University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology/ Risk Management	Spring semester, 2012 Restricted access
Writer: Farnaz Mirzaee	………………………………………… (Writer's signature)
Faculty supervisor: Professor Terje Aven External supervisor(s): PhD Espen Fyhn Nilsen (Statoil ASA)	
Title of thesis: Importance Analysis of Assumptions (uncertainty factors) in Quantitative Risk Assessment for the Oil and Gas Industry	
Credits (ECTS): 30	
Key words: Quantitative Risk Analysis Uncertainty and uncertainty factors Assumptions and premises in QRAs Sensitivity Analysis Risk Components in QRAs Risk Assessment	Pages: 175 + enclosure: 30 Stavanger, 16 July 2012

Importance Analysis of Assumptions in QRAs for oil and gas industry

Master Thesis by Farnaz Mirzaee

Spring-Summer 2011

University of
Stavanger

University of Stavanger

Faculty of Science and Technology

Department of Industrial Economics, Risk Management and Planning

Abstract

A quantitative risk analysis (QRA) should provide a broad, informative and balanced picture of risk, in order to support decisions. To achieve this, a proper treatment of uncertainty is a prerequisite. Most approaches to treatment of uncertainty in QRA seem to be based on the thinking that uncertainty relates to the calculated probabilities and expected values. This causes difficulties when it comes to communicating what the analysis results mean, and could easily lead to weakened conclusions if large uncertainties are involved. An alternative approach is to hold uncertainty, not probability, as a main component of risk, and regard probabilities purely as epistemic-based expressions of uncertainty. [6]

In this work, we have relied on the latter approach and have limited our scope to investigating one sources of uncertainty in QRAs; assumptions made for QRAs. We have pointed out the main components of risk description in a QRA and later defined them with respect to assumptions made. We emphasize on the role assumptions play in a QRA and the impacts they have on the total risk level and what consequences they cause if they are not valid.

An important issue addressed is how to communicate the shortcomings and limitations of presenting results only by probabilities and expected values. Sensitivity analysis plays a key role in this regard. Finally the intention is to rank the assumptions based on their importance according to their corresponding degree of uncertainty and sensitivity in a QRA.

In order to achieve this goal, we have selected some examples of assumptions from current QRAs provided by Statoil ASA for our review and study. We have discussed the assumptions description and their impacts on other parts of the QRA. Based on the investigation of assumptions and their relation to the results of QRA and by following a checklist suggested by Aven [6][7] we have assigned an importance factor to each assumption and ranked them accordingly.

The suggestion for further work is that assumptions will be presented in detail and preferably together with a sensitivity and uncertainty analysis to provide cleared pictures of risk results. This will help the stakeholders in a QRA to understand and interpret the results beyond just probabilities and expected values.

Acknowledgements

This thesis work has been prepared to fulfill the requirement for the Master of Science degree from the University of Stavanger, Faculty of Science and Technology and more importantly to fulfill my own personal desire in the topic.

During my work, I have received constructive and valuable comments and support from those I wish to express my gratitude here.

First of all, I would like to thank my extremely knowledgeable professor and supervisor at UiS, Terje Aven for his great guidance and insights and especially for being extremely patient with me during this work. He has always encouraged me with valuable comments and good humor.

I offer my sincerest gratitude to my dear professor, Ove Tobias Gudmestad, for his constant and invaluable support from my very first day of arrival in Norway up until now.

I would also like to thank Anne Sissel Svensen, Tanja Bergby and Sheryl Josdal for kindly assisting me with administrative work during this thesis.

I am so grateful to Jan Roar Bakke, my very kind and helpful professor in Technical Safety course at UiS for helping me getting started for this amazing experience of my life. I would not have been granted such an opportunity for writing my master thesis without his assistance.

In addition, I wish to thank Robert B.Olsen , Head of HSEC ST TSAS, Statoil ASA, for his being very flexible and providing me with a very active and professional work environment at Statoil HSE competence center, Forus, Stavanger. He has always been open to help and encouraging conversations. These past six months have been a wonderful experience for me due to his support.

Finally, I would like to deeply thank Espen Fyhn Nilsen, Risk Analysis Specialist at Statoil ASA, my absolutely knowledgeable mentor with fantastic competence, wisdom and sense of humor. He has always supported me and answered my constant questions and problems with a very good mood and encouraging conversations even during times of frustration and hard work.

Espen Fyhn, I think you are a very special and talented person and I am glad to have had the honor of having you as my mentor through these months. Your inspiring conversations and insights have absolutely challenged me and I am not the same person I was six months ago! You have helped me improve my ways of conceptions about many different things in life by encouraging me to think, think and even think more! You have reminded me to think outside the box and for that I will always be grateful to you. "*Dubito, ergo cogito, ergo sum.*" And whenever I think, I know I still "am"!

And last but not least, my sincerest gratitude goes to my beloved family and friends especially my supporting and amazing mother and sister! It feels great to be appreciated and supported from all across the geographical borders! I can never thank you enough for all your support, patience and love that made me survive through these two years of hard and challenging moments far away from home.

And especial thanks to Mina Karimi, Nima Ghanemnia, Milad Alizadeh, Alina Minikeeva, Bjørn Einar Nylund, Øystein Angelskår Haga, Ruben Holt and Kim A.Øvstebø.

Once again, thanks to all!

Farnaz Mirzaee

15 July 2012

Stavanger, Rogaland, Norway

Notations and Abbreviations

AIR	Average Individual Risk
ALARP	As Low As Reasonably Practicable
ASAP	Advanced Safety Analysis Package
CCR	Central Control Room
CPF	Central Processing Facility
DAL	Design Accidental Load
DNV	Det Norske Veritas
ESD	Emergency Shut Down
ETA	Event Tree Analysis
FAR	Fatal Accident Rate
FEED	Front End Engineering Design
FTA	Fault Tree Analysis
HAZID	HAZard Identification
HAZOP	Hazard and OPerability
HCR	HydroCarbon Release
HSE	Health and Safety Executive
IRPA	Individual risk per annum
LQ	Living Quarters
NCS	Norwegian Continental Shelf
NORSOK	Norsk Sokkels Konkuranseposisjon
NPD	Norwegian Petroleum Directorate
OLF	Oljeindustriens LandsForening (The Norwegian Oil Industry Association)
P&ID	Process & Instrument Diagram
PHSAT	Process Hazard Analysis Software Tool
PLL	Potential Loss of Life
PSA	Petroleum Safety Authority (Norway)
QRA	Quantitative Risk Analysis/Assessment
RAC	Risk Acceptance Criteria
TRA	Total Risk Analysis
P	Probability
U	Uncertainty
S	Sensitivity
C	Consequences
K	Background Knowledge

CONTENTS

Appendices

APPENDIX A Philosophy and Philosophers: Epistemology

APPENDIX B Kant Propositions and Assumptions

APPENDIX C Decision Making Under Uncertainty; cautionary and precautionary principle

APPENDIX D Classical Statistics versus Bayesian Approach

APPENDIX E Vessel Collision Risk Calculation Methodology

APPENDIX F Design Tips: Limit States

APPENDIX G Equipment Count and P&IDs

APPENDIX H Comparison between Valemon and Kalundborg Manning Level Assumption

Chapter 1

"It is beyond a doubt that all our knowledge begins with experience:

Experience without theory is blind, but theory without experience is mere intellectual play!

(And eventually)

All our knowledge begins with the senses, proceeds then to the understanding, and ends with reason. There is nothing higher than reason."

Emanuel Kant

1 INTRODUCTION

In this chapter, we will introduce some background information on risk, uncertainties and assumptions, relevant for this work. The purpose, the approach and the content of the work is also mentioned.

1.1. Background Information

Quantitative Risk Assessment plays an important role in HSE management in the oil and gas industry especially for offshore installations. A QRA should provide a broad, informative and balanced picture of risk, in order to support decisions. To achieve this, a proper treatment of uncertainty is a prerequisite. [6] The main issue in any risk assessment is that risk is related to possible future events and their consequences. As of today, the human mind has not proven to be able to possess absolute certain knowledge about future phenomena meaning that there are a lot of uncertainties with respect to occurrence of future events and their potential consequences. On the other hand, in a risk analysis, the intention is to know about the future event because the future consequences can be influenced by the actions we take now. Therefore we have to make some assumptions and foresee the possible future consequences in light of these assumptions and suppositions. Therefore, the only tool we have in order to predict the future events is probability. Yet the interpretation goes beyond that.

Many still believe that risk is primarily concerned with calculated probabilities and expected numbers based on historical data. However, while evaluating what can happen in the future, one must think more about surprises and uncertainties than on mere historical events. [6] In that matter, there have been different approaches towards uncertainty and probability in the concept of risk. (See section 2.2). However, in this work, while we are using probability as a tool to express uncertainty, it means that we have accepted uncertainty as a main component of risk. In that case, probabilities will just be regarded as epistemic-based expressions of uncertainty. So there have been identified uncertainties associated with risk and this uncertainty therefore lies beyond all the calculations of risk being done in a QRA. In order to be able to make a starting point for some uncertain quantities or events assumptions have to be made.

In time the importance of the uncertainty in risk analyses has been brought into attention and an extra emphasis has been put on assumptions made in QRAs. Sometimes it may be argued that assumptions are more important in a QRA than the results, at least in the long run. The importance of role of assumptions in a QRA goes to the extent that according to Odd J Tveit, former Chief Engineer Safety Technology, Statoil ASA, a risk analysis can be interpreted as "*Consequence analysis of the assumptions*".

In summary, the risk description in a QRA depends on a number of assumptions. [6]These assumptions made form part of the background knowledge and they are themselves based on the assessor´s background knowledge, which might differ to a great extent from that of another assessor. This difference originates from the difference human beings have with respect to background knowledge and the ways of interpreting it, reasoning and evaluating capabilities and various ways of cognition and perception.(For more information see section 2.6)

In conclusion, it should be acknowledged that uncertainties could be hidden I the background knowledge. The assumptions may to a greater or lesser degree constitute to uncertainty factors in the sense that assumptions might not be valid. If assumptions turn out to be wrong, the result could be that the actual outcome of a predicted quantity is surprising relative to the assigned probabilities.[6] However, assumptions are an inevitable part of any risk analysis and the final risk description must be seen in light of this basis. In a risk picture presented in a QRA, what is seen is rigid numbers, frequencies and fancy diagrams that might look very accurate in terms of calculations. What is NOT seen in the results is the basis for all those calculations; the assumptions. Therefore, to make a QRA a "living study", a concrete section in a QRA report for documenting assumptions should be considered. [4]Since assumptions and premises have a considerable influence on the results and invalidity or misinterpretation of them could eventually lead to poor judgments and decisions. It is worth mentioning once more, that the main purpose of a risk analysis is decision support because life is mainly about decisions and poor decisions cost a lot! The cost that is intended to be minimized to an acceptable extent.

1.2.Purpose of the work

The main purpose of this work is to emphasize on and define the importance of the role of assumptions in a Quantitative Risk Analysis for oil and gas industry. We intend to apply a suggested method [6][7] for ranking and comparing some examples of assumptions. We will further investigate how uncertainties associated with assumptions might affect different parts a QRA especially total risk level. The focus is to justify the importance of a classified, detailed and ranked assumption section being included as part of a QRA report. This is to mention that uncertainties are always present in a QRA, yet sometimes hidden in different parts of it and hence they need to be considered and presented along with the results. An effort has been made to present the importance of an assumption based on uncertainty and sensitivity of each assumption to provide a broader view on risk description beyond just the results.

We intend to answer the following questions:

1. What role assumptions play in a typical QRA study? What are the uncertainty factors associated with them?

2. Why is it critical to have a very detailed and classified assumption section?

3. How should assumptions be presented in a standard formal QRA and why?

4. What are the consequences if some assumptions are ignored, misinterpreted or not being valid? What parts of a QRA are affected by different kinds of assumptions?

5. How to rank an assumption as being "important" and how could one see beyond the risk calculations? How should uncertainties be revealed along with assumptions made in the report?

1.3. Approach of this work towards reaching the objectives

We shall first describe risk description in a QRA and discuss the basis and different interpretations of uncertainty and assumptions in theory. We will then develop our theories into practical work (applied QRAs) and make a comparison. We use different approaches in combination with our own background knowledge as a tool to understand and justify the importance of assumptions in QRAs and the consequences of them being invalid or disregarded.

Specific examples of assumptions from some QRAs chosen by Statoil are being reviewed in an effort to understand the criticality of them. The basis for forming the selected assumptions and the potential consequences of them being misinterpreted and invalid is also being discussed. All discussions are in light of the purpose of a QRA that is to help provide decision support. The impact of poor assumptions or documentation of assumptions would be considered in the basis for decisions that will lead to fatal or destructive consequences.

