score 2 or 4 depending on the situation and work task. When moving into exposure areas where there is a percentage of each hour with work restriction the scoring should be higher. For the exposure giving 0-33% restriction each hour should lie in the area of 6 or 8 depending on the work area and measures to reduce exposure. This should also take into consideration if the available work time will induce more stress to finish than usual. When the exposure gives a restriction of 67 to 100 percent, then there will probably be critical factors like exposure and stress dominating the work operation and influencing the operator's cognitive capacity, and the score should be en the area of 8 to 10. This can also be assessed against the work area and measures to reduce exposure. All operations that are to be performed with exposures higher than this shall be given a score of 10. According to the new weighting system presented in Risk OMT, a slight chill may be removed and only the exposure affecting the available working hour should get a weight. Here 0-33% restriction can receive a weight of 1, a 33-67% can receive a weight of 3, and finally a reduction in available work time by 67-100% each hour can be rated at 5. This rating can be assessed and re-evaluated. A slight chill can be divided into a separate RIF or included in the other exposure RIF. Like earlier, a rating of 5 should be used for all cases where the WCI is above 1600 W/m^2. The exposure levels refer to restrictions documented in table 10 and NORSOK S-002.

When scoring the RIFs the measures implemented to reduce the exposure and the type of work area should be a major factor, along with the use of PPE and procedures to contribute to the reduction. This area can contribute to considerable debate concerning what an industry average looks like, but the more thorough the outside work procedures is followed up from a managerial side, together with good work station screening and shielding measures, with appropriate PPE for the type of work performed, and with more information present to make a good judgement for the score the better.

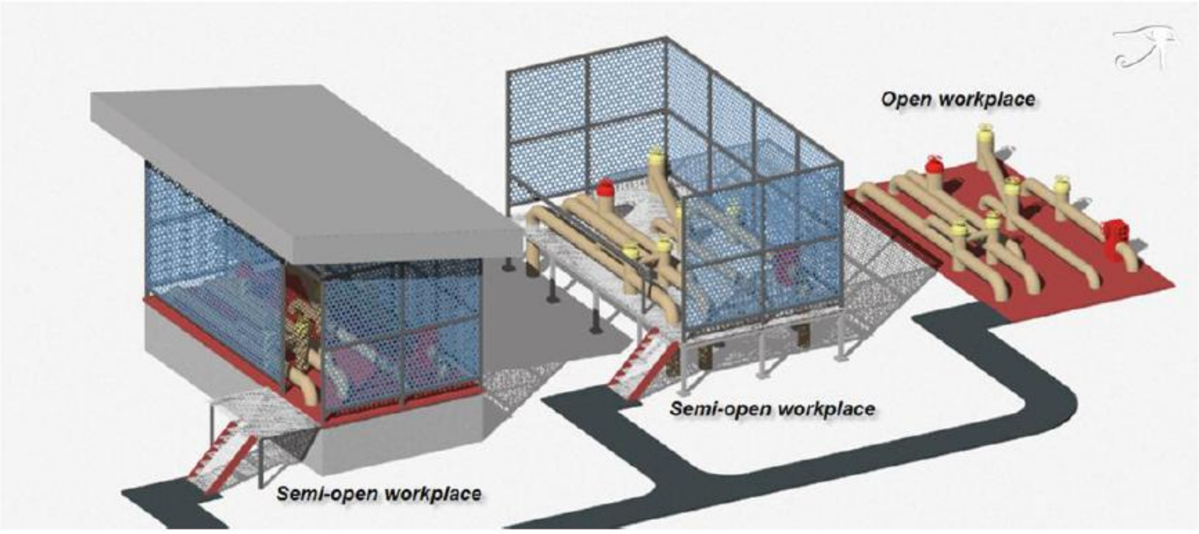


Figure 15: An example illustration of the workspace classification, winterized (Sundsbø, 2011, s. 12).

Fitness for duty

This risk influencing factor is affecting each operator differently. Some operators may be heavily influenced by these or some of the factors included here, while some are not affected at all. That is why the author has chosen the name fitness for duty. The name is taken from one of the performance shaping factors in the SPAR-H method mentioned in sub-chapter 2.1, and refers to whether or not the operator is mentally and/or physically fit to perform a task at a given time (Gertman, Blackman, J, Byers, & Smith, 2005). This is also suitable given the physical and psychological aspect placed in this RIF by the author.

This RIF is to represent factors like absence of daylight and consequences like depression and sleep deprivation (sleep deprivation can happen everywhere, but conditions in the arctic can pose a higher risk), the exposure effect that might be increased if the operator is not acclimated at the start of work rotation, and nausea due to seasickness. This RIF can also include if the operator is slightly chilly and represent a level of discomfort (this is also addressed earlier in this sub-chapter). The factors represented here are subjected to extreme variations from person to person. Even if these factors are somewhat remote from each other, they are all aspects that have the potential to reduce the operator’s cognitive performance. There will be no direct advice for how they should be weighed, but these factors on a separate basis can be considered to have a relatively low weight, but in combination they can be weighted higher, perhaps also they can be enhanced by factors in the WCI RIF or others. Interaction effects should be evaluated.

Scoring of this RIF will be similar to the WCI factor RIF, and finding an industry average may be difficult. Either way, if a thorough system for these factors is made and followed up from a managerial side together with a good system for making it work for the operators, the more information present to make a good judgement for the score the better.

3.7 Barriers – Risk reducing measures

In recent years the PSA has had an increased focus on barrier management and the risk of major hazard accidents, and is one of the PSAs main priorities. This is mainly because the operators to a varying degree is abiding the current legislation concerning barriers, and when an unwanted event has happened either a barrier failure or reduced barrier performance is one of the main causal factors (Ptil, 2011).

In chapters 2.2 and 2.3 barriers have been a topic, but not addressed and defined. In the Norwegian legislation for petroleum activity the management regulations have certain points that address barriers directly and indirectly. §5 in the management regulations states that (Ptil, 2011):

- There shall be barrier systems present that can both reduce the probability for errors, dangerous situations, and accidents, to develop and restrict possible damages and disadvantages.
- The barrier functions shall be preserved throughout the entire lifetime of the installation (offshore and onshore).
- There shall be demands for the performance of technical, operational, and organizational elements that are necessary for the separate barriers efficiency (this will be addressed in chapter 4).
- There shall be a strategy and principles for design, use, and maintenance of barriers.

The concept of the word barrier system is not found many places except in NORSOK Z-013 (Standards Norway, 2010) and the document on barrier management from the PSA (Ptil, 2011). PSA and

NORSOK Z-013 have in general the same definitions of the elements associated with barrier management:

Barrier system (no: barriere) – technical, operational, and/or organizational elements that either scattered or combined shall prevent a specific course of events from occurring, or affect it in an intentional direction by confining the damages and/or loss (Ptil, 2011). Z-013 defines it as a system designed and implemented to perform one or more barrier function (Standards Norway, 2010).

Barrier function (no: barrierefunksjon) – this is the task or role of the barrier system. Examples of this are: prevent leaks, prevent ignition, reduce fireloads, and ensure safe evacuation (Ptil, 2011). Z-013 defines it as a function planned to prevent, control, or mitigate undesired or accidental events (Standards Norway, 2010).

Barrier element (no: barriereelement) – technical, operational, or organizational solutions that is included in the realization of a barrier function (Ptil, 2011). It is according to Z-013 a physical, technical, or operational component in a barrier system (Standards Norway, 2010).

These definitions have the same content, but the PSA have also defined barrier management in addition to this:

Barrier management (no: barrierestyring) – coordinated activities done to establish and maintain the barriers, so that they may at any given time perform its function (Standards Norway, 2010).

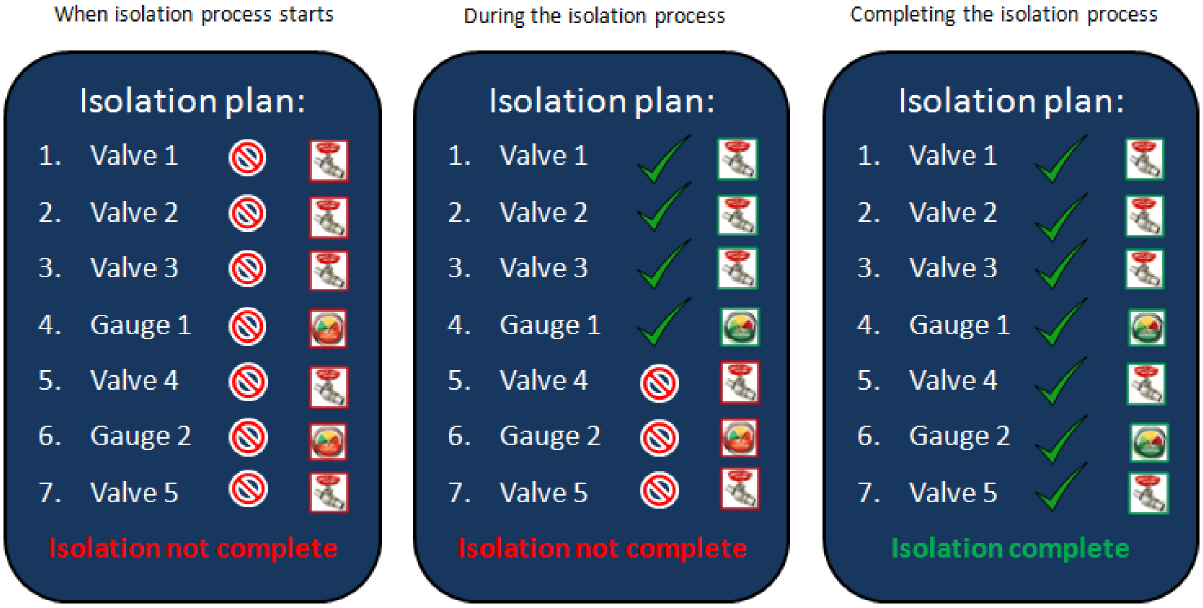
In most cases several barrier functions are organized in a hierarchy to realize some of the barrier functions. In almost all cases there is a need for technical, operational, and organizational elements to realize a barrier function (Ptil, 2011).

According to these definitions the barrier function for both the BORA project and the Risk OMT project is to prevent leaks. Each barrier function seen in figure 1, "Release due to incorrect fitting of flanges or bolts during maintenance", will be the barrier blocks. These blocks/functions can consist of a single or several other barrier elements with their own separate barrier functions. The barrier "Self control of work" can consist of elements like procedures, checklists, safe job analysis, and work permits, with their own barrier functions.

Improved barriers – Improved procedures by use of Ex-Safe screens

In the effort to see if there is an increased risk in the Risk OMT model by putting the operator into an arctic environment and exposing him/her to wind chill and other factors like darkness, acclimation issues, and nausea, it will also be beneficial to see if the risk can be mitigated by adding new or improve already existing barriers. The choice fell on the use of programmable Ex-safe screens and portable Personal Digital Assistant (PDAs).

The author's idea is to have programmable Ex-safe screen like the Wolverine III from metric industrial. It has sunlight-readable screen LED, touch screen, wide temperature range, and many other features (Metric Industrial, NA). By using sensors on valves and pressure gauges included in the isolation or blinding process, the Ex-safe screen can be programmed to have a checklist that can go from a "red" state to a "green" state when valve or gauge is in the correct position according to if doing isolation, blinding, or resetting is being performed. When all the steps in the checklist are "green" there can be an additional signal or sign saying that "isolation complete", etc. In an isolation process some of the actions may be performed from the centralized control room (CCR), but many of the actions demands a manual intervention on the module and by having a panel out in the field like the Wolverine III the checklist is available to the worker. In cases where a lot of walking and a stationary panel may prove cumbersome, a PDA solution like the i.roc x20n may be useful (Rugged Mobile, NA). This can also be used in combination with a panel and the wireless technology embedded in both products can give a real-time status to all parties involved. If the module in question is very big, the use of maps where the valve in question is marked with a tag number or special markings can be useful. This can be integrated into the checklist as a shortcut by tapping the valve or gauge in question. An example of how this checklist and screen can be arranged is found in figure 16 and 17. In regards to the nature of this system, manual overrides should not be possible. From time to time sensor failure will occur and with the real-time nature of the system that can be displayed in the CCR, at the module on the work station, and on the PDA, override should only be possible by a direct superior if the valve or gauge is checked and sensor error is the cause.



When isolation process starts

Isolation plan:
1. Valve 1 🚫
2. Valve 2 🚫
3. Valve 3 🚫
4. Gauge 1 🚫
5. Valve 4 🚫
6. Gauge 2 🚫
7. Valve 5 🚫

Isolation not complete

During the isolation process

Isolation plan:
1. Valve 1 ✓
2. Valve 2 ✓
3. Valve 3 ✓
4. Gauge 1 ✓
5. Valve 4 🚫
6. Gauge 2 🚫
7. Valve 5 🚫

Isolation not complete

Completing the isolation process

Isolation plan:
1. Valve 1 ✓
2. Valve 2 ✓
3. Valve 3 ✓
4. Gauge 1 ✓
5. Valve 4 ✓
6. Gauge 2 ✓
7. Valve 5 ✓

Isolation complete

Figure 16: Example illustration of how the Ex-screen can display the various stages towards a completed isolation process.

The use of this risk reducing measure can introduce less time consumption and competence issues in regards to personnel new to the installation, module, etc.