Eventually, for evaluating the role of assumptions in a QRA, we need to perform an uncertainty analysis since assumptions are in fact considered uncertainty factors. In order to define an importance degree to the selected assumptions we adopt Aven and Flage`s[6][7] suggested approach to hold uncertainty , not probability as a main component of risk. Therefore, to reflect uncertainty factors we use a semi-quantitative method as presented by Aven [6][8]; adjusted to include consideration of both risk and vulnerability. Uncertainty factors are analyzed with respect to effect on risk and vulnerability. The effect on risk and vulnerability depends on two dimensions:

- Degree of uncertainty.
- Sensitivity of the relevant risk and/or vulnerability indices to changes in the uncertain quantities. [6]

According to this approach and based on discussions and our own background knowledge about the assumptions selected, we will assign sensitivity and an uncertainty degree to each assumption. The assumption`s importance is then defined by the combination of these two degrees. And that is how we will rank the examples and we further suggest that all assumptions would be more efficiently presented if they are documented and ranked by more or less the same approach**.**

1.4. Contents of this work

This work consists of 9 chapters. In this work, in the first chapter we start with the introduction part. Some background information and the approach are introduced.

In chapter 2, we will thoroughly discuss and introduce the basics of risks and risk conceptions and misconceptions. In later sections of this chapter we will then continue introducing uncertainties and assumptions different perspectives in QRA.

We will also emphasize on importance of assumptions in current QRAs based on background knowledge, similar experiences and philosophic approach. We will end this chapter by defining what an assumption in a QRA means and how they should be treated.

In chapter 3, an introduction to a QRA and its main steps is given with emphasis on criticality of assumption section in a QRA report. We shall review some examples of assumptions documentation about how assumptions were presented previously in QRAs. We will go through some examples and then we will introduce Statoil´s guideline and NORSOK Standard on how to present assumptions in a QRA.

We introduce the suggested classifications of assumptions and then in the next subsections we shall introduce two valid and recent QRAs done for Statoil which comply to an acceptable extent with the presented guideline by Statoil and we will then discuss how this new approach have helped organize and process the result of the analysis. The two selected QRAs are Kalundborg Refinery TRA in Denmark and Valemon Field TRA in Norway, northwest of Bergen.

We will continue the discussion by an introduction to Kalundborg refinery description and the QRA method used and we will point to some examples of assumptions that have been presented in this QRA. We will end this chapter by an introduction to Valemon TRA and the selected examples of assumptions we intend to review and discuss in detail in chapter 5.

Chapter 4 is a thorough introduction to Valemon system description and the TRA methodology and steps applied for this field. The results of the QRA have also been presented.

In chapter 5, which is the data input chapter, we will focus on Valemon field as the main source of examples of Assumptions followed by the Statoil guideline. We have thoroughly introduced the field and the QRA method in chapter 4 and then in this chapter we will go through the assumption section (which seems to be informatively presented for readers` review, based on the writer's background knowledge) and we will discuss in detail and study further some assumptions that we have chosen from different categories and emphasize on the importance of them being presented and the misunderstanding they will lead to if ignored/invalid.

In line with our objective of this work, we will use the detailed discussions we have made as background knowledge to rank the assumptions according to the degree of uncertainty and sensitivity they hold inside. The results are presented after each assumption discussions.

Chapter 6 will cover the general discussions of the examples discussed in chapter 5.Some comparisons between those examples of assumptions mentioned in chapter 3 with the currently presented ones are also considered. The total ranking and comparison of assumptions are also presented in this chapter for final discussions.

Chapter 7 and 8 include the conclusion and further recommendation for this work. Chapter 9 is the final word.

Chapter 2

2. Risk description, uncertainties and assumptions in a QRA

In this chapter, we will describe what we mean by risk in a QRA and what the objectives of a QRA are. The concept of risk in a risk analysis and the main components of a risk description in a QRA are also discussed. Some misconceptions of risk have also been brought into attention. The main focus would be on uncertainties and assumptions with respect to risk results. In order to better understand the concept of an assumptions and uncertainties several approaches have been considered including Terje Aven´s suggested viewpoints towards interpretations of probabilities and an introduction to epistemology from different philosopher´s perspectives.

2.1 Introduction to risk analysis and associated challenges

The objective of a risk analysis is to describe risk that is to present an informative risk picture. [1]As for a QRA which is the concern of this work, a broad, informative and balanced risk picture is required as a result in order for the decision making support.

Risk analyses are often performed to satisfy regulatory requirements. It is, of course, important to satisfy these requirements, but the driving force for carrying out a risk analysis should not be these alone, if one wishes to fully utilize the potential of the analysis. The main reason for conducting a risk analysis is to support decision-making. The analysis can provide an important basis for finding the right balance between different concerns, such as safety and costs. [1][2]

We need to distinguish between the planning phase and the operational phase. In the planning phase, at first, the fact that we have many possible decision alternatives and limited detailed information implies, as a rule, that one will have to use a relatively coarse analysis method. As one gradually gains more knowledge regarding the final solution, more detailed analysis methods will become possible.

In the operating phase, we often have access to experience data, for example, historical data, on the number of equipment and systems failures. In such cases, one can choose a more detailed analysis method and study these systems specifically. Risk analyses are useful in all phases, but the methods applied must be suited to the need. [1]

2.1.1Risk analysis versus risk management and risk assessment:

The mentioned terms cannot be used interchangeably and each of them stands for a somewhat different concept which we will introduce in the following. *Risk management* is defined as all measures and activities carried out to manage risk. Risk management deals with balancing the conflicts inherent in exploring opportunities on the one hand and avoiding losses, accidents and disasters on the other to protect people, the environment and assets.[5][2]

The risk analysis process is a central part of the risk management, and has a basic structure that is independent of its area of application.

However, a clear distinction has been made between the terms risk analysis, risk evaluation and risk assessment as shown below:

Risk analysis + Risk evaluation = Risk assessment

The results from the risk analysis are evaluated. In this work, we use the term risk assessment to mean both the analysis and the evaluation.[1]

Generally, the main concern for this work is to deal with uncertainties and assumptions in quantitative risk analysis so we would not go into much detail for risk management and assessment but we will introduce the main components of Risk analysis especially a quantitative one.

Risk analysis is a methodology designed to determine the nature and extent of risk. It comprises the following three main steps:

1. Identification of hazards/threats/opportunities (sources)
2. Cause and consequence analysis, including analysis of vulnerabilities
3. Risk description, using probabilities and expected values.[2]

Figure 2.1 shows the main steps of the risk analysis process. We will frequently refer to this figure in the forthcoming chapters.

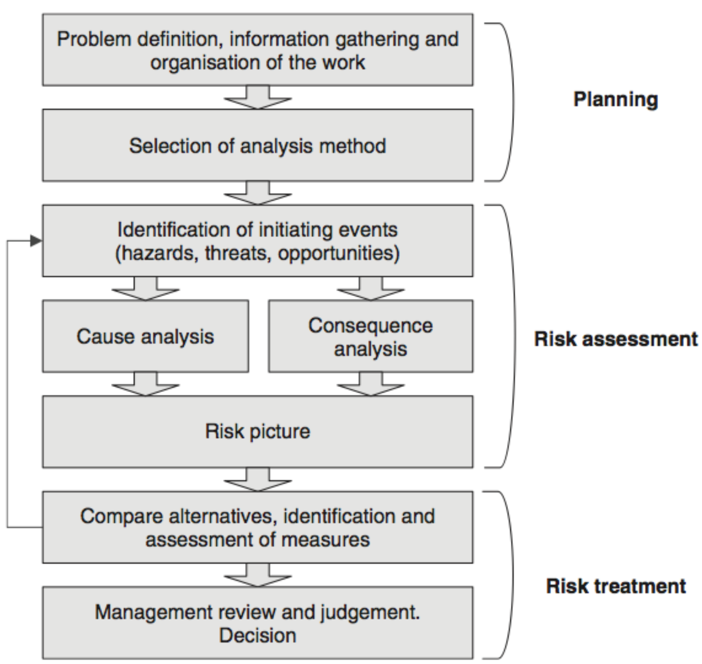


Figure 2.1. The main steps of the risk analysis process[1]

2.1.2Main challenges with Risk Management, Assessment and Analysis

The main challenge present yet most of the time hidden in all different steps of risk assessment, management and analysis is the issue of *uncertainty.*

Uncertainty is an inseparable part of risk yet it is hidden at a superficial evaluation of any risk assessment. The impacts of uncertainty, however, are revealed if one takes a more close attention.

As an example, the main challenge of risk management is **Decision-making under uncertainty.**

Risk management often involves decision-making in situations characterized by high risk and large uncertainties, and such decision-making presents a challenge in that it is difficult to predict the consequences (outcomes) of the decisions.

In high-risk situations, various decision-making strategies can form the basis for the decision. By “decision-making strategy” we mean the underlying thinking and the principles that are to be followed when making the decision. (for more information about decision making under uncertainty, cautionary and precautionary principles See Appendix C)

Additionally, according to Aven[2], Risk analysts know that the assessments are often based on selective information, arbitrary assumptions and enormous uncertainties. Nonetheless they accept that the assessments are used to conclude on risk acceptability.

Conclusion: We should consider uncertainty as one inevitable and inseparable component of risk which reveals its effect in all steps of a typical risk analysis. And in order to mitigate these challenges, it has been suggested that sources of uncertainties be defined to a possible extent for a risk analysis and results of the analysis be then presented along with uncertainty factors and sources.

Quantitative Risk analysis is the main focus of this work and there are lots of calculations based on assumptions and background knowledge which conceal a great deal of uncertainties. It is therefore useful to take a closer look at different concepts and perspectives on risk description for a QRA in the next section for better treatment and interpretations of uncertainties.

2.2 Risk Perspectives: Concepts and Misconceptions

The objective of a risk analysis is to describe risk. To understand what this means,we must know what risk is and how risk is expressed.

Risk is related to future events A and their consequences (outcomes) C. Today, we do not know if these events will occur or not, and if they occur, what the consequences will be. In other words, there is uncertainty U associated with both A and C. How likely it is that an event A will occur and that specific consequences will result, can be expressed by means of probabilities P, based on our knowledge (background knowledge), K. The main concern through this thesis is the main issue associated with this background knowledge: hidden uncertainties which weaken the results of the analysis.

2.2.1 Risk Description

There are different approaches of describing risk. In this work we have concentrated on uncertainty and hence we choose to accept uncertainty as a main component of risk which is mainly derived from the background knowledge and needs to be addressed along with other aspects of risk description. One approach of looking at risk would then be in terms of these dimensions that we have used inthis work.

Risk Description= (A, C, P, U, K)

Or if we would like to emphasize more on the fact that the probabilities are based on some background knowledge we could then rewrite the expression above as this:

P (A|K)

We should then note that there is a great deal of uncertainty associated with and hidden in this background knowledge. The uncertainty derives from the variety of sources of background knowledge (different persons, databases, etc.) and also in terms of interpretation of these background knowledge and previous experiences. We will highlight this matter more deeply throughout this work.

Since we have emphasized on the role of uncertainty in the concept of risk and serves as a challenge to risk assessment as mentioned in section 2.1.2, we have chosen that probability is a tool to express uncertainty with respect to A and C. However, it is an "imperfect tool." Uncertainties may be hidden in the background knowledge, K. The main point is to always acknowledge and express these uncertainties.

We will outline the main components of risk description in a QRA in detail in the next chapter but for now, we would like the reader to acknowledge the uncertainty factor in risk description.

2.2.2 Misconceptions of risk

As it was stated previously, risk is traditionally introduced by expected values and probabilities. But there is more to it as uncertainty is always a hidden yet very critical factor when it comes to describing risk. According to [9], Many still believe that risk is primarily concerned with calculated probabilities based on historical numbers and average considerations; when evaluating what can happen in the future, one must think more about surprises and uncertainties than on historical events. This is the pillar in modern risk assessments.

Consequently, an emphasis has to be made to look beyond just the expected values and probabilities. As we will explain further in the following chapter, we will see that sometimes uncertainty can be very important that we often consider it as the third element of describing risk. As much as expected values and probabilities are considered building blocks of a risk description, they should not be mistaken as the risk concept itself. We will have a through discussion about this in the next section based on Aven`s misconceptions of risk Book.[3] and we will state the reasons why some misconceptions cannot be replaced with the term risk itself.

2.2.2.1 Misconception 1: Risk is defined with Expected Values

According to [3], the concept of risk is not captured by the expected value due to the following reasons:

- The consequences or out comes could be so extreme that the average of a large population of activities is dominated by these extreme outcomes.
- In addition, the probability distribution could deviate strongly from the future observed outcome distribution.

2.2.2.2 Misconception2: Risk is defined through probabilities

The discussion about this misconception is the basis for our work since that is how we relate to uncertainties and assumptions in risk concept. There is a typical definition risk widely accepted as “Risk is the combination of probability and extent of consequences.” [2]. There exist many other definitions that limit the description of risk to probabilities. This definition of risk is, however, not meaningful without an interpretation of the probability P. There are generally two ways of interpreting a probability [2][3] and when describing risk via probabilities, we should distinguish between these two approaches.

1. Relative frequency interpretation or frequentist probability (objective approach, introduces aleatory uncertainties) [2][3]

A probability is interpreted as a relative frequency Pf: the relative fraction of times the event occurs if the situation analyzed were hypothetically “repeated” an infinite number of times; Pf is referred to as a frequentist probability. The “true” underlying probability is unknown and needs to be estimated. We then have to take into account that the estimates could be more or less close relative to the underlying true probability. We say there is an estimation uncertainty! This approach mostly involves classical statistics methods.

2. Knowledge-based probabilities (subjective approach, introduces epistemic uncertainties)[2][3]

For this approach, one compares the uncertainty and likelihood of an event with drawing a ball from an urn. Probability is a measure of uncertainty about future events and outcomes (consequences), seen through the eyes of the assessor and based on the background information and knowledge.(k). It is a probability in light of the current knowledge. There are always uncertainties in our future interpretations of background knowledge (k) since history never repeats itself the very exact same way. So we can never be certain what has happened in past will happen the very same way in the future- not to mention IF it happens in the future. Objective probabilities do not exist in a sense! If k denotes the knowledge the probability is based on what we refer to as background knowledge.

The advantage with these kinds of probabilities is that knowledge-based probabilities can always be defined, and they are introduced as the recommended tool for describing the uncertainties. The disadvantage on the other hand is that these probabilities cannot be compared to a universal reference point meaning that they could vary to a great extent based on the different background knowledge. That is why they are sometimes called "subjective" by definition. Each and every individual could come up with a probability of this kind and no one could challenge whether it is "true" or "false". This nature of knowledge-based probabilities justifies the requirement for the assessors to document their background knowledge together with the assigned probability for help provide better clarifications of the results.

According to the above discussions, one could write the probability as follows: P(A/k): Probability P is a subjective measure of uncertainty about future events and consequences, seen through the eyes of the assessor and based on some background information and knowledge

This approach is mainly based on the Bayesian perspective. (See App.D)

Summary of misconception of probabilities:

It is common to define and describe risk using probabilities and probability distributions. However, these perspectives have been challenged. The probabilities could camouflage uncertainties. The estimated or assigned probabilities are conditioned on a number of assumptions and suppositions and depend on background knowledge. Uncertainties are often hidden in that background knowledge so by limiting our vision to probabilities only, important uncertainty aspects are easily ignored leaving potential deviation and surprises unnoticed.[3]

In the next section, when we are going to discuss the term "uncertainty", we would refer to these two approaches mentioned about probabilities in order to understand what sort of uncertainty they set the basis for.

2.2.3 Uncertainties as a main component of risk

Based on 2.2.2, and according to the two approaches towards probability interpretations, we will reach to the following argument about uncertainties in risk descriptions:

For the first definition of probabilities, we produce estimates of the underlying "true" risk. This estimate is uncertain, as there could be large differences between the estimates and the correct risk values. The variation in the outcomes of the "experiment" generates the true value of Pf, is often referred to as *aleatory* (stochastic) uncertainty. On the other hand, following the Bayesian approach (the second approach of defining probabilities), we assign a probability by performing uncertainty assessments, and there is no reference to a correct probability. A probability is always conditional on some background knowledge, and given this background knowledge there are no uncertainties related to the assigned probability, as it is an expression of uncertainty by itself. [44] The latter uncertainties are known as *epistemic* uncertainties since they are by definition based on the analysts' (experts') knowledge (epistemology). (See Appendix A.)

The background knowledge could be based on hard data and/or expert judgments. Assumptions are also included, for example related to the use of specific models. The background knowledge needs to be reported along with the assigned probabilities.

In conclusion, probability is just a tool used to represent or express the uncertainties. Hence, risk should not be limited to (A,C,P). The uncertainties should be highlighted and presented.[1]

According to the approach we have defined for this work to investigate the assumptions in QRAs, we have defined that the aim of the risk assessment is to describe the uncertainties about the unknown quantities of interest.

Consequently, we have adapted the knowledge based probability assignment and hence when we are talking about uncertainties we mean specifically epistemic uncertainties. (Bayesian approach which is based on background knowledge). It is worth mentioning that frequentist probabilities are not measures of uncertainty. The uncertainty description therefore cannot be frequentist probabilities. Focusing on epistemic uncertainties in this work, we will therefore, treat assumptions in QRAs as uncertainty factors since they are based on analysts` diverse background knowledge and past similar experiences. We finally intend to point out and rank the importance of assumptions based on the degree of uncertainty they constitute.

2.3. Assumptions, Basis and concepts

We like to start this section with an example:

One may assign a probability of fatalities occurring on an offshore installation based on the assumption that the installation structure will withstand a certain accidental load. In real life the structure could however fail at a lower load level. The probability did not reflect this uncertainty. [6]

The above statement is considered an assumption in a risk analysis. Risk analyses are always based on a number of such assumptions.

The concept of assumptions especially in quantitative risk assessments is in close relation with comprehending the uncertainties in a QRA based on previous discussions. In other words, the concept of uncertainty and assumptions are interrelated. Since assumptions are normally based on some background knowledge and there are inherent uncertainties in that background knowledge. The assumptions are then themselves constitute uncertainty sources. In order to identify the importance of an assumption in a risk analysis report, it is very critical to understand which part of risk description is being influenced by these assumptions. In this section we shall discuss the relation of uncertainties and assumption in a QRA and then we will have a discussion on different interpretations of assumptions.

2.3.1 UNCERTAINTY FACTORS in a QRA

According to Aven [6], the risk description in a QRA depends on a number of assumptions. For example, the assumptions in QRAs of offshore oil and gas installations commonly relate to:

– Time to detection of abnormal situation.

– Number of persons in the area (module) at the time of an accident.

– Number of immediate fatalities.

– Impact energy that a structure will be able to withstand.

– Etc.

The assumptions made form part of the background knowledge, and the risk description must be seen in light of this basis. Then it should be acknowledged that uncertainties could be hidden in the background knowledge. The assumptions may to a greater or lesser degree constitute uncertainty factors in the sense that the assumptions might not be valid. If assumptions turn out to be wrong, the result could be that the actual outcome of a predicted quantity is surprising relative to the assigned probabilities. [6]

Generally, all assumed probabilities are conditional on a background knowledge k, which includes assumptions and suppositions. This background knowledge is an integral part of the results of the analysis and all probabilities need to be considered in relation to K. The probabilities produced are conditional on this assumption. [2]

These assigned probabilities, are in fact, knowledge-based probabilities that assessors have assigned and therefore they reflect epistemic uncertainties. Hence, we are required to look beyond just the probabilities and consider uncertainties in assumptions as well.

From a theoretical point of view one may think that it is possible to remove all such uncertainties from the background knowledge but we certainly know that it is not possible to do so in a practical risk assessment. Unless we are God, we should all agree that future and what happens in it is unknown to us. And the only thing we can do to conquer it is be prepared for it. As we will later see in this work, we have applied some basic uncertainty and sensitivity analysis (based on some criteria suggested by Aven [6][7][8] to rank each assumption`s degree of importance. And that is only one way of acknowledging uncertainties and looking beyond the solid probabilities. What is important to notice is that, always the uncertainty assessment goes beyond the probabilistic analysis.

2.3.2 Main challenge with establishing assumptions: background knowledge

So far we know that we need to look beyond the probabilities to express risk but the first step is for an analyst to assign some probabilities that form the basis of the rest of calculations in a QRA. There are of course a number of challenges related to the assignment of (knowledge-based) probabilities for example related to the use of expert judgments and the fact that different individuals (analysts, experts,...) have different source of background knowledge and for approved results of a QRA, a consensus has to be made between all assessors and stakeholders involved in the process in any way.

After having described that we need to address the background knowledge, the main challenge with establishing assumptions appears: What is the source for this background knowledge? How do we normally establish assumptions?

The main point is a typical QRA is normally carried out by some analysts and is reviewed by some other experts. Hence, the background knowledge of each and every one of the assessors could substantially differ from others so it is very important to provide this background knowledge and subjective views along with the results of a risk analysis to help understand the ideas and thoughts behind the results, probabilities and calculations. In other words, the data source should be clear and open to change if necessary. That is why assumptions need to be clearly stated and the source they have been based upon is also essential to be acknowledged. These sources could be hard data, personal experience, expert judgment, historical databases, similar experiences, assessor´s degree of belief, etc.

In the next section we will have an in-depth discussion about the basis of assumption from a philosophical view on perception and knowledge.

For better understanding what is meant by knowledge and the different sources of knowledge and conceptions based on different philosophers we will have a discussion on epistemology in the following sections and we will later relate this to understanding the basis for assumptions in QRAs.

2.3.3. Epistemology and Philosophical approaches towards it (For more complete discussions on this see appendices A and B)

Defined narrowly, epistemology is the study of knowledge and justified belief. It addresses the questions:

- What is knowledge?
- How is knowledge acquired?[40]

In Appendix.A we have introduced 6 philosophers and then reviewed their ideas and suggested approaches and proposals towards epistemology. We ended up dividing them into two groups of

- Empiricists: Aristotle, Hume who believed in senses and experiences in the only source of knowledge.
- Rationalists: Plato, Descartes, Spinoza who believed reason alone can provide knowledge.

And eventually we introduced Immanuel Kant who gained a label of a synthetic philosopher implying that he combined some points of empiricism with rationalism. Meaning that he suggested for a complete knowledge both reason and experience should be combined.

In this work, the approach towards knowledge about assumptions, is that we use past experiences (background knowledge) to establish the assumptions, yet we need reasoning and evaluation to justify the assumptions to maybe conform to future events. We need reasoning and expert judgments to apply assumptions efficiently. Accordingly, we have decided that we would (to some extent) follow Kant`s approach in this work for describing assumptions. Kant aimed to unite reason with experience to form knowledge.

He argued that while it is correct that experience is fundamentally necessary for human knowledge, reason is necessary for processing that experience into coherent thought. He therefore concludes that both reason and experience are necessary for human knowledge.[47]

We have further discussed Kant´s ideas and works in Appendix B.

We will explain more on how some of the above discussions make the basis for introducing assumptions and uncertainties in a QRA.

Based on the above discussions and Appendix A, we would like to rewrite the two approaches towards uncertainty and probability interpretations.

- Objective approach (frequentist probabilities, chances, and aleatory uncertainties and based on classical statistical approach)
  Could be rewritten as: **Plato`s perfect world, Descartes`s concepts of self,(true values for underlying probabilities), implies the use of reasoning to reach to knowledge, use of estimation – rationalist approach**
- Subjective approach (related to knowledge based probabilities and epistemic based uncertainties based on Bayesian approach)
  Could be rewritten as: Kant`s proposed use of senses or past experiences, develop different reference points for further reasoning—empiricist and rationalist approach

For the subjective approach to be accepted to count as "objective", a consensus has to be made and an agreement to be reached by all parties and members involved in a special case

In this work, we have adapted the second knowledge-based approach while addressing probabilities and uncertainties about possible future events in a QRA. It should also be noted that that there are uncertainties hidden in the background knowledge, not in terms of the knowledge in itself since it had already happened but uncertainties lie in interpretation and communication of the knowledge and its further application to future events.

2.3.4 Philosophical views and "assumptions"

So far, we have stated the role of different assessors´ background knowledge in establishing assumptions in a QRA. In this section we would like to discuss the possible sources of these differences between individuals.

According to our previous conversation we have decided that knowledge-based probabilities, Bayesian approach and epistemic uncertainties constitute the main framework of this work for introducing uncertainties and assumptions. Therefore, we could use some of Kant`s proposals and ideas with respect to our discussions about assumptions. We will relate Kant´s combination of reason and experience in developing knowledge (experienced) based uncertainties and the role they play in establishing background knowledge for assumptions.

The relation between assumptions, Epistemic uncertainties and Kant`s views

Based on Kant`s approach while we are referring to the background knowledge that assumptions in a QRA are based upon (analysts degree of belief) and the background knowledge these assumptions serve to base for others (reviewers, other than the analysts), we mean the knowledge that is based on past experiences which has to be justified with reason and further evaluated, and hence, we allow the subjectivity of the knowledge introduced in assumptions and assigned probabilities.

Kant`s propositions and their relation to assumptions in this work (App.A)

[43][45][47][48][49]

- According to Kant :"All our knowledge begins with the senses, proceeds then to the understanding, and ends with reason. There is nothing higher than reason."
  This statement in fact sets the grounds for the approach we have decided to choose when discussing how uncertainties are being handled and how assumptions will be made and what they are actually based upon (background knowledge). The knowledge about assumptions begins with past experience (historical data), proceeds to the understanding and then needs to be justified and evaluated with reasoning.