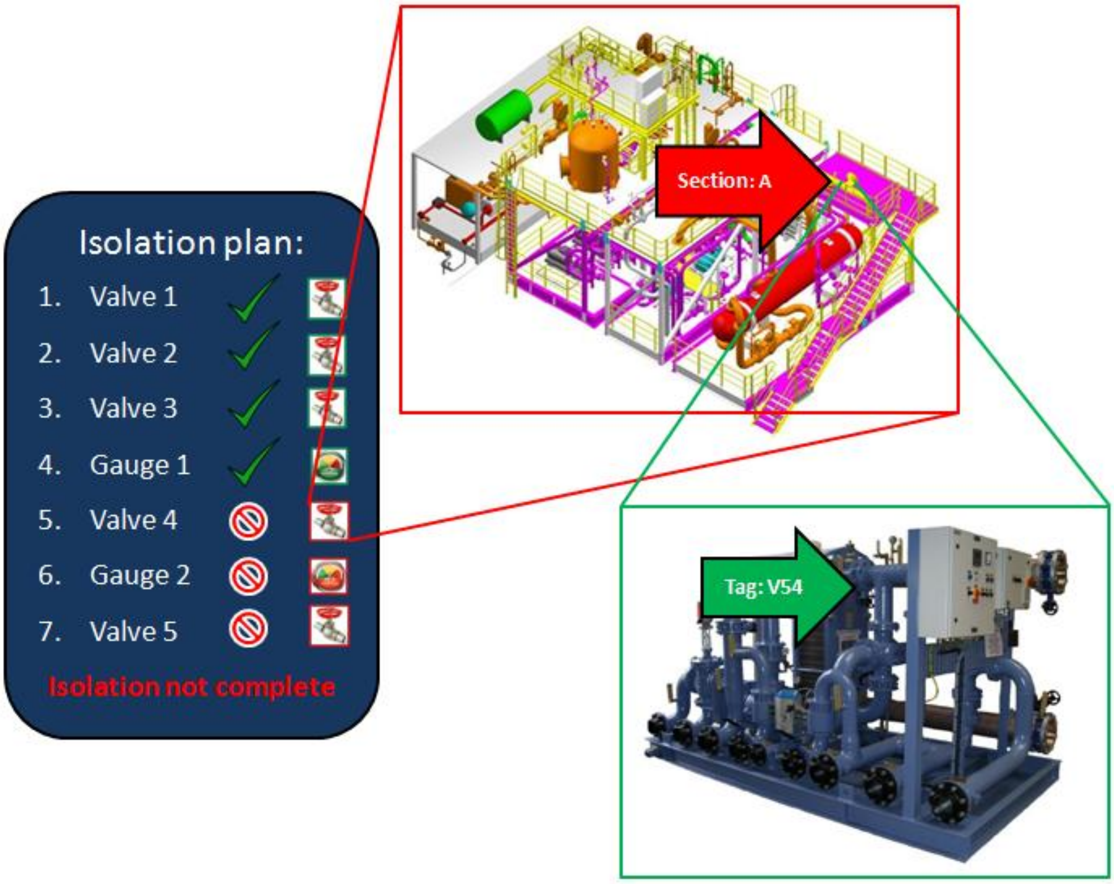


Figure 17: Example of how information can be layered by pressing icons to show valve or gauge location and tag ID.

The set-up described above is not a barrier in itself, but has the potential to improve and verify that other barriers are implemented and are in a "safe" state. This is thus a risk reducing measure. By implementing this measure the author has assessed that a series of tasks will be affected. The isolation/blinding (B1_B) task will be improved since the workers can in an easier way verify that the different steps are performed. The worker will also not be in a position to skip a step by mistake or take a short cut. This operation is followed by a separate team control (B1_1) that can be done with a higher probability of success, and maybe faster (that aspect is not considered in the simulation). After the maintenance work is complete there is the task of resetting the valves (B3_B). In this task the panel and/or PDA can shift mode into resetting and give a step-by-step as in the isolation/blinding, but in reverse. After this there is an end control (B3_1) that will work the same way as the separate team control. The improved procedure will in many cases signify a standard above industry average and the scores should be bumped up on the score. How big this improvement will be can differ from company to company. In the weighting the procedure can affect RIFs like governing documents, technical documentation, disposable work description, design, and Human Machine Interface (HMI). Other factors may also be improved and should be discussed.

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4. Performance standards and performance requirements

This chapter will look into the content of performance standards and setting of performance requirements.

The offshore petroleum industry has a long time spent considerable resources on engineering defences. These defences, or barriers, are for example protection from fire and explosion hazards, containment of leaks to avoid the spread of flammable material, and automatic shut-down systems when a leak occurs. How these systems shall perform and be followed up is described in the barriers performance standard (PS) and measured with Key Performance Indicators, though these follow ups are often not extensive (Vinnem(c), 2007).

As stated in the management regulations §5 for barriers, the operator or whomever responsible for running the facility/installation shall determine the strategies and principles in such a way that designing, use, and maintenance of barriers in such a way that the barriers function is preserved throughout the facility/installations lifetime. It shall be known which barriers are established and what function they are to preserve, and what demand for performance is set for the technical, operational, or organizational elements that is necessary for the barriers efficiency. Performance is in the interpretations of the paragraph defined as capacity, reliability, availability, efficiency, ability to resist loads, integrity, and robustness. §21 of the management regulations also stated that the follow up of all elements in regards to safety related systems and the follow up shall contribute to indentify technical, operational, or organizational weaknesses, errors, or shortcomings (PSA, 2013).

The Petroleum Safety Authority released in 2011 a document to emphasize the principles that the operators should follow in regards to barrier management. In this document it is stated that to ensure proper risk management is conditioned on that key personnel has a good understanding of why the barrier is established (its strategy) and what performance requirements (PR) is associated with it for the barrier elements ability to perform its function. The PSA emphasizes two main products in regards to establishing, updating, and maintaining an adequate set of barriers: a specific barrier strategy and specified performance requirements in specific performance standards. In this there is a requirement to performance as stated in the management regulation §5. Performance is by the PSA defined as the qualities a barrier function or element must have to ensure that the specific barrier function is effective. It is also specified that operational and organizational PS shall be made when these factors are central in regards to implementing different barrier functions. When the performance requirements are made they are grouped together in Performance Standards, either on a system- or functional level. This is the basis that NORSOK S-001 is founded on, and is recommended practice by the PSA. The PS should in addition to PR for barrier functions, also clarify what other systems or functions it borders (Ptil, 2011). NORSOK S-001 defines a PS as (Standards Norway, 2008, s. 12):

"Safety performance standard shall be the verifiable standard to which safety system elements are to perform. The objective of the specific safety performance standards is to add any supplemental safety requirements other than those specified by authority requirements and standards. The performance standards shall be based on the safety strategy document(s) and these should be read in conjunction with each other.

The specific safety performance standards shall ensure that barriers, safety systems or safety functions:

- *are suitable and fully effective for the type hazards identified,*
- *have sufficient capacity for the duration of the hazard or the required time to provide evacuation of the*
- *installation,*

- *have sufficient availability to match the frequency of the initiating event,*
- *have adequate response time to fulfil its role,*
- *are suitable for all operating conditions."*

Creating a specific barrier strategy and associated PS is crucial in an effective barrier management plan. By creating operational and organizational PS important subjects, like competence, verification activities, planning and performance of maintenance, establish risk indicators, surveillance and assessment, account for mistakes and exceptions, input for operational procedures, and many more can be addressed. When the strategies and principles all are documented in regards to barrier function, PR are set. These requirements are indicators of the barriers condition and are key factors in maintaining the barrier function throughout the installations lifetime. It is also important to chart important performance degrading factors like: work load, capacity, attitude, culture, and many more. In this aspect it is a requirement that it should be known which barriers are not functioning or degraded. The human factor is rarely completely disconnected as a valve, but it may be seriously degraded as a barrier. The "real-time" condition of the human factor can be monitored by an output from the Risk OMT method (and is documented in chapter 5), but how to preserve the condition of the many PS that will constitute the many aspects important for the human factor to perform in accordance with set requirements are not yet set. Operational and organizational barrier elements are in the same position as many technical barrier elements, in a position with no PR and no systems to verify how these elements are to be tested and verified in regards to performance. This is emphasized as a major area for improvement by the PSA. This is also in regards to recent potential and major hazard accidents where operational and organizational factors have proven to be important for the causality (Ptil, 2011).

Statoil have in relation to the OTS project developed a set of performance standards. These PS addresses areas as work practice, competence, procedures and documentation, communication, workload and physical working environment, management and management of change (Gran, et al., 2012). The work done in these performance standards will most likely give a good idea of how such operational and organizational standards should look and proper suggestions for performance requirements and how to verify them. This will especially be useful for areas not of a technical nature where performance is hard to quantify.

5. Barrier display

This chapter will look into what a barrier panel is, and what the main functions are. A suggestion for how to measure the human factor or operational condition will be presented along with the principles it will be based on.

It is the operating company's duty according to management regulation §5, to have at all times and during all phases of activity control of which barriers are established, not functioning, impaired, disconnected, or overrided, in accordance with section 26 of the activities regulation. The technical and operational regulations section 57 on monitoring and control during planning, operation and control during activities, also states that work activities that can affect health and safety shall be monitored and kept under control and personnel working with control and monitoring duties shall be able to gather and process this information in an effective manner. This information shall also be collected, processed and used in accordance with section 19 of the management regulation (PSA, 2013). These sections play a part with many of the other legislations to ensure proper barrier management on the installation.

All operator companies have their own system for maintaining control of their barriers. Some companies have an arrangement with a display and the various barriers presented and with some form of operational status attached to show the condition of the barrier. The operational status is in some cases represented by a "trafficlight", where green represent a fully operational condition, yellow a reduced, not updated, or past due with check-up or maintenance, and red condition where the barrier is not functioning or disabled. This arrangement with a barrier display will ensure an easy overview of the different barriers status and operational condition. Vinnem (2010) have discussed the use of barrier displays as a system for both leading and lagging indicators for major accident hazards. Here the barrier panel is defined as a system established for periodic reporting and follow-up of the performance of major hazard barriers. The intention of the system is to give attention to the follow-up of barrier performance to the management and operational personnel. It is suggested that barrier panels could be updated in intervals of every 3 or 6 months, with a rolling 12 month average. It is also noted that average for NCS are only updated once a year. In the conclusion there is a point made concerning the requirement for fluctuation in the data in fear that attention from management may be lost. A barrier display should present the status of the barrier, but also the recent trend, as seen in figure 18 (Vinnem j. E., 2010).

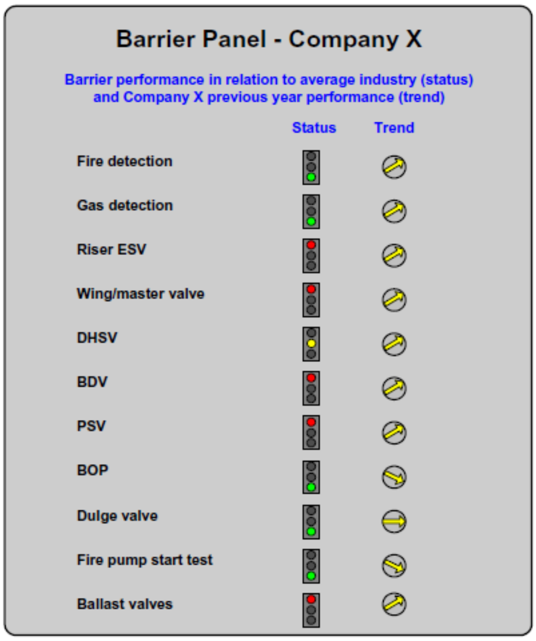

Figure 18: Barrier panel for a company showing barrier status and trend (Vinnem j. E., 2010, s. 783).

It is the authors suggestion to try and use the result from the simulations in Risk OMT to create a set of scenarios that present different exposures and other important conditional factors to present different conditions in the operational environment. These will be representative as long as a set of conditions are in accordance with the QRA until it is updated. When the QRA is updated the scenarios and exposure and other conditional factors must be updated and simulated again. These scenarios has the intention of being able to represent the "real-time" risk level given the operational environment and a set of variables. This is a somewhat excessive idea compared to the intervals presented earlier in this sub-chapter.

With the pre-defined scenarios created above and a barrier display, the operators can measure the operational conditions in an arctic environment. By placing thermometers and wind gauges at critical areas where work is performed, they can have a few real-time variables that can signal what exposure range the workers will be exposed to and immediately tell if there is restrictions on the available worktime. Results for how the wind chill exposure affects the leak probability will be presented in chapter 6.2. After this there are several other factors that can affect the risk of leaks. There is the fitness for duty factors that is an individual factor for reduced cognitive performance, depending on season, acclimation, prone to sea sickness, sleep pattern, etc. Results for how fitness for duty affects the leak probability will also be presented in chapter 6.2. Factors like competence can be addressed if there is a single worker or a crew, have the worker been on the platform before, or have the worker used or worked on this type of equipment before, and is the worker new to the work, has the worker been away for a longer period of time that may have deteriorated his ability to perform? These are all factors that can be plotted into a database before the start of a shift or major maintenance operation, and depending on the input the human factor can be represented by a varying probability of leak. This variation range can be divided into different levels representing a "green"-state, where the risk is in a tolerable range and operational conditions are good/normal, a "yellow"-state can represent an operational state where there is an increased risk, like a reduction in available worktime and an extra care for the work performed must be obtained, and a "red"-state where the risk for operational errors is high and extra precaution must be used. The "red"-state might even be an area of risk where work is ill advised and can represent conditions where legislations tells the operator that work shall only be performed in case of emergency, like when the WCI is above $1600W/m^2$.

This "human factor" or "operational conditions" should be available in the barrier display just like all the other safety systems being monitored at all times. By integrating this into the display with all the other safety systems there is a nuance that must be addressed. Unlike the other "hard" safety systems the operational conditions are not prone to maintenance or being offline, and the way "yellow"-state and "red"-state usually signifies states like past maintenance intervals, disconnected, offline, reduced, etc, is different. The operational conditions is maintained when there is a change that affects the operational environment, be it improved procedures, better work descriptions, more automation, different HMI, new equipment, etc. The scenarios must then be reevaluated and probabilities must be updated. Like all safety systems the operational condition or human factor will have a performance standard that also gives a description of the update frequency, independent of modification to systems and other changes that will also demand an update.

6. Result

This chapter will show the results from simulations in the Risk OMT database. The result will also be shown with the assumptions being made as a basis for the simulations. A separate sub-chapter will assess the results from the simulations.

6.1 Using the Risk OMT method and assessing its suitability to chart the human factor

The Risk OMT method as described in chapter 2.3 is a rather complicated method to start using, and with future use of interactions between RIFs and common cause failure embedded in the model will most likely increase the complexity of using the method. This does not mean that the method necessarily will be more complex to set up and ready for use than other systems.

Regardless of future development of the model, updates and changes will occur. This will be both in regards to update intervals but also as a consequence of changing operational conditions after modifications or other changes that can affect the operational risk. An observation when using the Risk OMT database was that the input-sheets were easy to use and adapt to new RIFs and their scoring and weighting. Factors like changes in human error probabilities and the score reliability can prove more challenging if they need change. In regards to barriers, the introduction of barrier improvement proved itself to be simple enough, but introducing new barriers will signify a drastic restructuring of the database. The proposal for using this method as input data for measuring human factor in an operational setting by using predefined scenarios looks good and the database have a structure that provides a way to create predefined scenarios of the different types that are needed.

The new Risk OMT database is considered an improvement to the HUGIN implementation. The result is done in one step compared to the HUGIN implementation where memory restrictions were an issue, and a number of simplifications lead to a step-wise solution.

6.2 Effect of the new RIFs

By introducing two new RIFs to the model a series of assumptions were made. These assumptions will be listed along with the input for the new RIFs and results. The task description used in the model is according to the Risk OMT project:

Table 11: Task description from the Risk OMT project and adapted.

	Task description
B1-B4_A	Failure in work package
B1_B	Failure_Isolation / Blinding
B1_1	Failure Control
B2_B	Failure_Control_Flange
B4_B	Failure_Control_Sealing
B2_C	Failure_Install_Flange
B2_1	Failure_Endcontrol
B2_2/B4_1	Failure_Leak_Test
B3_B	Failure_Resetting_Valves
B3_C	Failure_Open_Valve
B3_1	Failure_Endcontrol
B5	Maloperation of valve(s) during manual operations
B6	Maloperation of temporary hoses
C1	Break-down of isolation system during maintenance
C2	Maloperation of valve(s) during manual operation
C3	Work on wrong equipment (not known to be pressurised)

A series of assumptions are made in regards to the simulations, this is due to the authors lacking industry experience, lack of operational data for production rigs in the arctic and access to them, and ENI have at this stage no operational data or finished operational procedures that can contribute further. All the input before introducing new RIFs and risk reducing measures are dummy numbers and these have in turn been masked to avoid traceability. The assumptions in regards to testing of new RIFs are as following:

- The workspace/process areas are not considered optimized. Process decks are screened in accordance with exposure legislation in S-002, but no further efforts are made to reduce exposure. Wind chill studies are not used to analyze further if some areas are more exposed and need extra shielding, etc. This is addressed according to legislations and a weight C is used for the wind chill index RIF. The same principle with no extra measures is applied to the fitness for duty RIF.
- The score reliability and a priori belief of the RIFs are considered high due the amount of uncertainty in the data and rapidly changing nature of the arctic weather.
- It is assumed that wind chill will not affect planning processes since they most likely are performed indoors.
- In the sections where the Risk OMT project do not have any data (marked NA) the author will also assume that no data is available for the arctic RIFs.
- The author assumes that when a task has been given a weight in either “mistake”, “slips & lapses”, or “violations”, a weight *can* be given for wind chill effect or fitness for duty.
- Based on other RIFs weights the new RIFs are not considered documented enough to weigh them heavier than a few key aspects that are considered to affect the cognitive performance. This implies that if time pressure, workload, and the information based RIFs are for example weighed as high the new RIFs *may* be weighed as high for a task.
- The fitness for duty RIF is set as “low” just to test how a factor as that may affect the leak probability. The RIF is assumed to have the same exposure for all activities, but the validity of this will be debated further in the discussion.
- No separate assessment has been made in regards to management or level 2 RIFs, as seen in chapter 2.3. Impact of management factors in regards to cold climate factors are still considered, but not addressed separately in the RIFs.
- Sensitivity is measured against the “baseline case” with no arctic RIFs.
- When doing the simulations, the weight for the highest exposure was done first and reduced for the other exposure levels. This is an issue when weighting the medium and low exposures since the weight is never brought below “low”, and thus creating cases where the sensitivity is somewhat skewed. Removing a weight from “low” to nothing was considered quite drastic and not done. The effect of this will be discussed further in chapter 7. The weighting can be seen in table 12.

The input is like this.

Table 12: RIF weights for the new arctic RIFs over the different risk exposure ranking.

Task description				B1-B4_A			B1_B			B1_1			B2_B			B4_B			B2_C			B2_1			B2_2/B4_1			B3_B			B3_1			B5			B6			C1			C2			C3		
				M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V	M	S	V
Leak without Arctic RIFs	**Arctic**	WCI factor	Failure of omission																																													
			Failure of execution																																													
		Fitness for duty	Failure of omission																																													
			Failure of execution																																													
Leak with only Ffd	**Arctic**	WCI factor	Failure of omission																																													
			Failure of execution																																													
		Fitness for duty	Failure of omission							1	1	1	1	1	1	1	1	1				1	1	1	1	1	1				1	1	1															
			Failure of execution				1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1		1	1	1	1	1		1	1		1	1	
Leak with low WCI factor	**Arctic**	WCI factor	Failure of omission							1	1	1	1	1	1	1	1	1				1	1	1	1	1	1				1	1	1															
			Failure of execution				1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1		1	1	1	1	1		1	1		1	1	
		Fitness for duty	Failure of omission																																													
			Failure of execution																																													
Leak with low WCI factor and Ffd	**Arctic**	WCI factor	Failure of omission							1	1	1	1	1	1	1	1	1				1	1	1	1	1	1				1	1	1															
			Failure of execution				1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1		1	1	1	1	1		1	1		1	1	
		Fitness for duty	Failure of omission							1	1	1	1	1	1	1	1	1				1	1	1	1	1	1				1	1	1															
			Failure of execution				1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1		1	1		1	1	
Leak with medium WCI factor	**Arctic**	WCI factor	Failure of omission							1	1	3	1	1	3	1	1	3				1	1	3	1	1	1				1	1	3															
			Failure of execution				1	1	3	3	1		1	1	3	3	1	3	3	1	1	3	1		3	1	3	1	1	1	3	1		3	1		3	1	3	3	1		3	1		3	1	
		Fitness for duty	Failure of omission																																													
			Failure of execution																																													
Leak with medium WCI factor and Ffd	**Arctic**	WCI factor	Failure of omission							1	1	3	1	1	3	1	1	3				1	1	3	1	1	1				1	1	3															
			Failure of execution				1	1	3	3	1		1	1	3	3	1	3	3	1	1	3	1		3	1	3	1	1	1	3	1		3	1		3	1	3	3	1		3	1		3	1	
		Fitness for duty	Failure of omission							1	1	1	1	1	1	1	1	1				1	1	1	1	1	1				1	1	1															
			Failure of execution				1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1		1	1	1	1	1		1	1		1	1	
Leak with high WCI factor	**Arctic**	WCI factor	Failure of omission							3	3	5	3	3	5	1	3	5				3	3	5	1	1	3				1	3	5															
			Failure of execution				3	3	5	5	3		3	1	5	5	3	5	5	3	3	5	3		5	3	5	1	3	3	5	3		5	3		5	3	5	5	3		5	3		5	3	
		Fitness for duty	Failure of omission																																													
			Failure of execution																																													
Leak with high WCI factor and Ffd	**Arctic**	WCI factor	Failure of omission							3	3	5	3	3	5	1	3	5				3	3	5	1	1	3				1	3	5															
			Failure of execution				3	3	5	5	3		3	1	5	5	3	5	5	3	3	5	3		5	3	5	1	3	3	5	3		5	3		5	3	5	5	3		5	3		5	3	
		Fitness for duty	Failure of omission							1	1	1	1	1	1	1	1	1				1	1	1	1	1	1				1	1	1															
			Failure of execution				1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1		1	1	1	1	1		1	1		1	1	

The result based on the input is presented in table 13 and 14.

Table 13: Output from the Risk OMT database based on the assumptions made and RIF weighting from table 12.

	Leak without Arctic RIFs		Leak with only Ffd			Leak with low WCI factor			Leak with low WCI factor and Ffd		
Leak Scenario	**Prob. per work package**	**Yearly frequency**	**Prob. per work package**	**Yearly frequency**	**Sensitivity**	**Prob. per work package**	**Yearly frequency**	**Sensitivity**	**Prob. per work package**	**Yearly frequency**	**Sensitivity**
Leak planning	1,34E-04	2,00E-02	1,34E-04	2,00E-02	0	1,34E-04	2,00E-02	0	1,34E-04	2,00E-02	0
Leak B1	1,91E-02	2,86E+00	2,25E-02	3,38E+00	0,18	2,25E-02	3,38E+00	0,18	2,63E-02	3,95E+00	0,38
Leak B2/B4	5,87E-04	8,81E-02	6,52E-04	9,78E-02	0,11	6,52E-04	9,78E-02	0,11	7,20E-04	1,08E-01	0,23
Leak B3	1,21E-03	1,81E-01	1,38E-03	2,07E-01	0,14	1,38E-03	2,07E-01	0,14	1,55E-03	2,33E-01	0,29
Leak B5	1,25E-03	1,88E-01	1,34E-03	2,02E-01	0,07	1,34E-03	2,02E-01	0,07	1,44E-03	2,15E-01	0,15
Leak B6	1,28E-03	1,02E-01	1,34E-03	1,07E-01	0,05	1,34E-03	1,07E-01	0,05	1,40E-03	1,12E-01	0,09
Leak C1	1,13E-02	5,63E-02	1,18E-02	5,90E-02	0,05	1,18E-02	5,90E-02	0,05	1,23E-02	6,16E-02	0,10
Leak C2	4,76E-04	5,71E-02	5,03E-04	6,03E-02	0,06	5,03E-04	6,03E-02	0,06	5,30E-04	6,36E-02	0,11
Leak C3	1,10E-02	5,48E-02	1,13E-02	5,66E-02	0,03	1,13E-02	5,66E-02	0,03	1,17E-02	5,83E-02	0,06
Sum	**0**	**3,61E+00**		**4,19E+00**	**0,16**		**4,19E+00**	**0,16**		**4,82E+00**	**0,34**

Table 14: Output from the Risk OMT database based on the assumptions made and RIF weighting from table 12.

	Leak with medium WCI factor			Leak with medium WCI factor and Ffd			Leak with high WCI factor			Leak with high WCI factor and Ffd		
Leak Scenario	**Prob. per work package**	**Yearly frequency**	**Sensitivity**	**Prob. per work package**	**Yearly frequency**	**Sensitivity**	**Prob. per work package**	**Yearly frequency**	**Sensitivity**	**Prob. per work package**	**Yearly frequency**	**Sensitivity**
Leak planning	1,34E-04	2,00E-02	0	1,34E-04	2,00E-02	0	1,34E-04	2,00E-02	0	1,34E-04	2,00E-02	0
Leak B1	2,37E-02	3,55E+00	0,24	2,75E-02	4,13E+00	0,45	3,17E-02	4,76E+00	0,66	3,62E-02	5,43E+00	0,90
Leak B2/B4	6,76E-04	1,01E-01	0,15	7,45E-04	1,12E-01	0,27	8,05E-04	1,21E-01	0,37	8,78E-04	1,32E-01	0,50
Leak B3	1,43E-03	2,14E-01	0,18	1,61E-03	2,41E-01	0,33	1,72E-03	2,57E-01	0,42	1,90E-03	2,85E-01	0,57
Leak B5	1,36E-03	2,05E-01	0,09	1,46E-03	2,19E-01	0,17	1,55E-03	2,33E-01	0,24	1,64E-03	2,47E-01	0,31
Leak B6	1,43E-03	1,14E-01	0,12	1,49E-03	1,19E-01	0,16	1,55E-03	1,24E-01	0,21	1,61E-03	1,28E-01	0,26
Leak C1	1,23E-02	6,17E-02	0,10	1,29E-02	6,44E-02	0,14	1,34E-02	6,71E-02	0,19	1,40E-02	6,98E-02	0,24
Leak C2	5,15E-04	6,18E-02	0,08	5,42E-04	6,51E-02	0,14	5,70E-04	6,84E-02	0,20	5,97E-04	7,16E-02	0,26
Leak C3	1,15E-02	5,73E-02	0,05	1,18E-02	5,90E-02	0,08	1,22E-02	6,08E-02	0,11	1,25E-02	6,25E-02	0,14
Sum		**4,39E+00**	**0,22**		**5,03E+00**	**0,40**		**5,71E+00**	**0,58**		**6,44E+00**	**0,79**

It should be noted that an increase or decrease in work packages will contribute to an increase or decrease in the leak probability respectively.

6.3 Risk reducing measures by improving existing barriers

When implementing risk reducing measures like using programmable Ex-safe screens and sensors connected with this system, a series of assumptions were made. This is similar to chapter 3.2, where a series of assumptions regarding scoring and weighting of RIFs are made. The task description is the same as seen in table 11, and assumptions are made in regards to what tasks will be affected by the measure. Assumptions made in regards to improvement of existing barriers are:

- This is considered to be an improvement of already existing procedures and not a separate barrier.
- By introducing the risk reducing measure directed at isolation/blinding (B1_B), control afterwards (B1_1), resetting of valves (B3_B), and end control (B3_1), these scores were improved by upgrading the score by one, like from a C to a B.
- As a consequence of this measure a series of RIFs will be affected as well. The RIFs assessed to be affected are: governing documents, technical documentation, disposable work description, design, and HMI. Others may also be affected, but the authors lack of experience with offshore maintenance operations give little basis for making further judgement on this. The RIFs affected were given a reduction in weight. In some cases the weight was brought down from a "high" to a "low" given the nature of the measure. Weighting and how these were reduced will not be shown since this represent third party data and is restricted.

- In the sections where the Risk OMT project do not have any data (marked NA) the author will also assume that no data for weighting is available
- As in the RIF simulations the weight reduction as a consequence of the risk reducing measure will never make it go below "low", and there is no data to support such a move.
- Sensitivity is measured against the "original" risk with no arctic RIFs.
- No separate assessment has been made in regards to management or level 2 RIFs, as seen in chapter 2.3. Impact of management factors in regards to cold climate factors are still considered, but not addressed separately in the RIFs.

Table 15: Output from the Risk OMT database based on the risk reducing measures to a high WCI factor and Ffd scenario.

	Low risk w Ffd and improved barriers			**High risk w Ffd and improved barriers**		
Leak Scenario	**Prob. per work package**	**Yearly frequency**	**Sensitivity**	**Prob. per work package**	**Yearly frequency**	**Sensitivity**
Leak planning	1,20E-04	1,81E-02	-0,10	1,20E-04	1,81E-02	-0,10
Leak B1	2,46E-02	3,70E+00	0,29	3,51E-02	5,27E+00	0,84
Leak B2/B4	6,43E-04	9,65E-02	0,10	7,88E-04	1,18E-01	0,34
Leak B3	1,46E-03	2,19E-01	0,21	1,81E-03	2,72E-01	0,50
Leak B5	1,30E-03	1,95E-01	0,04	1,51E-03	2,26E-01	0,21
Leak B6	1,26E-03	1,01E-01	-0,01	1,47E-03	1,18E-01	0,15
Leak C1	9,76E-03	4,88E-02	-0,13	1,14E-02	5,69E-02	0,01
Leak C2	4,67E-04	5,60E-02	-0,02	5,33E-04	6,40E-02	0,12
Leak C3	1,09E-02	5,47E-02	0,00	1,18E-02	5,89E-02	0,08
Sum		**4,48E+00**	**0,24**		**6,20E+00**	**0,72**

Further assessment of the results and assumptions made will be done in chapter 7.