- Kant's emphasis on the role our mental faculties play in shaping our experience implies a sharp distinction between phenomena and noumena. Noumena are "things-in-themselves," the reality that exist independent of our mind, whereas phenomena are appearances, reality as our mind makes sense of it. According to Kant, we can never know with certainty what is "out there." Since all our knowledge of the external world is filtered through our mental faculties, we can know only the world that our mind presents to us. That is, all our knowledge is only knowledge of phenomena, and we must accept that noumena are fundamentally unknowable.[49]
  With respect to our work, since we are not aware of future events and the nature of future is unknown to us, we have to accept the uncertainties and include them in all aspects of the QRA, especially assumptions that are the main focus of this work. We should always address and present uncertainties associate with assumptions made.

- There are tow terms in philosophy (appA) that we briefly introduce here. The terms a priori ("from the earlier") and a posteriori ("from the later") are used in philosophy (epistemology) to distinguish two types of knowledge [43].A priori knowledge is independent of experience, a posteriori knowledge on the other hand is dependent on experience or empirical evidence. Analytic a priori is defined by Kant as something (some statement) that the conclusion is contained in the definition with no reference to experience; it is basically the way it is. These analytic a priories according to Kant are therefore non-informative. Synthetic a priori is however when some new information has been added to the definition of a fact; therefore adding new information to those already accepted facts. And finally, a synthetic a priori has its source on experience. Kant, then, the category of the synthetic a priori is the key to explaining how we gain substantive knowledge about the world.[49]

  Generally, in a QRA, a distinction has to be made between describing what has been accepted as facts, system description and assumptions that cannot be accepted as facts since they are not universally true and they have some references to experience. Those that are in turn called assumptions or premises in a QRA, which have references directly, based experience.

  In the writer`s opinion, according to Kant, facts can be explained with analytic a priories; system descriptions can be justifies with synthetic a priories and eventually by assumptions, however, one uses a synthetic a posteriori by adding some new information on the basis of observations (experiences) to an already accepted a priori. (See app.B)

  In general the truth or falsity of synthetic statements is proved only by whether or not they conform to the way the world is (experiences) and not by virtue of the meaning of the words they contain. Note that the role of deduction and reasoning has not been denied here; it has been applied in evaluating the added information to the accepted fact. [49]

2.3.5 Necessity justification of assumptions in QRA

It has been mentioned that some past experience and background knowledge are used to assign some probabilities about uncertain future events. But the uncertainties also exist in applying the background knowledge to future events. If we do not look wisely enough, it seems that we are entangled in a loop with uncertainties. Uncertainties exist. Yet, we have the power of thinking, reasoning and justifying! This power saves us to get out of the uncertainty loop. It is the reasoning and evaluation capabilities of responsible parties who have to decide to what extent uncertainty and assumptions could be acceptable and justified and make a stop in this confusing loop if uncertainties, assumptions and background knowledge.

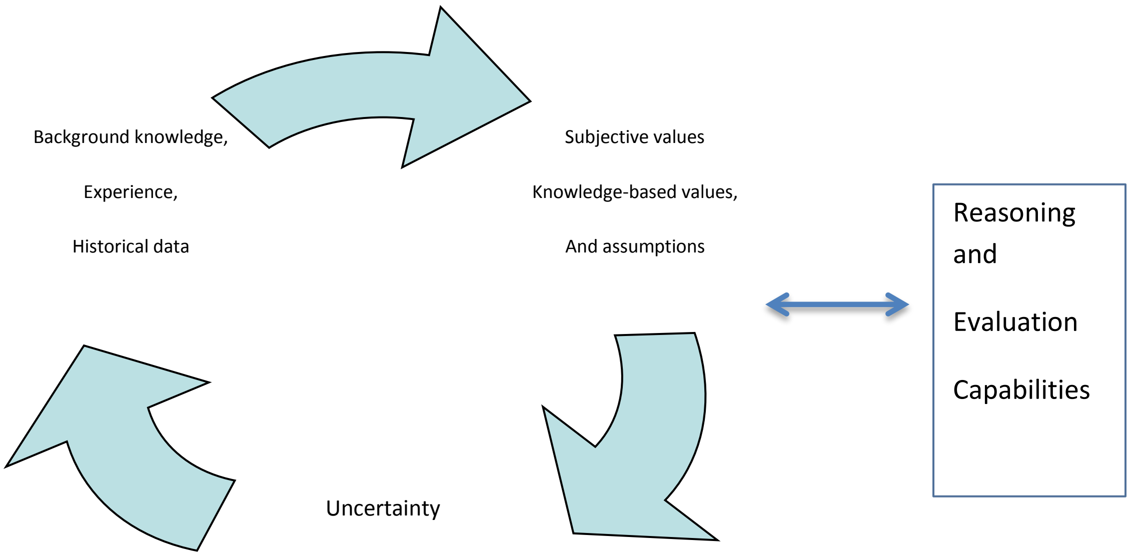


Figure 2.2. Uncertainty,Experience and Assumption loop

In other words, this subjective approach and synthetic application of experience and reason (according to Kant) serve as a basis for justifying and comprehending the assumptions. It actually helps define the assumptions by providing the necessary tools. These assumptions based on some background knowledge then need to be reasoned, justified and accepted by all influenced participants in a QRA in order to provide clear picture of the result for decision support.

To make sure that the risk analysis is based on valid information, it is important to document the assumptions made during the risk analysis process. Also, when design changes are made, or new information becomes available, the assumptions may no longer be valid. This is part of the safety follow up system in the project, where the effect on the risk picture is stated. In some cases, compensating measures will be necessary.[4]

And that is why the assumptions in a QRA should be listed, considered and approved so that all involved participants could deal with the challenges of the risk level being influenced in case of assumptions not being valid.

2.3.6. Assumptions: Definition

In this section an effort has been taken to answer this question: What is an assumption after all?
According to Terje Aven, Professor of Risk Analysis at UiS, one general description for assumptions can be stated as:

An assumption is a statement that is used as the premise of a particular argument.

There are many different possible definitions for assumptions. According to the discussions presented in this chapter, we have also developed a definition as follows:
An assumption is a subjective opinion experienced and developed by an assessor that may or may not reach the status of a fact.
An assumption is basically a simplified tool to overcome uncertainties hidden in background knowledge in any kind of work. It itself will then serve as a new source of uncertain background knowledge in further investigations.

In other words; assumptions or how we would like to see the world!

It is beyond our knowledge to know what the world really "is", therefore we make assumptions and will try to conform to them and see the world in light of them.

In the previous section, we had a philosophical approach to understand the term knowledge, and mostly based on epistemological terms developed by Kant we suggested a coarse definition for an assumption. Before we begin to explore the world of assumptions and uncertainties in existing QRAs, it is very important to differentiate between what we will from this point on consider an assumption and what does not fall in our framework of assumption definition; something that we can call on the other hand a fact or as Plato would have addressed as a FORM not an IDEA (assumption)(App.A). System descriptions also need to be separately mentioned. For further information about system description in a QRA, see section 3.3.
We will not discuss the details of what can be called a 'fact'. However, a coarse definition could be something that is considered a concept that has been agreed upon or according to a dictionary: something that is indisputably the case. A concept that cannot be proven wrong or interpreted in several other ways is usually referred to as a "Fact". Facts do not belong to assumption section and should be very clear in nature.

For instance, while performing a QRA for an offshore platform, the statement that

“we are somewhere in the middle of a water” is considered a fact. We know by definition of offshore that it is not solid ground we are talking about. (See section 2.3.4 analytic a priori). On the other hand, if the water depth is assumed to be deep or shallow is something that needs to be justified and therefore counts as a knowledge-based assumption and the definition varies subjectively. In addition, if the water depth has been measured according to accepted standards and documented in a report by value, it usually will not be considered as an assumption and it preferably falls into the system description category of that offshore field.
One way of possible relations between these three definitions has been shown in figure 2.3 below.

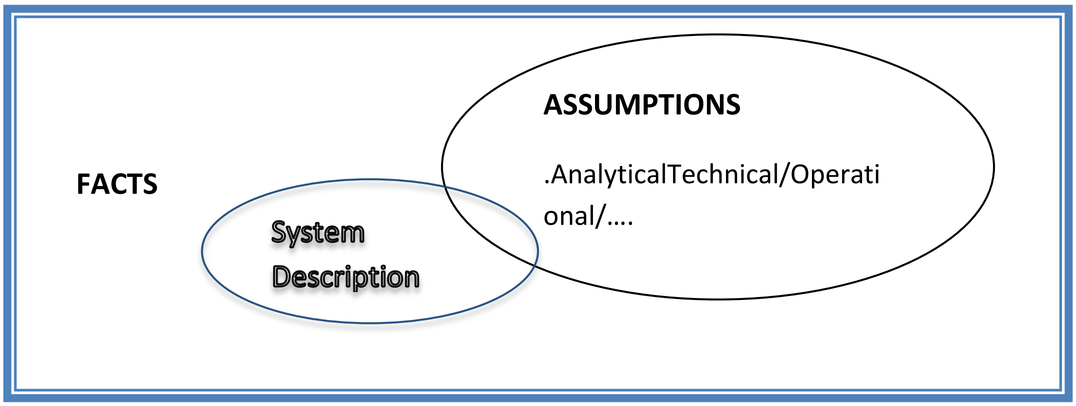


Figure 2.3. The relation between facts, assumptions and system description in a QRA based on the writer`s background knowledge

As it is shown from Figure 2.3, some assumptions and systems descriptions have a potential to be counted as facts, we just are not sure about them yet. But the opposite is not the case i.e. facts cannot be considered as assumptions. They are ‘true’ by definition and do not need a reference to experience. (See section 2.3.4)

What we here in this work intend to carry out is to address and clarify the different ways of documenting assumptions in different QRAs made for Statoil, make a comparison between them and state the pros and cons of each way of presentation based on the impacts different assumptions have on the total risk picture of each QRA. And more importantly, according to selected examples impact assessment on other part of the system, we will assign an uncertainty and sensitivity degree to each of them and will eventually rank them in the sense of being more `important` for the system.

Now that we have defined assumptions and uncertainties hidden in the background knowledge for establishing them, in the next chapter, first we will introduce the standard steps for a QRA and them discuss the role of assumptions and uncertainties with application of some examples in QRAs.

Chapter 3

3. Introduction to QRA and Review of some examples

In this chapter we will review some selected examples of QRAs chosen by Statoil (Source: Espen Fyhn Nilsen, Risk Analysis Specialist, Statoil ASA) and will investigate and comment on some assumptions and their presentation format in these reports. But first, we will introduce what is generally meant by a Quantitative Risk Assessment and the steps that should be included in the report.

What is a QRA?

QRA also referred to as Probabilistic risk assessment is a key tool used in these new approaches systemizes the present state of knowledge including the uncertainties about the phenomena, process, activities and systems being analyzed. It identifies possible hazards/threats (such as a gas leakage or a fire), analyses their causes and consequences, and describes risk. A QRA provides a basis for characterizing the likely impacts of the activity studied, for evaluating whether risk is tolerable or acceptable and for choosing the most effective and efficient risk policy, for example with respect to risk-reducing measures. It allows for the calculation of expected values so that different risks can be directly compared.[2][4]

In other words, Quantitative risk analysis (QRA) is a systematic approach for evaluating likelihood, consequences, and risk of adverse events.[2]

A typical QRA normally includes numerous calculations and assessment methods. The starting point for the assessment should be measurement of some historical accidental events. As far as possible these data should be objective [4]. It is acknowledged, however, that assessment of the safety level could not be based on hard data only. As safety is more than observations, it was necessary to see beyond the data and incorporate additional aspects related to risk perception. A full risk picture cannot be established in an objective way. A broad perspective is required. [6] We need:

- Observational data
- Risk analysis description
- Perceived risk description
- Judgments made by people with special competence
- Expert groups
- Group of representatives from the various interested parties to build trust and consensus

Basically, there are three categories of data that can be used to provide different types of information:

- Losses expressed for example by the number of fatalities
- Hazardous situations expressed for example by the number of major leaks and fires
- Events and conditions on amore detailed level, reflecting technical, organizational and operational factors leading to hazards

But each of the categories shows just one aspect of the total safety picture, and seen in isolation, data from one category could give a rather unbalanced view of the safety level. It was therefore decided that data from all three categories should be incorporated. **[5]**

3.1 QRA components [1][2][3][4]

Before we actually start to review and look through the examples of existing QRAs chosen by Statoil, we would like to give an introduction to what a QRA is in general, and what are the main steps that have to be applied or presented in the QRA report.

Consequently, we will take a closer look into the different activities required for a quantitative risk assessment, including identification of initiating events, cause (frequency) analysis, consequence (impact) analysis as well as risk description (risk picture). The methodology for a typical QRA is more or less the same, but the techniques for implementing various parts might be different. For example commonly used methods for cause and consequence analyses are FTA and ETA respectively but those are not necessarily the case for all QRAs. In this work, we will not discuss the different techniques for carrying out a risk analysis. What is important for us is the concept of the whole QRA methodology with a special emphasis on uncertainty and assumption section. Since later in chapter 5, we intend to investigate the impacts of assumptions on different components of a QRA report. Therefore, we will only point out the main steps of a risk analysis. See figure 2.1

3.1.1 Identification of initiating events [1][2]

The first step of the execution part of a risk analysis is the identification of initiating events. If our focus is on hazards (threats), then we are talking about a hazard identification (threat identification). It is difficult to avoid or to reduce the consequences of events that one has not identified. For this reason, the identification of the initiating events is a critical task of the analysis. However, care has to be taken to prevent this task from becoming a routine. When one performs similar types of analyses, it is common to copy the list of hazards and threats from previous analyses. By doing this, one may overlook special aspects and features of the system being considered.