6.4 Importance measure - RIFs

In the literature an importance measure is performed for both tasks and RIFs. In the thesis only importance measure on RIFs will be performed, since the aim of the thesis revolves around adding arctic operational conditions to the Risk OMT model and arctic RIFs are added, but no extra tasks are added. Based on the rather limited description from the articles and other related literature and including a change in simulation tools, several assumptions were made in order to calculate importance measure for a few selected simulations. The assumptions are as following:

- Based on the information in Vinnem, et al. (2012) F is the frequency for the critical end consequence is interpreted as the output from the Risk OMT model, meaning the overall leak probability from the simulations. Here will $F(\pi_j^{\Delta})$ and $F(\pi_j)$ be the leak probability after and before a change to the posterior distribution for RIF j.
- Inducing a "small change" to the posterior distribution of RIF j while maintaining the same variance is rather an unclear point in regards to where this is retrieved from and how the beta distribution is created from the material. It is understood that when having the beta distribution there is only two variables and by having the variance constant it is only a question of solving for two unknown given a change in the expected value, but there is no information as to what parameters in the model is changed. Therefore it is assumed that the change in variance is assumed constant.
- Based on the above point a "small change" is induced by changing the score of RIF_j down and using a 2:1 relationship (for example 2 on score B and 1 on score C) to introduce a notable

change in leak probability and change in the posterior distribution that is interpreted in the new model to be the "actual condition" of the RIF. This is an output given as a distribution over the intervals A-F and responds to changes in the RIF$_j$ score with a change in distribution for RIF$_j$ and in the leak probability.

- Since the distributions in Vinnem, et al. (2012) refers to a beta distribution which is over a 0-1 interval and supporting literature indicates that intervals with character intervals being given values: A=1/12, B=3/12, ... , E=9/12, and F=11/12, expected value is calculated using this method for the distributions for RIF$_j$ (Vatn, 2013).

These assumptions are followed and importance measure is calculated for four different simulations to investigate how changes to the arctic risk level affect the importance measure ranking for the RIFs. The importance measure is calculated using the formula illustrated in equation 6 in chapter 2.3. For each simulation each RIF is changed in order, and change in expected value and leak probability is documented. By using the assumptions made above the demands for a Birnbaum measure is satisfied with a small change in system performance over a small change to the component in question. The results are presented in table 17-19 and E1 and E2 represent expected value before and after a "small change".

Table 16: Importance measure from the simulation without arctic RIFs

Scenario without arctic RIFs						
RIF	**E1**	**E2**	**ΔEj**	**F(πj)**	**F(πj^Δ)**	**Birnbaum I(j)^B**
Competence	0,36356	0,38406	0,02050	3,60565	3,615	0,456
Governing documents	0,51667	0,53864	0,02197	3,60565	3,61342	0,354
Technical documentation	0,37709	0,40044	0,02335	3,60565	3,60846	0,120
Disposable work descriptions	0,37709	0,40044	0,02335	3,60565	3,62227	0,712
Supervision	0,36356	0,38406	0,02050	3,60565	3,62094	0,746
Workload	0,36356	0,38406	0,02050	3,60565	3,74335	**6,718**
Work motivation	0,43431	0,44990	0,01559	3,60565	3,66466	**3,785**
Time pressure	0,43431	0,44990	0,01559	3,60565	3,70866	**6,607**
Communication	0,36356	0,38406	0,02050	3,60565	3,66721	**3,003**
Design	0,43431	0,44990	0,01559	3,60565	3,64807	**2,721**
HMI	0,37709	0,44044	0,06335	3,60565	3,62956	0,377

Table 17: Importance measure from scenario with low WCI risk and Ffd factor

Low WCI risk scenario with Ffd						
RIF	E1	E2	ΔEj	F(πj)	F(πj^Δ)	Birnbaum I(j)^B
Competence	0,36356	0,38406	0,02050	4,82133	4,83154	0,498
Governing documents	0,51667	0,53864	0,02197	4,82133	4,83008	0,398
Technical documentation	0,37709	0,40044	0,02335	4,82133	4,82415	0,121
Disposable work descriptions	0,37709	0,40044	0,02335	4,82133	4,84067	0,828
Supervision	0,36356	0,38406	0,02050	4,82133	4,83847	0,836
Workload	0,36356	0,38406	0,02050	4,82133	4,98051	**7,765**
Work motivation	0,43431	0,44990	0,01559	4,82133	4,89013	**4,413**
Time pressure	0,43431	0,44990	0,01559	4,82133	4,94067	**7,655**
Communication	0,36356	0,38406	0,02050	4,82133	4,89357	**3,524**
Design	0,43431	0,44990	0,01559	4,82133	4,87025	**3,138**
HMI	0,37709	0,44044	0,06335	4,82133	4,84824	0,425
WCI factor	0,37709	0,44044	0,06335	4,82133	4,88192	**0,956**
Fitness for duty	0,37709	0,44044	0,06335	4,82133	4,88192	**0,956**

Table 18: importance measure from scenario with high WCI risk and Ffd factor

High WCI risk scenario with Ffd						
RIF	E1	E2	ΔEj	F(πj)	F(πj^Δ)	Birnbaum I(j)^B
Competence	0,36356	0,38406	0,02050	6,44217	6,45346	0,551
Governing documents	0,51667	0,53864	0,02197	6,44217	6,45026	0,368
Technical documentation	0,37709	0,40044	0,02335	6,44217	6,44500	0,121
Disposable work descriptions	0,37709	0,40044	0,02335	6,44217	6,46459	0,960
Supervision	0,36356	0,38406	0,02050	6,44217	6,46124	0,930
Workload	0,36356	0,38406	0,02050	6,44217	6,62576	**8,956**
Work motivation	0,43431	0,44990	0,01559	6,44217	6,52161	**5,095**
Time pressure	0,43431	0,44990	0,01559	6,44217	6,57969	**8,821**
Communication	0,36356	0,38406	0,02050	6,44217	6,52576	**4,078**
Design	0,43431	0,44990	0,01559	6,44217	6,49854	**3,616**
HMI	0,37709	0,44044	0,06335	6,44217	6,47301	0,487
WCI factor	0,37709	0,44044	0,06335	6,44217	6,68008	**3,755**
Fitness for duty	0,37709	0,44044	0,06335	6,44217	6,51208	1,103

Table 19: Importance measure from scenario with high WCI risk and Ffd factor and risk improving measure

High WCI risk scenario with Ffd and risk improving measure						
RIF	**E1**	**E2**	**ΔEj**	**F(πj)**	**F(πj^Δ)**	**Birnbaum I(j)^B**
Competence	0,36356	0,38406	0,02050	6,20269	6,21768	0,731
Governing documents	0,44083	0,46883	0,02800	6,20269	6,21367	0,392
Technical documentation	0,26286	0,28947	0,02661	6,20269	6,20572	0,114
Disposable work descriptions	0,26286	0,28947	0,02661	6,20269	6,23414	1,182
Supervision	0,36356	0,38406	0,02050	6,20269	6,22239	0,961
Workload	0,36356	0,38406	0,02050	6,20269	6,3854	**8,913**
Work motivation	0,43431	0,44990	0,01559	6,20269	6,28871	**5,517**
Time pressure	0,43431	0,44990	0,01559	6,20269	6,34403	**9,066**
Communication	0,36356	0,38406	0,02050	6,20269	6,30083	**4,788**
Design	0,36356	0,38406	0,02050	6,20269	6,25861	2,728
HMI	0,26286	0,28947	0,02661	6,20269	6,22044	0,667
WCI factor	0,37709	0,40044	0,02335	6,20269	6,45672	**10,878**
Fitness for duty	0,37709	0,40044	0,02335	6,20269	6,27681	3,174

6.5 Assessment of the results

The simulations were performed with the input and under the assumptions documented in chapter 6. It should be noted that the RIF input in chapter 6.3 is not included since that is restricted information, but how the input is performed is shown in table 12. When looking at the results the effect from the RIFs is simulated separately and along with a combination of these two.

The result from the low WCI factor case is the same as for the case with only fitness for duty as an extra RIF. This is due to them being scored and weighed the same. In most cases where the WCI factor and Ffd RIF is used in combination with each other, the leak probability is higher than the next level of WCI exposure without Ffd, except for the highest WCI exposure. In the cases where there is low and medium WCI risk and with/without Ffd, the risk increase is very shifting, before reaching a spike with the highest risk exposure. The source of this lies most likely in the weighting of RIFs. Based on the fact that the high risk case was developed first and then a reduction introduced as the risk level went down and the weighting is reduced “less” than the previous level with higher risk. As the risk level goes down the impact from the Ffd will be higher on the risk increase and cause the risk fluctuation seen in table 13 and 14 and figure 22. This is a consequence of the assumption that no weight set in the first case (high WCI w/ Ffd) can be totally removed. If the weighting was reduced with supporting data that certain risk aspect could be removed then a more linear risk increase would be more likely compared to the simulations, where there is a gradual increase.

The proposed risk reducing measure by using Ex-safe screens to improve the procedure for isolation/blinding, resetting of valves, and associated controls, is also tested through simulations in the Risk OMT database. From the simulations a risk reduction is obtained, but the reduction is not near to be equal to the risk increase induced by the arctic RIFs. It is clear that this measure has a risk reducing potential, but the RIFs affected by the measure is not that significant in regards to the leak probability as shown by the result and later by the IM result. The risk reducing measure presented and simulated is affected by the same constraints in regards to data and assumptions as the risk inducing arctic factors presented earlier. That means that the result and degree the RIFs are changed and what RIFs have been changed is a subject for further debate.

As seen in chapter 6.4 the results from the importance measure show a quite consistent ranking. In almost all the cases workload, time pressure, work motivation, design, and WCI are high ranked RIFs. Workload is topping almost all the simulations along with time pressure. The inclusion of the WCI factor is also a high ranking factor and has an almost unnatural high leap in the last ranking. As seen from the simulation results in chapter 6.3, the factors adjusted due to the risk reducing measure are almost all low ranking RIFs and would explain why the result from the simulation have very limited effect on risk reduction. This could be subject to further debate in regards to if the RIFs adjusted could be expanded.

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7. Discussion

In this chapter a thorough discussion will be made in regards to the methods presented. How the changes to the BORA method have changed into the Risk OMT and why this method could be suitable to measure human factors, and if it is suitable for measuring human factors in the arctic. This will entail both a review of the methods and their adaptability to new RIFs and with the simulations made. The use of importance measure results is also discussed. Problems with setting performance standards and performance requirements pertaining to operational, human, and organizational factors will also be discussed. Further it will be discussed how the simulation results can be used on a day-to-day basis through a barrier display, to monitor how the risk for leaks are affected and changing due to the human factor in the operational phase of an oil and gas installation.

In general – the methods and their ability to chart the human factor

When the BORA method was developed a set of criterias was developed. These criterias were developed as a result of the discussion of what the purpose of the analysis method should be. The criterias were as following (Aven, Sklet, & Vinnem, 2006, s. 682):

1. Facilitates identification and illustration of safety barriers planned to prevent hydrocarbon releases.

2. Contributes to an understanding of which factors (technical, human, operational, and organizational) that influence the performance of the safety barriers and the risk.
3. Reflects different causes of hydrocarbon releases.
4. Is suited for quantification of the frequency of initiating events and the performance of the barriers.
5. Allows use of available input data as far as possible.
6. Allows consideration of different activities, phases, and conditions.
7. Enables identification of common causes and dependencies.
8. Is practically applicable regarding use of resources.
9. Provides a basis for “re-use” of the generic model in such a way that installation specific considerations may be performed in a simple and not too time-consuming manner.

An assessment and documentation of how the BORA method fulfills the criterias mentioned above was performed. As stated in Aven, Sklet, & Vinnem (2006), criteria 1-4 and 9, are fulfilled. Through the use of barrier block diagrams a method has been facilitated to identify and illustrate safety barriers (1). The model that combines the use of fault trees, event trees (the barrier block diagram), and risk influence diagrams, and allows inclusion of human, operational, technical, and organizational elements along with the ability to graphically illustrate the connections between barriers and RIFs in a way suited for presentation and disussions that can increase the understanding of RIFs (2). The BORA method allows for the analysis of both technical and human errors as initiating events. Along with analysis (extensive or not) of human, operational, and technical barriers (3). Through the use of event trees, fault trees, and risk influencing diagrams, one is able to quantify frequencies of initiating events and the performance of the safety barriers in an lucid fashion (4). If a generic model is developed, it can be made to carry out installation specific considerations about the platform status, but it will also be able to carry out simple comparisons with other platforms. This can be in regards to operational barriers like third party control, self control of work, inspection procedures, or others (9). The generic risk model developed in the BORA project can be seen in figure 19.