It is therefore important that the identification of initiating events be carried out in a structured and systematic manner and that it involves persons having the necessary competence. Figure 3.1 illustrates how such an activity can be carried out with respect to hazard identification.

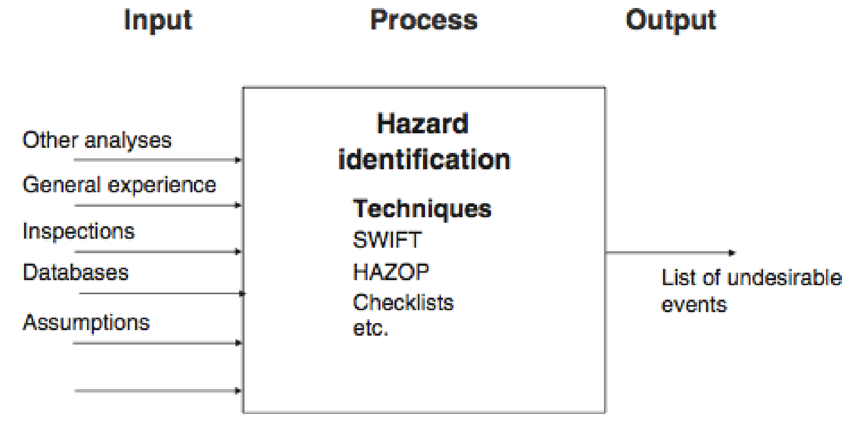


Figure 3.1 Hazard Identification [1]

The development of the list of initiating events is based on different types of input, including similar types of analyses as mentioned above, general experience, databases, inspections and assumptions. Special techniques are often used, for example Hazard and Operability studies (HAZOP). A common feature in all the methods is that they are based on a type of structured brainstorming in which one uses checklists, guide words, etc., adapted to the problem situation being studied. [2]

3.1.2.Cause analysis [1]

In the cause analysis, we study what is needed for the initiating events to occur. Several techniques exist for this purpose, from brain- storming sessions to the use of fault tree analyses and Bayesian networks (see App.B). In Figure 3.2 we have shown an example using fault trees. Experts on the systems and activities being studied are usually necessary to carry out the analysis. An in-depth understanding of the system is normally required.

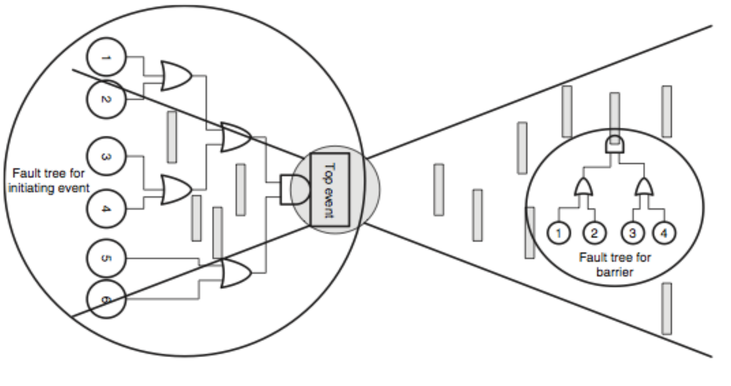


Figure 3.2.Use of fault trees

3.1.3 Consequence analysis[1] [2]

For each initiating event, an analysis is carried out addressing the possible consequences the event can lead to. See the right side of Figure 3.2.

An initiating event can often result in consequences of varying dimensions or attributes, for example, financial loss, loss of lives and environmental damage. In the consequence analysis we study the effects the initiating events A may have on human beings, the environment and financial assets (or something else that humans value). Scenarios are developed showing how the initiating events could lead to specific consequences.

The event tree analysis is the most common method for analyzing the consequences, but other methods such as Bayesian belief networks are also used. The number of stages in an identified scenario depends on the complexity of the safety and control-systems (barriers).

According to NORSOK standards[10], the following are the objectives of consequence analysis:

> *a) to assess possible outcomes of identified and relevant initiating events that may contribute to the overall risk picture;*
>
> *b) to analyze potential event sequences that may develop following the occurrence of an initiating event, determine the influence of the performance of barriers, the magnitude of the physical effects and the extent of damage to personnel, environment and assets, according to what is relevant given the context of the assessment.*

3.1.4 Probabilities and uncertainties in a QRA [1][2]

A QRA normally develops several scenarios with respect to frequency and consequence analysis. However, how likely are these different scenarios and the associated consequences? Some scenarios can be very serious should they occur, but if the probability is low, they are not so critical [1]. A sensitivity analysis is often required as well.

Probabilities and expected values are used to express risk. In a quantitative risk analysis/assessment (QRA), risk is typically described using probabilities and expected values. For example, commonly used personnel risk indices in offshore QRA include IR, PLL, and FAR values. [6][4]

However, all types of uncertainties associated with what will be the consequences are not reflected through the probabilities. As discussed in Chapter 2, a risk description based on probabilities alone does not necessarily provide a sufficiently informative picture of the risk. The probabilities are conditional on some certain background knowledge, and in many cases it is difficult to transform uncertainty to probability figures.

3.1.5 Risk picture: Risk presentation [1][4]

This part depends mainly on the type of risk analysis. The risk picture is generally established based on the cause analysis and the consequence analysis. Generally, the risk picture will cover:

- Predictions (often expected values) of the quantities we are interested in (for example, costs, number of fatalities);
- Probability distributions, for example, related to costs and number of fatalities;
- Uncertainty factors;
- Manageability factors.

The point here is to reveal uncertainties and manageability factors that can give outcomes that are "surprising" in relation to the probabilities and expected values that are presented. Depending on the objective and the type of analysis, the risk picture can be limited to some defined areas and issues. In many cases, it will be appropriate to present risk by means of a risk matrix and to discuss uncertainties and manageability factors.

Of importance in this context is the recognition that risk is more than just the numbers in the risk matrix. All probabilities and expected values are characterized by a certain background knowledge K. The probability P(A) should be written P(A|K). The background knowledge is a part of the risk picture and the risk presentation. And uncertainties associated with this background knowledge should be acknowledged as well.

According to Norsok z013u3[10]

Calculations needed to establish the risk picture

For the calculations needed to establish the risk picture, the following requirements apply (if included in scope):

> *a) the following fatality risk contributions shall be considered and, when applicable, calculated and presented separately: 1) immediate fatalities; 2) offshore transportation fatalities including shuttling; 3) escape fatalities; 4) evacuation and rescue fatalities; 5) off-site risk.*
>
> *b) the fatality risk contributions shall be split into areas or exposed employee groups and, if relevant, between 1st and 3rd party;*
>
> *c) when required, the probability of loss of main safety functions is established in accordance with guidelines given in Annex B;*
>
> *d) the environmental risk shall as a minimum be calculated for the environment in general, but it is recommended to calculate risk for identified environmental risk indicators or specific sensitive resource.*

However, for a typical QRA, as we will see in this chapter and chapters 4 and 5 mainly, the risk picture mainly consists of: [17]

- Personnel Fatality Risk, first and third party,
- Impairment Frequency of Main Safety Functions
- Environmental Impact, usually oil spill and emissions

For Personnel risk, Individual and Group risks are mentioned both for first and third parties. This is usually done with calculated (estimated) values of FAR and PLL and they are compare with RAC defined for each case and major contributors of FAR and PLL are usually presented in diagrams.(per area or per accident category,…).F-N curves are sometimes presented as well.(See definitions page iv)

For Impairment frequency of main safety functions, one could normally refer to:

- Escalation Prevention
- Main Load bearing structure
- Safe areas
- Escape and evacuation routes

3.1.6 System Description in a QRA[4]

According to Vinnem [4], a risk assessment should always start with a system description. A precise definition of the system being analyzed assists both the analyst and more importantly those who will review or evaluate the study and the results. The system description should include:

- Description of technical system, relevant activities and operational phases
- Statement of the time period to which the analysis relates
- Statement of the personnel groups, the external environment and the assets to which risk assessment relates
- Capabilities of the system in relation to its ability to tolerate failures and its vulnerability to accidental effects

The purpose of the system description is to make the analysis sufficiently transparent, so that other personnel are able to review and comment on it. Another important aspect is to ensure a comprehensive documentation of assumptions and premises for the analysis. Assumptions and premises need to be documented where they belong in relation to calculations. In addition, there should be a summary of all assumptions and premises as a reference source. We will discuss this matter in the next section.

3.1.7.Assumptions and Uncertainties

A number of assumptions are made during the course of the analysis process. These assumptions must be documented in a systematic way, and they must be presented to those who use the risk analysis for decision-making support. The results obtained from the risk analyses must be viewed in the light of the assumptions made. Operational personnel should be aware of these assumptions, and it is essential that the assumptions be incorporated into the maintenance program and the emergency preparedness planning, etc. In practice, it is a challenge to achieve all this successfully.

According to Norsok z013[10]:

> *e) assumptions and presuppositions shall be clearly and explicitly documented and categorized in the following groups: 1) analytical; 2) technical; 3) organizational/operational.*
>
> *f) assumptions and presuppositions which imply restrictions to the operation of the facility, the activities assessed or to modifications/changes in the system basis shall be described in a manner which is understandable and easy to use for the various users of the risk analysis. This includes a description of the implication of deviations from these assumptions and presuppositions. The need for sensitivity analysis in order to identify and to assess the implications of changes in the study basis shall be considered and performed when necessary. For quantitative risk analysis see also 5.6.3.4;*
>
> *g) results, premises and assumptions shall be documented in a manner which enables easy use as input to planning of operational activities, maintenance and modifications;*
>
> *h) an evaluation of the robustness of the conclusions given in the assessment with respect to changes in study basis shall be presented;*
>
> *i) background for the choice of assumptions/presumptions shall be given;*

3.1.7.1 Influence of uncertainty

There will always be uncertainty as to whether certain events will occur or not, what the immediate effects will be, and what the consequences for personnel, environment or assets may be. This uncertainty reflects the insufficient information and knowledge available for the analysis, in relation to technical solutions, operations and maintenance philosophies, logistic premises etc. There will always be some uncertainty about what may be the outcome of accidental events, even when the installation has been installed and put into operation. [1][4]
The uncertainties are expressed by the probabilities that are assigned. There are as such no expressions of uncertainty. But it is nevertheless important to consider and reflect on what the sources of uncertainty are. [1]

According to [15]:

Uncertainty is inherent and unavoidable in performing risk analysis since it belongs to the physical variability of a system response and also to the lack of knowledge about the system In general taxonomy, the uncertainty due to natural variation or random behavior of a system is named aleatory uncertainty, whereas the uncertainty due to lack of knowledge or incompleteness is termed epistemic uncertainty (see section 2.3.2). These two types of uncertainty can be introduced from any of the three different sources represented in Fig.3.3 below. According to the figure, the sources of uncertainty can be classified as data uncertainty, model uncertainty and quality uncertainty. Quality uncertainty refers to the complete and comprehensive evaluation of hazards, including the identification and description of their relationships in developing the fault and event tree.

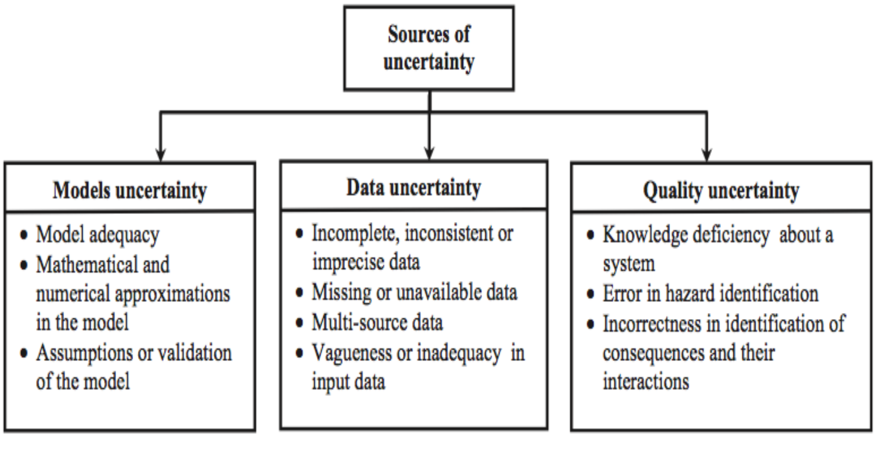


Figure3.3 . Proposed Sources of Uncertainty in a QRA [15].