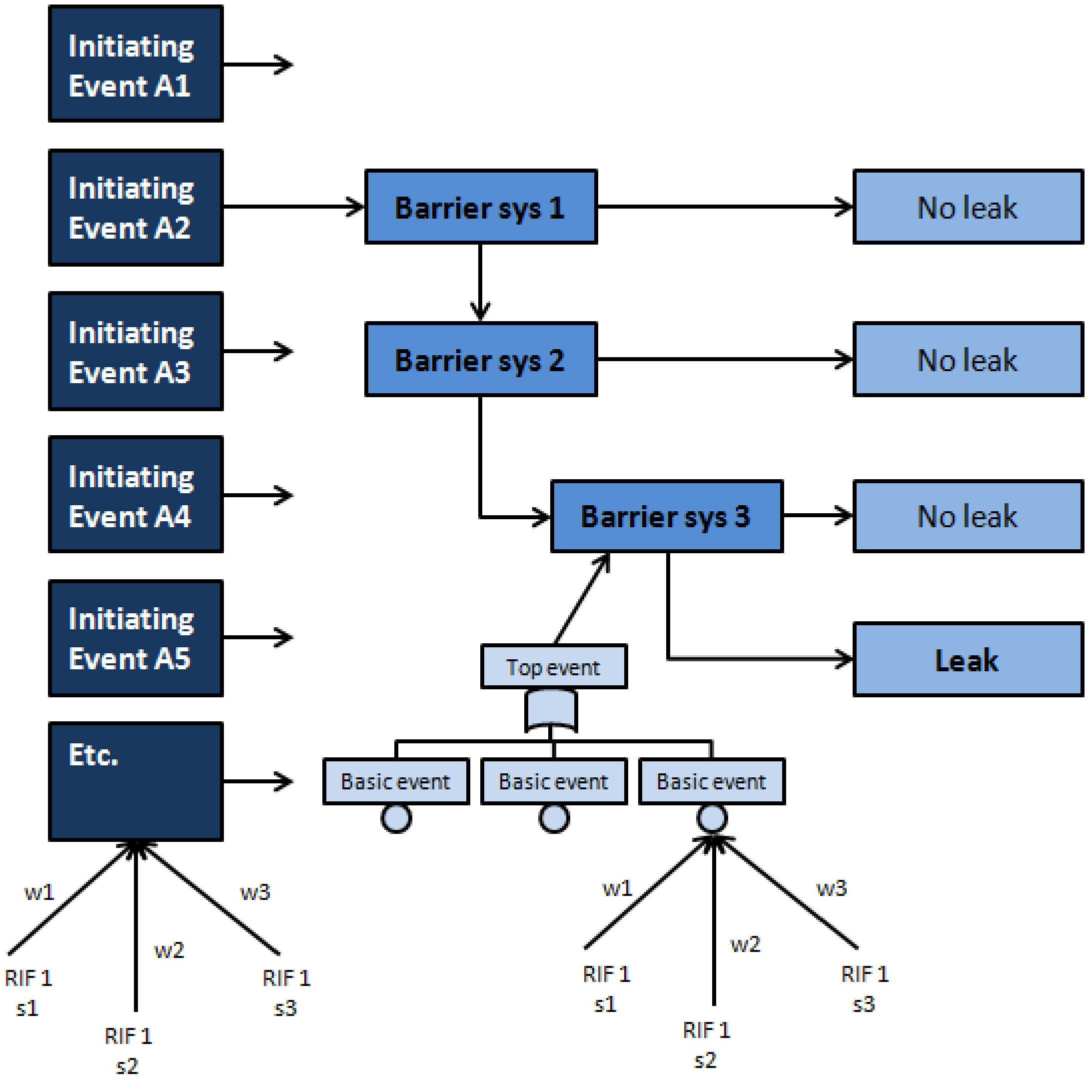

Figure 19: Illustration of the generic risk model in the BORA project . Adapted: (Seljelid, Haugen, Sklet, & Vinnem, 2007, s. 3).

As stated earlier the generic modelling of leak risk was further developed in the Risk OMT project. The new model that was developed includes work operations as barriers and connects them with initiating event that can arise during the operation in question, see figure 5. In addition it has the opportunity to take into consideration activity that will require coincidence planning when performing several tasks. This is addressed in regards to planning and performing tasks (Vinnem, et al., 2012). This can be seen as a clear improvement from the original model where each task or IEs was addressed separately. The ability to view the leak risk in relation to the entire work flow process and the different events that can lead to a leak is valuable knowledge. This model also appears to be a lot more generic in regards to a “re-use” and time consuming perspective, and can be viewed as a clear improvement of criteria (9) and still preserves the qualities of criteria (1) – (4). The new database will in many cases be very applicable for re-use where only plant specific data is needed and perhaps some new RIFs must be inserted, given that there is no change in the tasks being performed. A change in tasks being performed will introduce more work in the database (exactly how much work is at the moment unknown to the author). Still the new event tree or barrier block diagram clearly shows how the combination of tasks being performed and how introduction of error can introduce a leak to the system in a very clear manner, as seen in figure 5.

The new model may appear in some ways less detailed than its predecessor, but it is fact more complicated as can be seen in figure 20. This might be from the change where one goes from assessing each IE with barrier analysis that clearly states how this specific event is protected by separate barriers, to a new event tree that represents the entire work flow and do not clearly indicate actions specifically targeted at a specific IE. Figure 20 indicates that several IEs are modelled together if the work flow process includes tasks where the IEs can occur. The new fault tree structure may also increase the impression of being less detailed (can be seen in chapter 2.3, figure 6). Though the new model have clearly addressed human and organizational factors to a whole new level this may still appear less detailed, but then the purpose is to analyze how these basic event only addressing HOFs, affect the tasks being performed. This way of modelling may also create an easier foundation to collect data from compared to the very detailed predecessor on this level, where a fault tree could to a certain degree be intricate and very unique from each other compared to the new event tree with a very generic solution covering all the human error mechanisms. In many cases the new fault tree is the same as before, but arranged differently and new definitions include many aspects in a new way. The technical aspect where a malfunction or equipment failure induced error (like failure in measuring equipment, etc) is removed and the author is assuming it is now considered more an issue of reliability, but appears not to be addressed in the material published on the Risk OMT method.

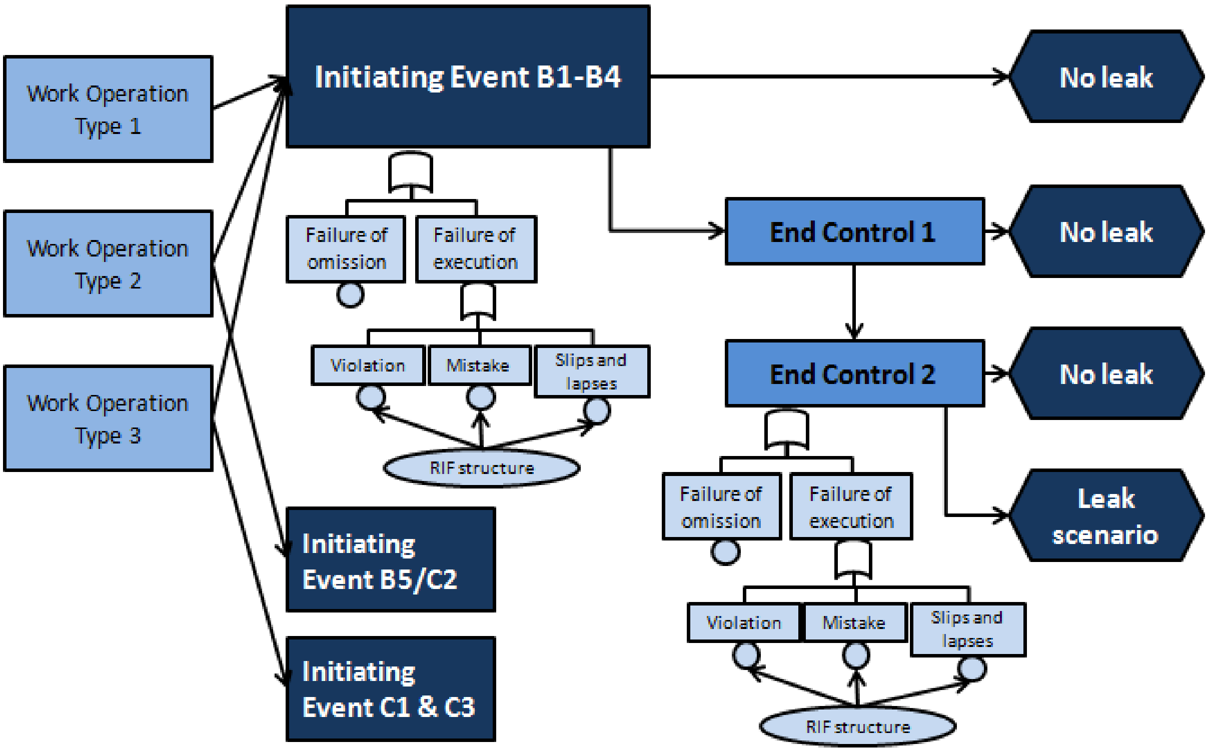

Figure 20: The new modelling for the leak scenarios. Adapted: (Vinnem, et al., 2012, s. 278).

Not all the criteria on the list in regards to the BORA method are fulfilled to the same degree. Problems may arise in respect to the availability of relevant input data (5). As mentioned earlier in chapter 2.2, there may be a necessity to collect new types of data, and to produce relevant input data. This goes especially for the human reliability field where it seems to lack relevant data from the offshore field. Some data have been collected on the British sector, but the data is limited only to a few activities. In the BORA case studies the project has found it necessary to use data from the nuclear industry (Aven, Sklet, & Vinnem, 2006). In the OTS project a lot of work was put into creating a system for assessing the operational safety condition on an offshore installation. The project had special emphasis on how operational barriers contribute to prevent major hazard risk and how HOFs affect the barrier performance. OTS mainly contributed to increase the qualitative aspect of HOFs, and a dedicated questionnaire survey with focus on work practice performance during interventions in the process systems and associated work groups. The Risk OMT project presents a further development of both the qualitative and quantitative aspects for operational barriers and their contribution to reduce major hazard risk and how the HOFs affect the barrier performance (Vinnem, et al., 2012). The emphasis in Risk OMT is on a more comprehensive modelling of RIFs and how they affect the performance of the operational barriers, and the program is built on analysis of questionnaire survey data, leaks, and in depth analysis of critical hydrocarbon leaks in the past based on investigation reports (Gran, et al., 2012). Compared to the BORA method the Risk OMT with its new way of modelling with work tasks in an event tree, in line with the work process flow, and fault tree based around different human failures appears more applicable to use of generic failure data. The basic events also seem easier to separate into the different failure types due its more generic nature compared to the more individual and more complex set-up in the BORA method. The data in general have most likely not changed significantly and the method will most likely suffer under the same need to analyze them in detail before being able to insert them into the model. Still the Risk OMT model appears easier to handle in regards to this aspect. On the other hand more applicable data could be underway through other projects like the SPAR-H method presented in chapter 2.1.

Concerning criteria 6, the focus in the project have been on failures introduced during normal production, maintenance, shutdown, and start-up within the normal operational phase of the life-cycle of the platform. All of the failures have been put into a system with established safety barriers introduced to prevent releases due to specific failures. So far the project have not looked at latent failures from the design phase, or safety barriers to prevent these (Aven, Sklet, & Vinnem, 2006). The Risk OMT project appears to retain the same focus as the BORA project and have not yet started to focus on different life cycle phases of an installation, where latent errors are introduced and barriers are implemented to migitate latent failures introduced in pre-operational phases.

Criterion 7 states that the method should enable identification of common causes and dependencies. The events in the BORA method are considered independent conditional of the RIFs. If there is independence can be questioned. From a practical point of view, the statement is considered sufficiently accurate. A positive correlation adjustment is proposed to account for interaction effects from RIFs influencing one basic event. This means that one RIF may have a different effect on the event depending on the status of another RIF. For example if the competence of the personnel is poor, it will probably be worse if the quality of the procedure is also poor. The positive correlation effect has a simple approach for the analysis of interaction effects among RIFs in the BORA method. It says that if two or more RIFs are assumed to interact and the status is lower than average (D,E, or F), the score of one of these are reduced by one category. This means that the competence may be reduced from a D to an E if the quality of the procedure is also low. Similarly this correlation will also affect interacting RIFs that are better than average. Still, more sophisticated methods should be considered, like Bayesian belief networks that can more accurately model the interactions between the RIFs. With the development of risk models that includes safety barriers that may prevent, control, or mitigate accident scenarios through in-depth modelling of barrier performance allows explicit modelling of common cause failures. There is however a need to further research in order to assess the effect of residual common cause failures that may lead to simultaneous failures of more than one safety barrier (Aven, Sklet, & Vinnem, 2006). The issue with common cause and dependencies and RIF interaction has received a lot of attention in the Risk OMT project and several solutions have been produced for the model, but they are not yet implemented and are addressed separately outside the model. The issue with dependencies and common cause failures have introduced a model based on four factors the project found most relevant and introduced a β-factor to represent a conditional probability for a subsequent failure given a first failure. A dependency level has been introduced with a weighting, scoring, and baseline dependency level for the different types of human error. This way of modelling dependency and common cause failures can be implemented in two ways: either through introducing new basic events, which is a possible solution for a HUGIN implementation, and a post-processing of the minimal cut sets, which is suggested for hybrid implementation where BBN, FTA, and ETA are used in different stages. With the introduction of the new Risk OMT database an approach with new basic events and RIFs representing these common cause failures will be most likely be easiest to implement into the model that already uses direct calculations of the basic events. Which way to implement this in the easiest and most applicable way is however outside the author's knowledge of the database, and the previous statement is a subject for scrutiny. Either way, one of the before mentioned methods is most likely applicable to be introduced to the database ensuring that dependencies and common cause is addressed. This is highly relevant and there are very few tools and methods that are able to do this. Only negative effects of the interactions have been addressed, and the literature states that the method developed is not able to look at positive interactions and neutralizing affects of interactions, for that a use of negative values must be developed. Interactions between RIFs are also an issue improved in the Risk OMT method. The modelling developed for common cause and dependencies is not applied into the model, but developed as a part of the project. A use of weights on the level 1 RIFs with a correction factor is used on subsets involving interacting RIFs. This new method is easy to implement in the hybrid model since it is only multiplied by the original weights, but in the HUGIN implementation it will require manual steps (Gran, et al., 2012). In the Risk OMT it can be included by weighting dependent on scores. This should be relatively easy to specify, but difficult to implement.

Criterion 8 deals with the practical applicability with respect to the use of resources. The complex reality of a process plant will always be demanding, and therefore will a comprehensive analysis demand a lot of resources. For the purpose of adequate support for decision-making there is a need for a level of detail in the analysis that reflects the reality of the platform (Aven, Sklet, & Vinnem, 2006). The Risk OMT is improved in regards to its ability to reflect the reality of the platform. As a consequence the method may be more resource demanding than before, but the result has more uncertainty than its predecessor. Another important factor in this debate is the somewhat subjective topic of benefits, and whether the operator feels the necessity for a risk reducing measure, and a reduction that is very difficult to measure due to its proactive nature. This is an important part of priorities from a cost-benefit perspective where many arguments can revolve around statements like "Why do we need such a time and resource demanding system, when we have these pieces of equipment with very good reliability and very low leak rate". It is a matter of priority and higher focus from authorities on the subject of operational barriers and HOFs can increase the "value" or the cost-benefit ratio. It is also pointed out by Vinnem, et al. (2012) that the work involved in the analysis and modelling is not prohibitive, meaning that the work input is reasonable compared to the results produced.