The extent of assumptions that have to be made will usually increase as one gets further into the accident sequence, and more and more uncertainty is introduced. There are more sources of uncertainty associated with calculation of fatality risk compared to physical accidental loads or consequences. This should also be considered.[4]

3.1.7.2 Documentation of assumptions and Premises [4]

Assumptions and premises for an analysis are important because these often have a considerable influence on the results, and because they are the best way to make a QRA study a `living document`. According to Vinnem[4], typical examples of assumptions and premises include:

- Activity Levels on the installation, such as the number of crane movements, extent of hot work activities, etc.

- Manning level, distribution, work schedule

- Operation of Safety systems

- Performance of Emergency Response systems and actions

Sometimes it may be argued that assumptions are more important in a QRA than the results, at least n the long run. Results are important for the immediate follow-up but the necessary actions have to be taken in a relatively short time span. The assumptions on the other hand, constitute perhaps most typically the `living, element of a study. The following are the important aspects in relation to assumption:

- Assumptions need to be identified at an early stage and discussed with the organization in charge of the installation, for verification and acceptance.
- Assumptions need to be collected and presented systematically and to appear in the documentation where they are relevant. It is also advantageous to indicate what the likely affects of changes to assumptions will be –which we intend to carry out in the following sections-Extensive cross referencing is important.
- Assumptions need to be followed up and reviewed regularly when the study is completed, in order to make the study `living`.

According to Vinnem [4] it may be a good solution to split the assumptions into three categories, because the persons must directly involved in the review and follow-up will be different.

- Design basis
- Operational Assumptions
- Modeling Assumptions

Almost the same categorization of assumptions has been suggested by Norsok z013 standard and Statoil Guideline GL0282.[10][11]

3.1.8 Sensitivity and robustness analyses[1][4]

Sensitivity studies could be claimed to be the main purpose of most QRA studies if the overall objective of the work is the comparison of alternative solution s or identification of risk reducing measures. One of the main efforts in planning and executing a QRA should be directed towards achieving efficient sensitivity studies, in such circumstances. It has been found that sensitivity studies are more effective and refined if attention is given to defining in detail the scope of the studies. When studies are planned with sensitivity modeling in mind, the modeling becomes more focused. [4]

The risk picture is not complete unless we have carried out sensitivity and robustness analyses. These analyses show to what extent the results are dependent on important conditions and assumptions, and what it takes for the conclusions to be changed. The depth of such analyses will of course depend on the decision problem, the risks that are analyzed and the available resources.[1]

In practice, we often start with the conclusion, and ask what it takes for it to change. One can then "go backwards" in the analysis, and find out which conditions have a significant impact on the conclusions. We are talking about a robustness analysis. To carry out sensitivity analyses on all conditions is not feasible in practice. [1],[2]

In this work, we have done a somewhat qualitative sensitivity analysis about some examples of assumptions to define their scope of impact on the total risk level. We then followed a checklist suggested by Aven [s1,2] to assign a sensitivity ranking to each assumption, combined the results with the assigned degree of uncertainty in assumptions and finally decided on an `importance level`.

3.1.9 Risk evaluation

It is normally the case that results of risk picture are compared with and evaluated against the RAC defined for the project. This is part of risk evaluation and the intention of risk analysis is that eventually the results could be evaluated and used for further decision support. Through the risk analysis and the discussion of the results, the analysts will be able to give their message (the risk picture and the risk presentation), and then the management and the decision-makers will become more involved.

The mentioned steps have been identified to be the most important ones according to framework (especially NORSOK standards)[10], nevertheless, there have been several other categorizations as well, mostly because some parts were not practicable but the main steps have been the same. As an example we present a typical QRA steps in figure 3.4.

Finally, it is important to mention that all steps of the QRA should be done in line with he whole framework (standards will be discussed further in chapter 5). As one can claim from the diagram in figure 3.4, a separate step for assumption and uncertainties has not been mentioned. Yet, these assumptions and uncertainties exist in all parts and steps and they become more critical especially in risk picture, calculations and evaluation parts.

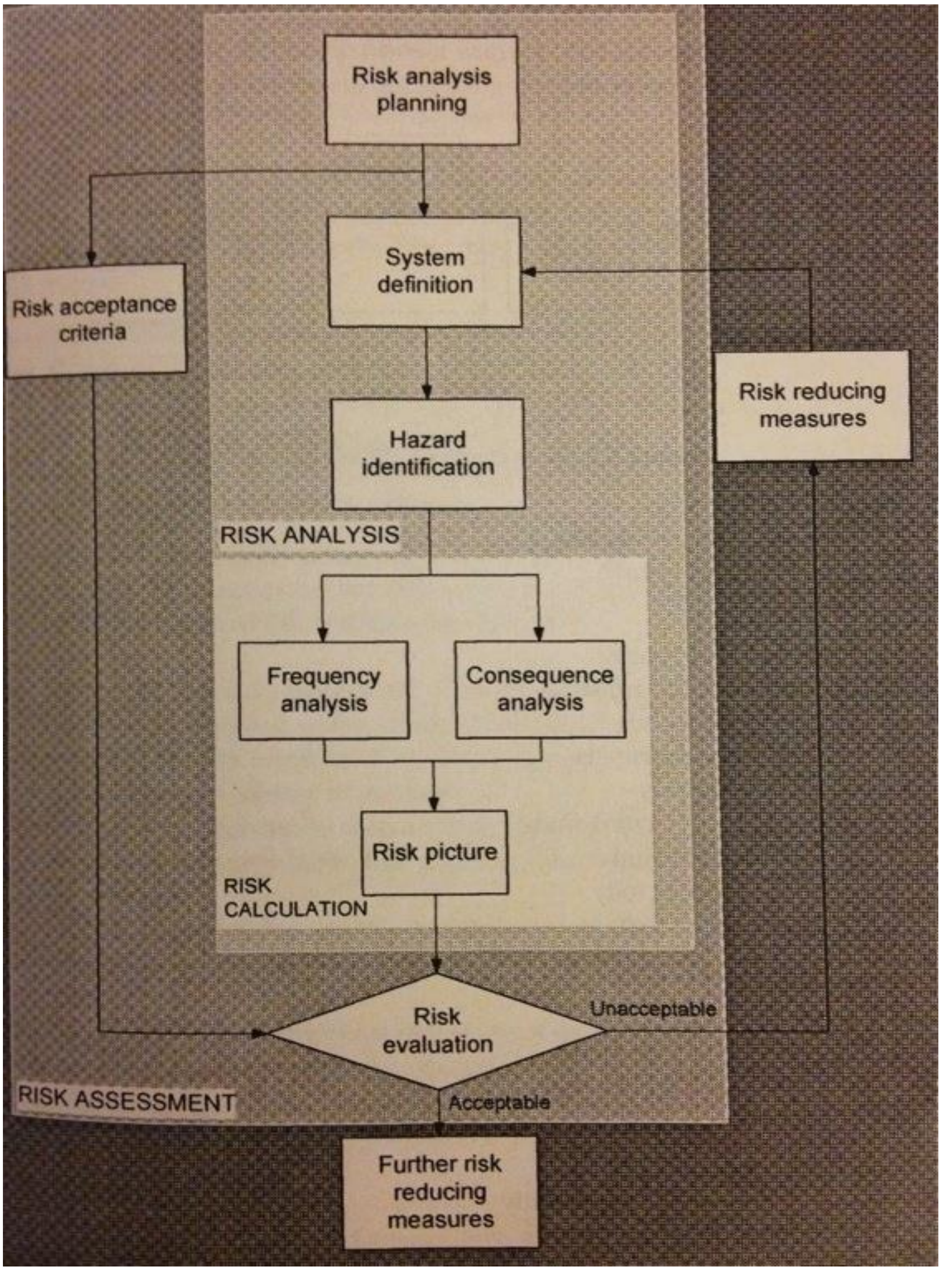


Figure 3. 4. Main steps in a typical QRA [4]

According to the discussions above, we have decided to provide a section for discussing the role and impacts of uncertainties and assumptions in a QRA.

We will point out the risk components in a QRA and our main focus will be on uncertainties associated with risk description.

3.2 Background information on assumptions

In this work, whenever we mention probabilities or uncertainties, we associate them with knowledge (epistemic)-based. Also, when it comes to assumptions these aspects are of great importance and the role of background knowledge which serves as an uncertainty source is considerable in assumptions in a QRA. The aim of risk assessment is therefore to describe the uncertainties about unknown quantities in this work, so the first task is to identify these unknown quantities. [3] Some typical sources of uncertainty in QRAs were outlined in section 2.2.

In this context, the responsibility of the analyst is to predict these unknown and uncertain quantities and to describe uncertainties about them, which are the key component of risk in this approach. For prediction of unknown quantities, access to historical data is normally available for the analyst. Yet, the interpretation and application of this historical data depends mainly on the approach of the analyst himself. Based on the historical data and his own background knowledge, the assessor can then propose and document some assumptions regarding the unknown quantities .The main concerns in a risk analysis are the future events; the way they actually are going to happen could be different from the way we are prepared to manage them. And the way we see the future events via risk results of a QRA today, depends strongly on the assessor`s presented assumptions and how much deviation from reality lies in the assumptions depends on the validity of the assumptions. It is all traced back to the background knowledge.

The hidden yet the most ruling factor in the discussion above is the role of uncertainty; the uncertainty which is inevitable in any kind of analysis when it comes to future events; the uncertainty which human minds have been currently proved to be incapable of conquering. Having accepted this impotency of human mind in predicting future, efforts have been made to fill the gaps by some assumptions and presumptions towards the unknown quantities for future. The aim of risk assessment is to predict these quantities and to describe uncertainties to the most possible extent.

The later experience would then either proves or denies the validity of the assumptions. In conclusion, past experience would serve as basis of forming the assumptions and future experiences will set grounds for validity of those assumptions. The results and possible discrepancies are always evaluated and justified are lessons are learnt for further studies. And that is the way knowledge about different phenomena is formed.

3.2.1 Approach for uncertainty treatment in assumptions

It has been accepted that a probabilistic analysis is always based on a set of assumptions. The main issue would therefore be that "the assumptions could be wrong (leading to poor predictions)". [6]

According to Aven [2], an analysis based on the historical numbers could easily become too narrow and imply that extreme outcomes are ignored. Surprises occur from time to time, and suddenly an event could occur that dramatically changes the development, with the consequence that the rates jump up or down. In a risk analysis such events should ideally be identified (surprising events). However, the problem is that we do not always have the knowledge and insights to be able to identify such events; because they are extremely unexpected.

Therefore, the risk perspective adopted motivates assessment of uncertainties beyond the probabilities assigned. [2] To achieve this, a practical tool used may be a list of uncertainty factors that could strongly influence the results to occur in the future.
Each factor's importance should then be measured using a sensitivity analysis to understand its importance in the analysis. We next address the uncertainty of this factor. If the uncertainties are assessed as large, the factor is given a high risk score. Hence to obtain a high score in this system, the factor must be judged as important for the risk indices considered and the factor must be subject to large uncertainties. [2][3][6] This uncertainty assessment goes beyond the probabilistic analysis. Aspects to be considered to judge the uncertainties to be high are outlined in table 5.10 together with a checklist for sensitivity ranking checklists. This is the approach we intend to use to rank our examples of assumptions.

3.2.2 Classification and Presentation of Assumptions in a standard QRA

According to NORSOK z-013 and Statoil Guideline GL0282:[10][11]
Assumptions and presuppositions shall be clearly and explicitly documented and categorized in the following groups:

1) Analytical;
2) Technical;
3) Organizational/Operational.

- Assumptions and presuppositions which imply restrictions to the operation of the facility, the activities assessed or to modifications/changes in the

system basis shall be described in a manner which is understandable and easy to use for the various users of the risk analysis.

This includes a description of the implication of deviations from these assumptions and presuppositions. The need for sensitivity analysis in order to identify and to assess the implications of changes in the study basis shall be considered and performed when necessary.

- Results, premises and assumptions shall be documented in a manner which enables easy use as input to planning of operational activities, maintenance and modifications;

- Background for the choice of assumptions/presumptions shall be given; [11]

In the following examples of QRAs chosen by Statoil for this work, it is important according to [10] that all assumptions and presuppositions be accepted by Statoil. Different units within Statoil will be responsible for different assumptions. Any presuppositions that are different from standard Statoil requirements or practices would need to be specifically emphasized.

Care should be taken to assure quality in data/assumptions provided by Statoil. Communication might be necessary regarding level of detail and precision needed for various types of data.[10]

Organizational/operational assumptions will normally imply restrictions to the operation of the facility. This might also be the case for some of the technical assumptions. The consequences of deviations from each of these assumptions should be described.
As we have mentioned before, by evaluating assumptions, we are in fact performing a consequence analysis for the assumptions to define their degree of importance in the system.