When using the BORA method the main area of application is not the calculation of the release frequency itself, but to use the method in assessing the effect of the risk reducing measures and risk increasing changes during operations. The method allows for sensitivity analysis that can analyse the effect of changes in human, operational, technical, and organizational RIFs. With a focus on relative changes in the release frequency instead of absolute change may increase the credibility of the results. The method also allows for new barriers to be analyzed (Aven, Sklet, & Vinnem, 2006). These strengths have been preserved and sensitivity measurements for the simulations have been made and are presented in chapter 6.2 and 6.3. The Risk OMT has increased the decision support area with the ability to perform importance measure analysis in addition to sensitivity analysis. This presents the ability to rank either the task or RIF in accordance to their ability to affect the risk level. The risk reducing measure to implement will then require further analysis. This ability can be very valuable for simulating new barriers and RIFs. Importance measure for the new arctic RIFs and improved barriers is presented in chapter 6.4. With the improved methods and lower uncertainty factor the results of the new analysis will also be more representative. Compared to traditional QRAs, the BORA and Risk OMT method provides a more detailed risk picture and addresses causal factors towards loss of containment. Through the qualitative analysis of the release scenarios knowledge is generated about the factors influencing the risk of hydrocarbon release within the process plant without performing a quantitative analysis. This knowledge may again serve in support of decisions made for the future performance of the safety barriers. When adding the quantitative part and performing the analysis inside and outside the model like IM, dependencies, interactions of RIFs, etc. the result produces a quite covering analysis of the operational risk level with plenty of input to the decision makers.

The Risk OMT model has through case studies shown its merits and it is claimed that the model provides a very useful result for the purpose of quantification of effects from HOFs in modelling of risk associated with hydrocarbon leaks on oil and gas installations. Based on the work in the OTS project a more generalized and improved model have been developed based on the BORA method. The new hierarchy of RIFs is considered an improvement, and the new way of categorizing human errors into mistakes, slips/lapses, and violations, and how the different RIFs influence different error types is an important refinement. The new way of structuring human failure by, creates a clear distinction between human error (mistakes and slips and lapses) and violations. The first one being a consequence of failures in perception and cognition, versus violations that have a more socially constructed cognitive schemata and conscious understanding and interpretation of work and its context (including peoples norms, believes, and attitudes). In general the case studies have shown that the Risk OMT with the BBN model is considered sufficiently applicable to various installations. It is noted that if installations with the same operator are considered, the CPTs are expected to be re-used on a general basis without modifications. If there is a shift in operator company, there will be a requirement for modifications to some of the CPTs (Vinnem, et al., 2012).

The literature describes three important factors for the new RIF model: all relevant RIFs are identified, the RIFs are measurable, and that the relationship between the RIFs and risk is known. As it can be clearly seen from tables 3 and 6, the number of RIFs included in the BORA has been drastically altered compared to the one seen in the Risk OMT project. Extensive literature studies aimed at identifying RIFs were conducted in both cases. In regards to relevance, the Risk OMT has created two RIF models: one for planning, and one for execution and control activities (Vinnem, et al., 2012). This is an improvement over the BORA as it includes the planning aspect before an activity. The technical qualities are only addressed in one RIF, design, and the literature study pointed out several other important relations between technical factors and performance of activities. A few conditions have been pointed out as missing: lack of standardization, operational complexity, operational options and number of malfunctions. The conditions presented are considered to have a substantial impact on the disposition for human error and violations, and represents a significant limitation in the RIFs and RIF structure used. The generic aspect also appear to be somewhat lacking, since the quality of the RIF structure is still unknown. Some RIFs have a general quality, the structures represented cannot be said to be valid for all phases, like commissioning, etc, and covering all mistakes, slips and lapses, and violations, for these phases and any activity in any organization. This will most likely also be visible when including cross-cultural factors into the mix, and causing different configurations of RIFs and RIF influences (Vinnem, et al., 2012). This signifies that a lot of work is created when different activities are explored for use in the model, and where cultural factors can introduce a significant effect on the results. In regards to the second demand that RIFs should be measurable, the RIFs are considered possible to describe and quantify. This will require some efforts, but the use of experts and qualitative evaluation, based on interviews and other sources, will lead to each RIF receiving a grade from A to F. In regards to the third condition, relating to that the relationship between the RIFs and risk should be known. This is also done through expert evaluation. The cause-effect relationships addressed in this topic is complex and inter-disciplinary, and very demanding. Risk OMT has had special attention on the topic on interactions and its effects and many experts have worked on the topic. Even with all the effort and inter-disciplinary effort the expert evaluations are vulnerable, but through use of the model a contribution could be made towards refinement and validation of the RIF-risk relationship (Vinnem, et al., 2012). This is as previously stated a great improvement, but not yet implemented and with only a focus on negative interactions and little focus on positive and neutralizing effects. How to implement this in the Risk OMT database will also be an issue since the HUGIN implementation is no longer used.

The Risk OMT models way of addressing RIFs under the assumption that there is a true underlying RIF that is impossible to reveal and therefore treats the RIFs as random quantities. This means that the scores given are assumed to represent realizations of that true underlying RIF. Based on this statement, it can be hard to assess the RIF when there are limitations in the observation method. Another point in this discussion is that there is a “real” variation between shifts, personnel groups, changes made over years, etc. Otherwise the RIF is scored in the same way as before with letters A to F and if no data source is available the score is set to a industry average, a C. The Risk OMT has also the ability to assign distributed scores. This means that a score can be distributed between different scores on the scale. The distribution intention is to reflect real variation in observed scores, as also mentioned above. Internal distributions can be given as ratios, like 1-1 for the score B-C or 1-2 for A-B. The 1-1 distribution signifies equal distribution between the two observed values. RIFs are also assessed in regards to the reliability of the score compared to the previous score. This assessment is performed qualitatively by attributing a score for each RIF as high, medium, or low reliability. The project refers to high reliability as the most concrete observable, like physical conditions or operations near the sharp end, like the quality of the technical documentation. A score of medium will refer to a less concrete observable, like competence and communication. Low reliability will in term refers to uncertain or inadequate observations (Vinnem, et al., 2012). This way of handling RIFs and defining RIFs, shows that the Risk OMT have thought about the uncertainty in both data and the true nature of the RIF and the “true” operational environment. The result will be a more nuanced image of the RIFs than in its predecessor.

The BORA project did extensive studies into human error probabilities (HEP) and these data are also used in the Risk OMT as basis for the assessment of generic HEPs in the model. HEP are based on human reliability data and is used for all failures that are modelled. The literature makes a note of the fact that human reliability data are scarce and limited considering the demand that the data shall be directly applicable for the project. Evaluating data for the error probabilities are therefore evaluated with that in mind. It is also noted that further research is made into this field (Vinnem, et al., 2012). That is not very different than the conclusion on the same topic in BORA, and is also mentioned earlier in regards to relevant input data.

Failure of omission data is very scarce and is not easy to obtain. That is the general statement on omission data, but the OTS project supplied some data that is used. The data obtained is further used as a basis for expert judgment on the remaining failures of omission. Even if the data gives a probability for omission of a certain stage of the maintenance process, how often that particular omission introduces a failure into the system is not indicated. Therefore the probability of omission is multiplied with a given fraction in order to express how often the omission actually leads to a failure in the process. Since there is little or no data on the subject a fraction of 1/20 is multiplied with the HEP based on relevant arguments under the topic of distributions between misses and accidents. In the project human error has been separated into mistakes, slips and lapses, and violations. It is suggested in relevant material that a general error rate for an act performed incorrectly should have a probability of 10^{-3}. The distribution between mistakes and slips and lapses are set to 90/10, based on human error probability ratios between diagnosis errors and action errors described in SPAR-H. The project has big difficulties with obtaining HEP concerning violations. A violation is a deliberate or unintentional deviation from the formal procedures and the only data found was in relation to either only performing part a part of the task, or performance of the task without the use of checklist/procedure. Similar to failure of omission a fraction of 1/20 is multiplied with the HEP to express how often a violation actually introduces a failure in the maintenance process. Planning of tasks is the exception to this, since a violation here will introduce a failure in the disposable work description, the product of the planning process (Vinnem, et al., 2012).

There are two separate ways of implementing the Risk OMT model, the HUGIN with a full BBN implementation and the hybrid implementation where the RIFs and their relation is modelled as a BBN, but the fault and event trees are calculated in accordance with ordinary processes. The full BBN implementation has an advantage since the model explicitly recognizes that the basic events are influenced by subsets of the same RIFs. This leads to uncertainties in the true RIF values being propagated through the model, in both the RIF structure and the basic events. Since the subsets of RIFs are similar for all the basic events, dependencies will arise between the basic events due to the strong correlation between the RIFs attached to the various basic events. This will lead to a higher leak frequency compared to the hybrid model or others where the RIFs are treated to influence the basic events independently. A corresponding effect of this is that risk reducing measures will have a higher effect. The Risk OMT database will have the same effect. A challenge with the full BBN model is the amount of CPTs and the size of CPTs. The use of parent nodes and the weighting of these and the impact on the child nodes due to dependencies have been hard coded into the HUGIN tool by the research group. This cumbersome implementation creates a “real” user challenge if they need to change the structure in the model or the CPTs (Vinnem, et al., 2012). This user friendly factor has been highly improved and the interface for implementing changes is very simple in the new Risk OMT database. The challenge is the same as before when there is a need for implementing new tasks into the model.

The way the model has to be implemented in the software is also an issue creating a direct influence from a RIF on a basic event before any actual observations are made. This is an effect of arrow directions as the model uses influence diagrams and if the arrows are reversed the amount of parent nodes and CPTs would be too high, but would be more correct from a frequentist point of view (Vinnem, et al., 2012), an example that can be seen in figure 9. This is now calculated directly in the Risk OMT database and the direction is no longer significant. A major advantage of implementing the full model in a BBN implementation is that all the event and fault trees and “soft” influences can be included, but this has its limitation in computational time and memory. An advantage is the common cause effects that may be modelled explicitly, but how this should be done in detail to model the intended effect remains to be seen. A clear disadvantage is that the HUGIN model provides no clear visualization of the combination of barrier failures in the same way as a traditional fault would present minimal cut sets (Vinnem, et al., 2012). Both implementations have their advantages but work on ways to implement dependencies and interactions were made in the HUGIN and hybrid project, and will most likely be done towards the newest methodology, the Risk OMT database. If the next generation will become like the one described in Vinnem, et al. (2012) with a hybrid program with standard fault and event tree and RIF structures that can be specified in a graphic editor or a further development of the database doing all the calculations directly remains to be seen.

The general conclusion from the Risk OMT project is that there is still work to be done in relation to the RIF structure and development for how to include more technical factors that may impact and lead to failures of execution. In the operational phase the information available through audits, interviews, surveys, or from expert sessions, and the models intention is to reflect these installation specific data and present it in the risk level. As an international industry, the petroleum industry is quite standardized and many countries rely on the same sets of standards, etc. providing opportunity to use this tool in other countries where similar standards and maintenance operations are similar on complex offshore installations. As stated earlier for other companies, data sets will in this case have to be revised (Vinnem, et al., 2012). This generic use is in line with criteria 9 presented in the BORA project. By creating a generic tool that can be used on an international market can create a greater acceptance of the important role HOFs have on the risk level given broader use and in turn create a greater need for more applicable input data. It is noted in Vinnem, et al. (2012) that the nature of the preventive maintenance work separates the oil and gas industry from other industries making transferring of the model limited. This is also the case with the nuclear industry who where the first to work with HOFs, since the risk mechanisms are very different and the analytical emphasis is on response to incidents and not on preventing leaks. Commercial aviation is also considered quite different even if there is a high focus on HOFs, but comparison between CCR operators and pilots are similar due to the high focus on HMI and communication with personnel outside the location. (Vinnem, et al., 2012). However research shows that less than 10% of leaks can be attributed manual interventions from the CCR, making comparison with commercial aviation marginal (Vinnem, Seljelid, Haugen, & Husebø, 2007). Another general conclusion based on the simulations in HUGIN and the hybrid model is that they can both reflect relative differences between installations. This creates an argument for the importance of HOFs and improvement of these factors (Gran, et al., 2012).

Even if the research and the results from the Risk OMT project are very promising, there is still some critique in relation to newer research on the availability of operational barriers. Vinnem(a) (2013) has made a detailed study of hazards and barrier failures in relation to leaks and their circumstances for a five year period, with the objective to present a more realistic barrier models for maintenance work on process systems on offshore installations. The leak data is from the years 2006-2010 in the Norwegian offshore sector, compared to the data used in the Risk OMT project being based on leak data from the same sector, but relatively old data from 2001-2005. The work is done in order to more accurately model hydrocarbon leaks related to being used for risk analysis in the operational phase. The long term goal is that knowledge about leak causality may contribute to a reduction in the number of leaks. A major focal point in the article is the importance of the verification of the performance of the work process steps (Vinnem(a), 2013).

The new model for the leak scenarios developed for the Risk OMT project can be seen in figure 20 shows two independent barrier elements and the error free execution to the task that represents an operational barrier. Having two independent control barriers represents a very reliable system. The leak data analyzed shows that about 70% of the leaks for the period 2006-2010 are due to initiating events B2, B3, and B4. These leaks belong in the latent leak category. Of the data belonging to the events B1-B4, only seven out of 22 leaks occur after start-up (the total number of leaks for B1-B4 is 29, but information was not available for seven). This means that approximately two thirds of the leaks occur before a leak test can be performed. A leak test is in this case end control 2, seen in figure 20. The implication of this is that the two independent barrier elements considered in figure 20 and used in simulations, etc., are not relevant for the majority of the cases analyzed. A very reliable system is built up around the assumption that there are three barriers, but the majority of cases show that there is a maximum of two barriers affecting the outcome, and in some cases only one (being the task execution). How many barriers that is available is looked upon as a very important aspect of the modelling and during testing of possible improvements actions in the Risk OMT model, it was observed that very few actions had significant effect on the risk level. This result may have been heavily affected by the number of operational barriers present in the modelling. If the reality is that only one or two barriers are available for the majority of leaks, then the effect of improvement measures, especially directed at the barrier elements being available may have been significantly under predicted. The next step is then to try and establish if loss of containment is likely to occur before verification has taken place (Vinnem(a), 2013). Table 20 shows leaks for B1-B4 leaks used in the Risk OMT model.