3.2.3 Traceability and reporting

The results of the risk analysis should be traceable through the analysis, without access to comprehensive data tools. For all large risk contributors, it should be possible to identify the mechanisms/pieces of equipment which are the risk sources.[10]

For quantitative analyses, it is important that the calculations can be traced in the report. This means that the basic data (incl. references) and a sufficient number of intermediate results should be tabulated so that it is possible to follow the calculations without having access to the spreadsheets and other models that have been used. The effect of assumptions and other considerations should also be clearly presented, e.g. through sensitivity calculations.

The above statements regarding traceability and reporting should be interpreted based on the purpose for the risk analysis, and an appropriate level of details should be applied. For analysis with long lifespan, like TRA, more details would be relevant than for short-term analyses that are done for one specific problem and within a limited timeframe.[10]
In the following chapter, we emphasize on the importance of traceability of assumptions several times. It is very important the areas of influence of assumptions be detected as easily as possible.

3.2.4 Main components of risk description in a QRA [6]

There are several components of risk defined for QRAs based on different approaches. Here, we only mention the main components within the scope of this work.

According to Aven [6], to describe risk we need to take into account both the potential consequences (or the severity of the consequences) related to the activity or system being considered, and the associated uncertainties. The risk description presented here takes as a starting point the following general definition of risk.

By risk we understand the two-dimensional combination of (i) events A and the consequences C of these events, and (ii) the associated uncertainties U (about what will be the outcome), i.e. (C,U). For simplicity we only write C, instead of A and C.[1]

The main components of a risk description in line with this definition are reviewed in the following.[6]

Events (A): An event is defined by ISO (2002) as the occurrence of a particular set of circumstances. In a QRA some main categories of events can be identified:

Consequences or outcomes (C): A consequence is defined by ISO (2002) as the outcome of an event. It is sometimes useful to distinguish between two levels of consequences or outcomes in a QRA:

Uncertainty (U): Uncertainty is understood as lack of knowledge about unknown quantities, i.e. about A and C. There is uncertainty about the occurrence of events (A) and what will be the consequences or outcomes (C) if an activity is carried out or a system is put into operation.

Probability (P): Probability is a tool used to express uncertainty about events, consequences and outcomes. Probabilistic expressions include probabilities, expected *values, probability distributions and prediction intervals.*

Background knowledge (K): The description of risk (i.e. the events and consequences considered and the description of uncertainty about these) depends on the background knowledge of the analyst. For an event A or consequence C the dependence of probabilities and expected values on the background knowledge K can be written as P(A|K) . The background knowledge covers inter alia assumptions and presuppositions, historical system performance data and knowledge about the phenomena involved.

Sensitivity (S): The sensitivity of probabilistic risk indices can be investigated by altering the input parameters, or more generally the background knowledge. As pointed out by Bedford & Cooke (2001), sensitivity analysis is not the same as uncertainty analysis. Sensitivity analysis simply shows the effect on overall results of altered input parameters/values. By doing so it is possible to say something about the importance of assumptions and suppositions. A so-called backwards approach can be used to investigate how large changes in input parameters/values are needed to change conclusions.

The last three components of risk description are in fact the main focus of this work when evaluation assumptions in chapter5, that is why we should pay attention to the description of them presented above.

3.2.5 Final word on assumptions in a QRA

So far, we have concluded uncertainty is seen as the main component of risk and the risk description. In conclusion, evaluation of uncertainty is a required aspect according to the regulatory requirements. The evaluation of uncertainty will be dependent on which statistical approach that has been used. [4]

In the rest of this chapter as well as chapter 5, while discussing some examples of assumptions in different QRAs, we will define the uncertainties related to each example. However, in this chapter, the focus is mainly about commenting on the presentation of assumptions rather than their impact assessment. In chapter 5, we will cover both aspects.
By presentation of assumptions, we will evaluate and comment on the examples according to Statoil Guideline (GL0282)[10] suggested categorization of assumptions (our reference) to maintain consistency with the rest of selected QRAs.

As we will review some examples of assumptions in QRAs, we could easily notice that there has been no consistent way of organizing and classifying the assumptions in the selected examples. And almost none of the examples in this chapter are totally in line with Statoil's guideline on assumptions section (maybe only to some extent).

On the other hand, it is also worth mentioning that not all these classifications (suggested by GL0282[10]) are always practical. Since there is sometimes a thin line between defining assumptions whether as to count as analytical for example or as technical. But this is another issue and needs to be stated as well. The unclear nature of an assumption by no means justifies its not being documented and classified, in our opinion.

3.3.Review of Presented Assumptions in Existing QRAs

In the previous sections of this chapter an emphasis was made on the importance of assumptions and uncertainties and the role they play in a standard QRA and how the assumption section serves as a basis for the efficient interpretation of results of a QRA. Assumptions in our idea could be interpreted as a way of presenting known unknowns with unknown being uncertainties and known being the background knowledge the unknown is best estimated, assigned or generally assumed upon. We cannot assume the things we do not know of, that is why unknown unknowns are not even listed in a QRA and when they occur (if they occur) as surprises, their occurrence will be added to the background knowledge afterwards.

The assumptions in a QRA are highly associated with treating uncertainties. According to Odd J Tveit, former Chief Engineer Safety Technology, Statoil, risk analysis can be defined as: " *Consequence analysis of assumption*". Which is relevant for this thesis work, since what will basically go through is to discuss what consequences would occur in case of deviations/alterations from the documented assumptions.

The approach in this chapter is that we start by introducing 4 QRAs and will comment on their way of documentations of assumptions and will make a comparison between them with respect to assumptions listed and based on criteria we mentioned in 3.2. (The 5th QRA example is introduced in chapters 4 and 5)

During this thesis, we are basically concerned with some existing QRAs of some fields operated by Statoil ASA with the main concern on their assumptions presentation and importance. The various natures of the fields and status of their operation is not of interest of this work. What we are basically concerned about here is the concept of assumptions with respect to the previous chapter we have discussed and introduced. The main components of risk description in this work will be uncertainties, background knowledge and sensitivities. Probabilities are just considered as a subjective tool for presenting the results of risk picture.

We will in this chapter start by introducing some past QRAs done for Statoil and we will then introduce the current and more updated ones to compare how the assumptions were listed and presented before in comparison to current practice. Once again, we emphasize that in this chapter we will not be considering the scientific and systematic effect of the assumptions or their detailed effect on other parts of the QRA report. This chapter is basically has focus on the way of presenting assumptions in some QRA reports chosen as examples so there will be variety of different examples from different parts of the selected systems. We will mainly comment on how the assumptions are listed/mentioned and possible pros and cons of each different way.

We will list the 5 current QRAs that we have chronologically:

- Leismer CPF facility QRA report, Statoil Hydro Canada by Det Norske Veritas (15.10.2008)
- Aker Spitsbergen- Risk Assessment for Riser Operations, Statoil Hydro by Scandpower (05.08.2009)
- Concept Risk assessment for the Statoil Bressay Concept study Project for Worley Parsons Europe Ltd by Risktec solution Ltd (30.11. 2010)
- Kalundborg Refinery QRA for Statoil AS by Scandpower As(23.06.2010)
- Valemon EPC-TRA for Grenlad Group by Lilleaker Consulting AS(24.02.2012)

3.3.1 Leismer CPF facility QRA (Example1)

This report has been done in 2008 and in our opinion seems relatively thorough and informative. A spate part of the report has been assigned for documenting main assumption. Yet, there are many other important assumptions left unnoticed and undocumented. We are going to have a short introduction to the facility and the QRA methodology that has been used in this report. We have the following data according to the report [28].

3.3.1.1 Short introduction to the facility and the QRA methodology [28]

StatoilHydro is currently the holder of oil sands leases in the Athabasca oil sand deposits close to Fort McMurray in northern Alberta, Canada. The oil sands leases will be developed through in-situ bitumen extraction by means of steam assisted gravity drainage ("SAGD") technology. The long-term goal is to produce more than 200,000 bbl/day of bitumen. Steam Assisted Gravity Drainage (SAGD) is an enhanced oil recovery technology for bitumen. The intention is to expand the Leismer Hub in order to increase production capacity from 20,000 bbl/day up to approximately 37,000 bbl/day of bitumen.

Project development within Statoil Hydro requires a Quantitative Risk Analysis (QRA) to be developed in the detailed project development phase. Det Norske Veritas (DNV) has been requested by StatoilHydro to carry out the QRA for the Leismer Hub 1 Central Processing Facility (CPF) including expansion with production up to 37,000 bbl/day of bitumen.

QRA methodology[28]

The objective of the QRA is to give the best possible understanding of the risk picture for the Leismer Central Processing facility, and to describe and characterize risks that are significant to the CPF.

The methodology used in this report can be seen in figure3.5 below:

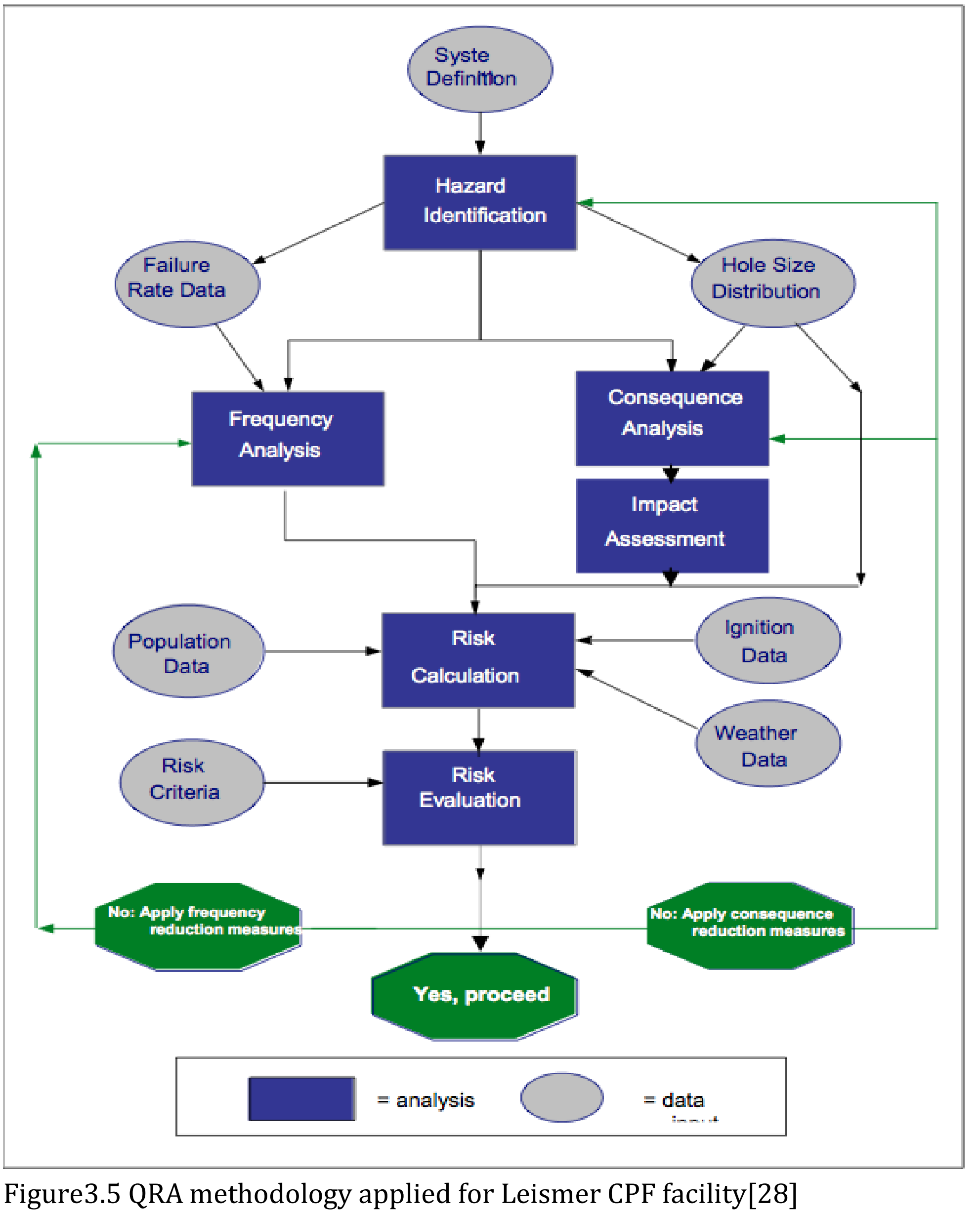


Figure3.5 QRA methodology applied for Leismer CPF facility[28]

3.3.1.2 Assumptions

In this QRA report that we have introduced, assumptions are mentioned several times in different ways, which we intent to address some of them in the following sections.
According to the report, the risk of each event was estimated by combining the frequency and the consequence of the event. DNV has applied assumptions, methods and data sources widely accepted in the oil and gas industry to assign branch probabilities in established fault and event trees.

One positive and advantageous point about this QRA is that even though it has been done in 2008, it has complied with the assumption presentation format presented in section 3.4 in this work to an acceptable extent. The assumptions are categorized and listed in one separate appendix after the results of the report has been presented.