Table 20: Summary of phases for when B1-B4 leaks occur with highlight on when verification can be performed. Adapted: (Vinnem(a), 2013, s. 117).

Leak during error during	Preparation	Execution	Reinstatement	After start-up
Planning	0	1	4	1
Preparation	0	0	0	1
Execution	0	0	5	3
Reinstatement	0	0	5	2
			Verfification can be performed	

It is considered that all leaks occurring in the reinstatement phase or later are given opportunity for verification. As seen in table 20, all but one has opportunity for verification and gives reason to assume that errors in categories B1-B4 allow for verification to be performed. There are two verification errors being performed, omission failure and execution failure. The ratio is 4:1 for ”verification not performed” versus ”verification performance failure”. Based on the information presented here, a revised work process model is suggested in figure 21. This is based on the new data and discussion. The upper part of the illustration presents the events where the leak occurs after start-up. This is one third of the cases and two independent barriers are available plus the task execution as a barrier. Two thirds of the cases will not have the leak test barriers available and only one additional barrier element will be available in addition to the task execution (Vinnem(a), 2013).

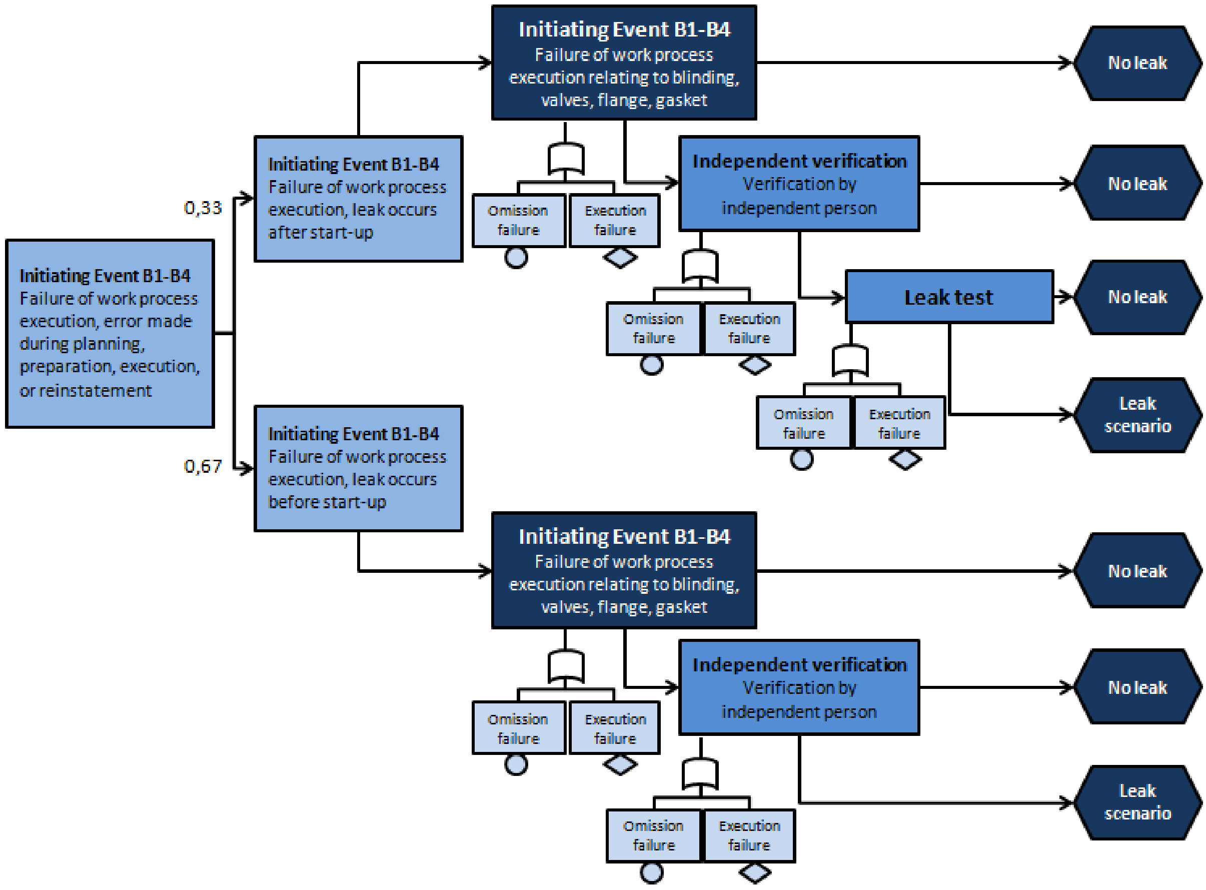

Figure 21: The improved modelling for leak scenarios B1-B4, given new data. Adapted: (Vinnem(a), 2013, s. 118).

Based on the data presented in Vinnem(a) (2013) it is clear that omission failure dominates over execution failure. These failures are often due to "silent deviations". This could be failure to comply with controlling documentation; procedures, instructions, and isolation plans. Compliance with controlling documentation is the foundation when performing verification activities and meeting the necessary requirements. This will also be in regards to requirements to carry out the verification itself with the intention to ensure that potential errors are detected. The independent verification of work processes is one of the most important aspects of the work process for intervention in hydrocarbon systems. There is still much for the industry to learn in this area and very little attention has been awarded to this in root cause investigations in regards to leaks. A suggestion to deal with these compliance failures is the implementation of the A-standard introduced by one company. The A-standard is aimed at work being performed in accordance with all applicable requirements and specifications. This system is highly dependent on management and supervision to ensure that all tasks are performed correctly the first time. The new risk reducing measure suggested in chapter 3.3 can in many cases act as a guidance and surveillance tool in regards elimination of "silent deviations", where it will be easier to perform surveillance, but also to ensure compliance with procedures, other technical documentation and work descriptions (Vinnem(a), 2013). Points made in the article shows that even if the Risk OMT method is a very suitable method for charting HOFs it also has points for improvement to better portray the real operational environment.

The simulations and testing of arctic RIFs and risk reducing measures

Based on the results showing a high risk increase potential due to the new arctic RIFs, and a low risk reduction from the risk reducing measure from the simulations, along with results from the importance measure analysis, raises several topics for discussion.

As can be seen in figure 22 and table 13 and 14, the risk increase with the high WCI factor and Ffd introduces an increase in leak probability by 79%, which is a drastic increase. It is worth noting that this is not a constant effect since the wind will change and screening of process decks will reduce some of the impact from wind chill, but a certain amount of air circulation must be preserved rendering exclusion from this effect impossible. In periods from November until March one must expect conditions that can produce wind chill conditions of varying degree. Consider a mean average wind speed of 8 m/s which is not a very high speed, will at $0^{o}C$ have an 1177 W/m^2 exposure, and reduced available work time as a consequence. Reaching exposures that will have a high wind chill factor will not be difficult in the Barents Sea, but measures we take before going in there can greatly reduce the exposure. The results produced in this thesis may not represent actual conditions. Rating of weights and what exposure will qualify as low, medium, or high must be debated in regards to cognitive performance and other factors important to the WCI RIF. With that in mind, results presented here can be re-evaluated and more representative rating can be made based on real operating conditions and how often such exposure will occur. The system for weighting presented in this thesis may be a correct approach, but periods with such exposure can be marginal. As mentioned in chapter 3.6, use of PPE and other solutions (since the demand mentioned in S-002 in for exposed skin, but ergonomics have to be assessed) may reduce the exposure from wind chill and help bring down the periods with reduced available work time. Though regulations state that they are to be abided, and proving that having a better system/procedure/routine does not qualify for being exempt from them.

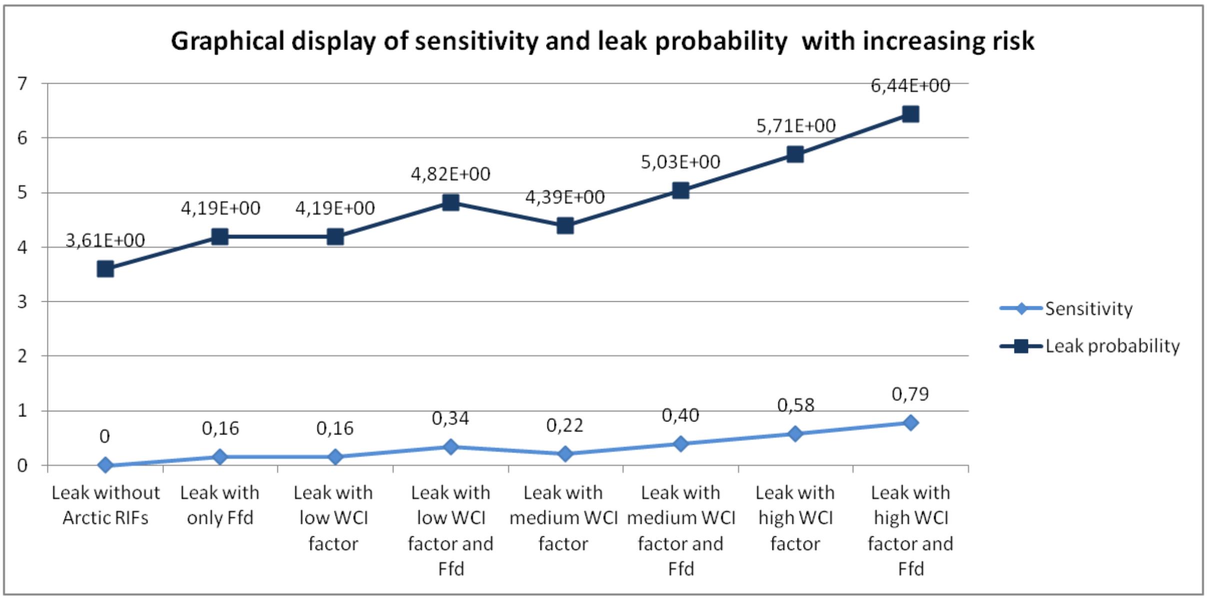

Figure 22: A graph of the changing sensitivity and leak probability from the simulations.

There is a possible adjustment to be made in accordance with the use of Ffd. This revolves around the statement that the weight is set to low on all tasks being given a score to represent an extra risk influence during operations to see how big a "static" risk influence will have on the risk compared to the more changing WCI. Based on the fact that the Risk OMT model separates between planning, process, mechanic, and separate work crews can introduce a need to analyze thoroughly which ones are affected by the Ffd factor. Having to make such an assessment will most definitely reduce the leak probability, but can also lead to make a more thorough estimation on whether low, medium, or high should be used. Even planning can be assessed to be affect by certain aspect of this RIF like sea sickness and the depression and sleep related symptoms related to long periods of no daylight. As explained in chapter 3.6, this RIF is very individual and can have great fluctuations between shifts depending on conditions and crew characteristics. This same argument will affect the WCI factor in the same way where certain areas and different crews can be affected differently. This can lead to a lower increase in leak probability at least for the Ffd influence. Still an increase in risk is noteworthy and may create good procedures to deal with factors included in the Ffd definition.

As mentioned in chapter 6.5 regarding RIFs affected by the risk reducing measure, additional factors like time pressure can for example be reduced. The author has limited knowledge about time consumption during these activities and therefore has no basis to say if it creates a more time efficient procedure. Another RIF possibly affected is communication in regards to the ability to display the isolation/blinding plan on several screens giving for example personnel in the CCR or other areas ability to monitor the process and can improve communication related to these operations. Calculations on importance measure can easily reveal if there are other RIFs that will have a greater impact on risk reduction than used in the simulation. Evaluation of those results can be found later in this chapter. In general it is in the author's opinion that by implementing a measure such as this, a reduction in violations in regards to omission or violations in regards to control tasks can be achieved since the screen can easily notify the controller if the checklist/procedure has been performed or not.

In regards to risk reducing measures, it is clear that the arctic wind chill exposure RIF increases the leak probability significantly. Even if not simulated, there are many risk reducing measures that can in many ways reduce the leak probability more than the Ex-safe screens can. By using weather data and wind chill simulations, good assessments can be made in regards to where tasks are performed and what kind of exposure different wind directions, temperatures, etc., will produce. When this is known local screening measures can be implemented or a solution with portable walls (permeable and can be made of hard plastic and stiffened) and some form of tethering arrangement or floor mounts can be used. By removing the walls after performing the work task no extra risk of debris or pressure build up (explosion risk) is induced after task completion. During work performance a leak will be able to escape through the permeable walls and reduce the explosion risk during task performance. With extra screening less cumbersome PPE can be used and increased ergonomics will be less strenuous working conditions. This is an idea based on the Goliat process deck arrangement and their outer wall which is winterized with a wafer design for ventilation, but reducing inflow of snow and reducing wind speed. Since the Goliat FPSO will be installed with a fixed position, the ability to position the process deck by using a turret solution will signify that winds will on occasion (not known how often, since the author has not seen the wind chill study) come from a direction that can induce unfavourable wind conditions on the process decks. On a global platform scale a solution with for example Statoil Rotating Walls might provide a better solution for a moored platform unable to rotate. This is a similar wafer concept, but with hydraulically operated walls that can regulate ventilation and have a special technique for non-manual deicing. Otherwise there are many risk reducing measures that can be implemented from an operational standpoint. Proper systems for breaks and warm beverages (for hydration purposes), foreman/buddy systems, seasonal maintenance planning, and many more are suggestions in ISO 15743:2008, on how to reduce cold climate induced risk in an HSE perspective (European Committee for standardization, 2008). The measures to reduce HSE related risks will in many cases also be beneficial and contribute to reduction in the risk for major hazard accidents. This is since the main purpose of ISO 15743:2008 is to reduce the risk for accidents in general from an operational standpoint. There are also many measures that can be introduced to also reduce the impact from factors portrayed in the fitness for duty RIF. Routines for acclimation processes, follow-up in regards to dark seasons and depression if one is exposed to this, medication for sea sickness, and awareness in regards to both cognitive aspects as well as somatic effects of being slightly chilly. In regards to cold exposure a good system and procedures for layered clothing can be a good measure. All of these risk reducing measures demand a willing organization that is vigilant and sees the benefit from winterization and operational measures for a cold/arctic climate.

Importance measure – Decision support

Almost all the high ranking RIFs belong to the task oriented RIFs and a clear signal towards risk reduction would be to implement actions to improve these. As a debate, the use of improved procedural aid tools like the Ex-safe screen could, if work dynamics and demands for control of work allow it, have a positive effect since less time may be used to double check since the improved checklist shows the progress and step the worker is on. If this is the case, it is outside the authors experience and only a suggestion in regards further debate on the topic.

In regards to risk reduction it is clear that the WCI factor is one of the higher ranking RIFs and as the results show, the high risk exposure creates a 79% increase in the leak probability. Actions towards reducing the exposure like local screening of work sites or improved equipment that reduces the time period exposed to wind chill, can together with good routines and procedures pertaining to exposure, reduce the risk significantly. This will have a good effect both on the major hazard risk, but also on the HSE risk level. This can have greater synergy effects than other task oriented improvements.

The leak probabilities are all affected by the authors own scoring and weighting and risk level may be significantly different given more accurate data to work with. Even though this importance measure is somewhat outside the intended use of the Risk OMT model suggested in this thesis, it is a quite useful tool in regards to decision support for the continuous risk reduction work that should be performed on an everyday basis.

The methodology in calculations made is somewhat uncertain in regards to correct result. Explanations in regards to correct execution is not straight forward in the literature and the Risk OMT database could provide a different basis than the HUGIN tool in regards to finding the posterior distribution. Therefore assumptions are made in regards to correct use of data and use of a new model. In any case all the importance measure calculations are done in the same fashion and should for the simulations made in the thesis provide a reasonable basis for comparison. A quick test of the ranking shows that by changing one of the low ranking RIFs and one of the high ranking RIFs, a higher reading is seen on the high ranking RIF. This is in line with what the literature describes as an easy way to verify the accuracy of the importance measure calculations.

The Risk OMT model as a suitable method for charting the human factor in arctic conditions

It is quite clear based on the criteria set and discussion about BORA and Risk OMT and how these criteria are fulfilled, that Risk OMT is the better choice of the two. It is a model thoroughly tested and adjusted through cases that shows a clear adaptability to include new factors; both risk increasing and risk reducing. With that established, an assessment must be made in regards to its applicability to chart the human factor in an arctic operational environment. First of all the Risk OMT method is as discussed earlier a through method that has been improved significantly in regards to model implementation, RIF structure and failure mechanisms creates a more generic tool, and common cause, dependencies and RIF interactions have received a lot of attention. The model presented in the literature has been improved and a new model made easier to implement have been introduced. If in turn the previously mentioned factors are introduced into the model or in a future model, the tool would be quite complete. Still, the result from the simulations performed is useful and is able to depict how HOFs affect each installation individually, and in combination with its ability to introduce new RIFs, as done in the simulations presented in this thesis. It shows a method with a very good potential that will only be improved and more complete if the measures presented are performed while the model retains or improves its ability to be user friendly. As stated earlier it is not difficult to improve barriers, but introducing new barriers will require some effort, but that will most likely either way be a part of a major modification and entail change to the model either way. An important factor is the use of arctic RIFs, and how to use them. This should be investigated more before making a final decision, but the prospects looks good in regards to implementing them into the model. All in all, the model appears to be a suitable method for charting the human factor in arctic conditions based on its adaptable and generic structure, but the improvements mentioned would benefit the Risk OMT method. Based on the PSAs request for ways to chart operational barriers and monitor barrier conditions in light of major hazard, this is a method filling a gap concerning a period in time when many safety systems are either disconnected of partially impaired.

Use of barrier display to display operational conditions

As portrayed in chapter 5 a more “real-time” solution function in the barrier display is suggested. Here the operational barrier in regard to leak risk will be displayed in a quantitative way with green, yellow, or red condition, and a trend indicator. As this method evolves into including other aspects like marine systems, reactive barriers as presented in the SPAR-H method under development, drilling, and other aspects with important operational aspects in regards to major hazard risk, a pure operational barrier panel would be optimal. This would contribute to separate the “slow” to update technical barriers from the more “real-time” and changing operational environment. The way of implementing the human factor in a barrier display as a “real-time” solution comes as a consequence of changing weather and other operational conditions that will change according to time of day, crew, weather, time spent on the installation, experience (with equipment, platform, module, etc.) and others. These are factors that will have to be of a completely different nature if they are only going to be updated with months apart. By being able to cross out a few data before each shift to create a “profile” of the new shift with additional operating conditions, a leak probability can be found from predefined simulations that only need to be re-simulated after significant changes are made to the operating conditions. By reducing the variables per shift to a few selected RIFs this should be a system that is quite manageable and these conditions should also be used during meeting where workers receive information and other task important factors are discussed like briefings, etc. Less uncertainty in relation to the operational barriers will most likely be observed as a consequence.

By having a system like this the workers will be much more exposed to how the QRA works and how the operational risk level looks like. This is also a good tool to raise awareness around barriers, common cause failures, dependencies, and why violations are not tolerated even if they are done with nothing but good intentions. This is in line with the encouragement in the article "Risikoanalysen må opp av skuffen" (Antonsen & Værnes, 2012). A consequence of monitoring the operational barriers in such fashion is that it is a step towards having a level 4 QRA. In such a system the QRA is combined with risk indicators to reveal status of safety barriers, the QRA is an integrated part of the safety and risk management system, results from the QRA form the basis for the daily risk management, and the QRA is known and accepted at all levels of the organization. The different demands for including HOFs in the QRA can be found in table 1.

Performance standards and performance requirements

The Risk OMT method provides a way to measure the condition of the human factor in the operational environment. Critical factors for the human factor must be subjected to testing and maintenance through specific performance requirements specified in performance standards.

It is now clear from chapter 4 that the human factor as a barrier element have several aspects that must to be charted and performance requirements set and put into performance standards, before satisfying legislative requirements. How is then a performance requirements set, and how are very qualitative factors measured? These are perhaps the biggest challenges associated with operational factors. As for other safety systems risk indicators have been commonly used as an effective way of following up and monitoring the risk level and how it changes. This is often used in the operational phase as a follow up to the QRA. That is what is needed for the performance requirements to have something to compare the requirements with. The parameters or indicators measured should be able to identify important factors with strong impact on the risk level and the effect changes have on the risk level. By using such parameters or indicators effective monitoring can be performed. Literature suggests indicators like hydrocarbon leak frequencies, extent of hot work, availability of safety systems, and essential RIFs in regards to human and organizational factors and accidents causations. In the risk analysis a certain value is assumed or established for these indicators and in the operation phase a change in values can indicate a trend that can act as an early warning sign of the indicators ability to meet risk acceptance levels. This acceptance level can be viewed as the performance requirement. These trends have to be closely monitored and relatively continuously, in regards to the nature of the indicator (Vinnem(c), 2007). The problem is then to establish suitable and measurable risk indicators for HOFs or other factors affecting the operational environment.

As mentioned earlier the OTS project has developed a set of performance standards. These were for the areas work practice, competence, procedures and documentation, communication, workload and physical environment, management and management of change (Gran, et al., 2012). If such performance standards were available a deeper analysis of how other factors not addressed could be performed in more detail, but the authors' lack of knowledge and operational environment makes it difficult to address this in detail. Risk indicators in the form of number of qualified personnel of a certain competence, number of hot work performed, use of near misses as indicators (especially major accident precursors), procedure violations discovered, use of omission data in relation to verification, HMI, the tools used, and organizational factors like competence rating, training achievements, etc, are possible ways to monitor risk levels and help achieve performance requirements being set. As expressed by the PSA, operational and organizational performance standards with appropriate requirements are virtually nonexistent apart from a few companies and PFEER assessments made (Vinnem(c), 2007). With the use of more electronic tools like the Ex-screen setup suggested more data could be available on the performance and deviations in regards to such processes. This can in some cases be transferred to other checklist based operations and provide more performance data and increase knowledge about failures and in turn help set performance requirements and performance standards. This could especially be useful in regards to verification activities where there is according to Vinnem(a) (2013) a great deal of omission failure. In many cases human reliability data will be scarce for a single platform and this will most likely give a very little basis to make comparisons in regards to risk levels. In many cases the regulations can seem difficult to use in regards to operational and organizational performance standards since all the interpretations are somewhat directed at technical systems and using guidewords like: capacity, efficiency, reliability, availability, integrity, ability to sustain loads, and robustness (Ptil, 2011). These guidewords can in some cases not be applicable to HOFs at all and perhaps new guidewords should be created for these kinds of performance requirements.

Another aspect in regards to operational performance standards should be related to the environmental exposure, in this case the arctic RIFs. This could be in very extreme conditions be verified through biometric readings, to availability of PPE, monitoring of exposure and follow-up that outdoor restrictions are being upheld. Another aspect is for example in regards to the fitness for duty where the author addresses acclimation and where procedures from this can be measured by available outdoor work time per day and regulated for a certain time period. Seasickness can also most likely be measured in regards to dispensing of seasickness medication, use, etc. In general it is very clear that methods to measure performance requirements (hopefully in a quantitative way) are needed.

How these performance standards should be made to show interaction to other systems can also be of subject to debate. It could be beneficial to divide the human factor into certain areas depending on the type of work operation being performed, be it normal operations, crane operations, maintenance, shut-downs, or emergency situations. It is the author’s belief that with an increased use of barrier display or operational display where the human factor is measured, the demand for human factor related performance standards will increase.

8. Concluding remarks

In this chapter the conclusion to the thesis will be presented along with suggestions for further research pertaining to this field.

8.1 Conclusions

The arctic is an area with great potential for resources and the Norwegian government and other nations in the arctic with other interested parties are on their way with full force. Some activity has been, and is still going on in certain areas, and valuable lessons are derived from these early projects. Proper risk management and high focus on safety will be key factors for the operational environment in these areas where exposure can be high. The human factor will be an issue, but will vary most likely significantly depending on location and season. In regards to measuring the human factor with the Risk OMT method the following conclusion are made:

- The Risk OMT method shows a clear potential to measure the operational condition on an oil and gas installation from an operational barrier perspective. By using this method a thorough charting of human error probability is made and thus the human factor is considered.
- The model shows adaptability able to include a myriad of external influences on the operational environment and both new RIFs, risk reducing measures, and barriers can be introduced to the model. Making it very adaptable with changing exposure.
- In light of critique associated with availability of operational barriers, the model shows a potential for improvement in regards to reflect actual operational conditions.
- The quantitative nature of the models output creates a very good basis for using the output in a barrier display giving the operator opportunity to chart the changes on a day-to-day basis or on a shift-to-shift based arrangement. The quantitative output creates the opportunity to have a scale signifying different risk levels.
- As a consequence of the proposed barrier display arrangement for the operational factors related to leaks, the arrangement can signify a step closer to having a QRA with level 4 compliance to inclusion of HOFs.
- The human factor appears to be divided between several Performance Standards that will to a certain degree composite the input and evaluations being made in the Risk OMT method. It appears that the risk influencing factors are a good starting point for setting Performance Standards, but good risk indicators like human reliability data, incident data, competence goals, etc., is sorely needed for qualitative factors.
- By using output and analysis like importance measure on the RIFs creates a great output towards the management on which areas that have the highest influence on the risk level and which factors should be focused on in regards to risk reduction.
- The implementation of an operation panel will set demands far beyond the current practice and will most likely be years away from being realized, if ever.
- Just for the fact that HOFs are addressed is a very good quality with Risk OMT, and a method that addresses it so thoroughly is a leading example in showing the possibilities within the field of operational barrier management. If this method is the best today or tomorrow is unknown to the author.

8.2 Suggestions for further research

Based on this thesis a few suggestions for further research are suggested.

- In regards to the Risk OMT method, further research surrounding arctic RIFs is necessary. Especially in regards to categorization, scoring, and weighting. Establishing an industry average will also be a key factor.
- In that sense, more attention should be directed at exposure reducing measures, especially in regards to arctic RIFs through winterization measures like screening especially.
- Practical application and use of the Risk OMT method in regards to barrier display integration is also necessary to explore.
- There is a need for human error data adapted to this method and data on HOFs. A more annual project in cooperation with RNNS could be an option.
- As suggested in the literature, better maintenance intervals should be researched to reduce unnecessary maintenance that increases the risk of leaks through manual intervention. Here better knowledge about arctic exposure on reliability related subject is important.
- Studies to see if there is positive correlation between omission and violation failures by using the A-standard to reduce the risk level.
- Studies should also be done in relation to cognitive performance under exposure and other factors important for human error.
- A great effort must be made in the area of creating human, operational, and organizational performance standards and requirements, and finding suitable risk indicators to further this work.

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Appendix

Appendix A: Verification of Risk OMT Exel database from Safetec Nordic AS.

Appendix A

Til den det måtte angå

SAFETEC
Safetec Nordic AS

Hovedkontor:
Sluppenvegen 12 E
NO-7037 Trondheim

post@safetec.no

Bank: 9490.05.01670
Org. nr.: 985 188 068 MVA

Vår ref: O.M.Nyheim | Prosjektnr.: P99011 | Dato: 2013-05-30

BEKREFTELSE PÅ TILLATELSE TIL BRUK AV BEREGNINGSVERKTØY

Det bekreftes med dette at Ole Kristian Madsen, som fremtidig ansatt i Safetec Nordic AS, er gitt tilgang til bruk av vårt verktøy Risk OMT Excel, ver. 0.7, i forbindelse med arbeidet med sin masteroppgave ved Universitetet i Tromsø. En betingelse for bruk av verktøyet er at detaljer rundt oppbygning og beregningsparametre ikke offentliggjøres gjennom masteroppgaven.

Det bekreftes videre at Risk OMT Excel versjonen Madsen har fått tilgang til har vært gjenstand for intern validering og kvalitetssikting i Safetec.

Med vennlig hilsen
Safetec Nordic AS

Ole Magnus Nyheim
Fagsjef

SAFETEC NORDIC AS:
Trondheim +47 73 90 05 00
Oslo +47 67 57 27 00
Stavanger +47 51 92 92 20
Bergen +47 55 55 10 90

SAFETEC UK LTD:
Aberdeen +44 122 439 2100
London +44 203 301 5900

AP SAFETEC SDN. BHD:
Kuala Lumpur +60 3 2161 9987

SAFETEC RISK MANAGEMENT PTY. LTD:
Perth +61 41 99 82 160

www.safetec.no www.safetec-group.com

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