Although there is a separate appendix included in the current report where the assumptions are included, there are still some assumptions that are discursively referred to. In this section we will discuss some of these hidden and indirect assumptions in the text and then will proceed to select some of the examples of the assumptions presented in the general assumption section.

3.3.1.2.1 indirect assumptions

As mentioned above, there are several indirect and unnoticed assumptions in the text, which we will mention below in the original context. Nevertheless, in order to clarify what assumptions we mean, we present them in italics. Most of the text presented in the following chapter is extracted from Leismer QRA report. [28]

Indirect assumption in presenting FAR value

According to the report, the overall FAR value exceeds StatoilHydro's acceptance criteria. A comparison to other StatoilHydro onshore facilities is done here to explain some differences. *A factor that contributes significantly to the overall FAR is the manning distribution. All personnel within the onshore unit is to be considered in the assessment and the StatoilHydro onshore facilities Mongstad, Kollsnes and Kårstø have an administration building normally out of reach of any of the hazards from the processing plant/refinery. The manning distribution applied for the Leismer CPF are all within the process units and the control room/administration building is close to the process unit which means that all personnel are within the hazard zones of a large part of the hazards.*

The above implied assumption is a very important one when it comes to the total risk picture and FAR values. It has been presented as if it is known to the reader as part of the system description but in our opinion the stated statement could count as an assumption related to manning level. There is also an assumption dedicated to manning level under the assumptions list that we will discuss in the next part but if this paragraph itself was supposed to serve as the only assumption on how to assign the manning level and its influence on calculated FAR value, the results would have been misleading as the reviewers might be confused about the sources of FAR estimation since it is not clearly pointed out.

Indirect assumption in Leak frequency estimation

According to the report [12], the basis of the leak frequencies is the Piping and Instrumentation Diagrams (P&ID) of the Leismer CPF.
The frequency analysis was performed using DNV's commercial software LEAK. The DNV LEAK program contains leak statistics from the UK HSE Hydrocarbon Release Database (HCRD) that is used to assign representative leak frequencies for each band of hole sizes. The hole size categories used in this analysis, and the hole size used as representative for each category, are shown in Table below:

Table 3.1 Hole size categories according to DNV report[28]

Category	From (mm)	To (mm)	Representative Orifice Size (mm)
Small	3	35	10
Medium	35	80	50
Large	80	150	100
Rupture	150	-	Line Size

The HCRD data is collected from offshore platforms in the United Kingdom sector of the North Sea. Although providing the most comprehensive available failure data for a wide variety of equipment types and leak sizes, the HCRD data requires some interpretation to be used effectively.
Experience shows that using the data directly, i.e., assuming that all releases occur at normal operating conditions, provides overly conservative inputs to a QRA study. A proportion of all leaks (and hence the leaks detailed within HCRD) occur at conditions that produce less onerous releases than would be modeled using standard QRA assumptions. For example, many of the recorded leaks occurred during maintenance, while equipment is depressurized, or where rapid isolation is achieved.

The above paragraph in italics represents another way or presenting assumptions while introducing a topic (leak frequency estimation here). The source and background knowledge for the leak frequency estimation has been documented. It is appreciated that the assumption has been referred to even indirectly but this way of presenting assumption might be challenging for the reviewer to find and analyze. Another thing to be challenged here is the assigned terms to size of the holes in table 3.1 above. The assigned diameter size and the categorization based on that might be confusing for these kinds of interpretations are mainly subjective and depend greatly on different individuals with different backgrounds according to chapter2.

The size titles assigned to holes, are very important since they are mainly related to leak rate and duration risk. It is the one of the prerequisites to understand what is meant by small, medium, large and rupture leakages. This is the kind of assumptions that need to be certainly documented since it is greatly subjective.

Indirect Assumption in Part Count[28]

According to the DNV report, typically, the P&IDs are analyzed to determine appropriate isolation points and identify the process equipment within isolatable sections. An isolatable section is defined as all equipment between emergency shutdown valves (ESDVs*). The maximum inventory available for release is defined assuming that shutdown will be initiated if a release occurs*.
Based on the P&IDs for the process plant at Leismer, a part count covering all potential release sources (e.g., flanges, valves, fittings, pumps, vessels) within each isolatable segment were performed. The results from this part count were then entered into the model for calculations of generic leak frequencies.

In the paragraph above two types of assumptions are mentioned. The first assumption in italics sets the condition on which another definition has been established and the second assumption can be considered an underlying assumption for the source of equipment count, which is stated to be the P&IDs. The number of equipment contribute directly to process leak frequencies so here the underlying assumption could also be challenged whether it is the right choice or not for that matter. We will have a more detailed discussion about this type of analytical assumption in chapter 5.
Therefore, the above quote in italics also serves as an indirect assumption on how the calculation of leak frequencies is done. If not mentioned and emphasized correctly, this assumption remains unknown and the results of leak frequency estimation would confuse the reviewers.

Discussions about the indirect assumptions

As we revealed some examples of indirect examples of assumption in the main body of the risk analysis report, we gathered that:
The whole report uses relevant historical occupational data and risk assessments from other StatoilHydro facilities as a basis for background knowledge for the Leismer CPF risk analysis; there are still a great deal uncertainties in applying this background knowledge to conclude about the future events. But this background knowledge and other assumptions the rest of the calculations and estimations are

based upon need to be mentioned as clearly as possible and in an organized and classified way.

Another thing to observe was that it is always useful to state the sources of the information and the basis for calculations when the results are being discussed but it might also be challenging if we are talking about the results and refer back to the references at the same time.
It could therefore be wise to dedicate a whole section (chapter) with all the assumptions the report is based upon. This might also be challenging but with great consideration the assumptions could be organized and classified according to their types (organizational/occupational, technical and analytical) and the specified areas of the report/facility they might influence/have influence upon.

3.3.1.2.2 Direct/listed assumptions

According to the main DNV report [28], assumptions for the Leismer CPF Quantitative Risk Assessment (QRA) are presented. These assumptions form an important basis for the assessment and may thus have a significant impact on the end results. It should be noted that changes in the assumptions might have an impact on the calculated risk levels.

The intent of this document is to clarify the assumptions made by DNV related to how key information provided by the client has been interpreted in this study and what has been assumed when detailed information has not been available. [12]

It is one of the advantages of this report including this assumption section and also the explanation and the clarification accompanied by it. However, as we ill see, the discussions around the assumptions do not seem extensive and informative enough. Analysts have used their experience and best judgment in establishing the required assumptions.

The assumptions made are categorized as analytical, technical or organizational/administrative that are in line with Statoil GL0282 guideline as well. The Analytical assumptions are numbered starting with A. For the Technical and Organizational /Administrative assumptions, the numbering starts with T and O, respectively.

Part of the assumptions used in this report is shown in figure3.6 below.

DET NORSKE VERITAS
Appendix A: Assumptions (Rev 1)
StatoilHydro Canada

MANAGING RISK DNV

Table of Contents ***Page***

Figure.3.6 Part of Assumption List in DNV report for Leismer CPF[28]

In the following we have selected some examples of assumption description from different categories of assumption with the intention of presenting the assumptions and briefly commenting on them.

An Example of Analytical Assumptions: Hole size distribution

Table 3.2 Assumption Example for Leismer CPF QRA [28]

Assumption No: A02	**Revision no:** 1
Subject Area: Hole size distribution	

Each release scenario will be modeled with four different hole sizes. The ranges of diameters of the hole sizes and representative hole sizes are shown in the table below.

Category	Representative Orifice Size (mm)	From (mm)	To (mm)
Small	10	3	35
Medium	50	35	80
Large	100	80	150
Rupture	Line Size	150	Full Bore Rupture

The diameter of the line modeled will represent the hole size for the rupture event. For pipe diameters less than 150 mm, the line size will represent the hole size for the large event; for pipe diameters less than 80 mm, the line size will represent the hole size for the medium event.

Hence, for pipes with a diameter equal to or less than 150 mm, the number of categories will be reduced.

For modeling purposes, the pipe rack is assumed to be located 5 m above ground level. Events located on top of vessels were also modeled 5 m above ground level while events by pumps, heat exchangers and on piping between vessels were modeled 1 m above ground.

As discussed in the previous indirect assumption section a lot of calculations and assigned probabilities are based on this way of categorization of hole sizes. Therefore, it is a very wise choice to dedicate a place for this assumption in the assumption section as well. Discussion about the basis of the assumption falls beyond the framework of this chapter but we encourage the reader to consider other possibilities of categorization of the hole size. The following questions might be good to think about:

Are four categories (small, medium, large and rupture) sufficient enough for creating a clear image for the reader concerning the hole sizes?

If the categories were further narrowed down, the calculations and assigned probabilities would probably be more exact but at the same time more challenging and time consuming. It is the job of the risk analysts, to choose the best compromise that leads to the most practical results and finally gives a more clear judgment basis for the decision makers.

<u>An example of analytical assumption: Equipment Count</u>

This assumption falls into analytical assumption categories and as we will discuss it in detail in chapter 5, the importance of it is associated with the leak frequency; the more equipment in the system, the higher would be the possibility for leaks – the relation is not quite linear though.

Table 3.3 Part count example [28]

<table>
<tr><td>Assumption No: A05</td><td>Revision no: 1</td></tr>
<tr><td colspan="2">Subject Area: Parts counting and categorization.</td></tr>
<tr><td colspan="2">Active hydrocarbon process and steam/hot liquid lines and components are counted as input to frequency estimation for the whole facility for the Hub1 including the debottlenecking project.

All parts as valves, flanges, small bore connections, pressure vessels, pumps, compressors, process pipes (as number of meters) etc. were counted.

Categories used as input to the leak frequency calculation program, LEAK, are as follows:

• Process vessels; includes slug catchers, separators, scrubbers, knock-out drums, dehydrators, etc.
• Pumps, divided in centrifugal and reciprocating
• Compressors, divided in centrifugal and reciprocating
• Heat exchangers, divided in shell, tube, plate and air cooled
• Filters, includes strainers
• Valves greater than 50mm: divided in actuated, manual and Emergency Shutdown (ESD) valves. (Valves less than 50mm are counted as small bore fittings.)
• Small bore fittings (all intrusive equipment is counted as a small bore fitting if smaller than 50mm or as the corresponding equipment item with associated flanges, valves, etc.).
• Process lines:
    • In addition to category, the size is also recorded. Process lines, valves, flanges and small bore fittings are categorized as the diameter of the line. Other equipment is categorized as the diameter of the largest connected pipe section.</td></tr>
</table>

In this assumption the underlying assumption (counting equipment based on P&ID of the facility) has not been mentioned. The method of counting as well as some compensation, conservative factors are missing as well.

An example Technical assumption: Emergency shut down

In Table 3.4 a technical assumption has been mentioned for design basis.

Table 3.4. Technical (design) assumption for Leismer CPF QRA[12]

Assumption No: T06	**Revision no:** 1
Subject Area: Probability of unsuccessful Emergency Shut Down (ESD)	

The probability of not having a successful emergency shut down of a segment takes into account the following parameters:

- Leakage or fire are not detected visually, by process instrumentation system or by the fire and gas detection system.
- Operator fails to initiate ESD from the panel in the control room
- Failure occurs in the necessary ESD valves including failure in the logical panel system.

The following has been assumed for the Leismer CPF:

- Possibility for the leak/fire not detected visually, by fire and gas detection system or by the process instrumentation system is assumed for different hole sizes (Ref. /T06-2/):
  - Small – 0.05
  - Medium – 0
  - Large – 0
  - Rupture – 0
- The human error factor of operators failing to initiate ESD when needed is 0.05 (Ref. /T06-1/).
- The possibility of the logical panel system not working is 0.0003, based on OREDA Phase 2 data base.
- The probability used for an ESD Valve not working on demand is 0.03. This assumption is based on assumptions done for StatoilHydro's facilities at Kårstø and Mongstad.

In the description of this assumption, some other assumptions (hole sizes) have been used; meaning that the fire/leak detection system 100% detects the leak/fire if the hole size not considered "small". Enough care should be taken when assigning these probabilities with respect to the underlying assumption of hole size.
The assigned probabilities for other failure causes are mere assignments based on some background data or some already practiced standards such as OREDA or NORSOK.

Organizational/Administrative Assumption: Manning distribution

In this part, a very important assumption has been mentioned. As we will later see in chapter 5, manning level is directly associated with results on the risk picture and is usually considered one o the most uncertain assumptions due to human being involved in it.

Table 3.5. Manning distribution assumption for Leismer CPF QRA[28]

Assumption No: O01	**Revision no:** 1
Subject Area: Manning distribution	
The Hub 1 manning associated with the debottlenecking is assumed to be as follows: • 10 people will be in the administration/control room building during the day shift. • 25 people will be on site during the day shift, equally distributed around the plant. • 3 people will be in the administration/control room building during the night shift. • 4 people will be on site during the night shift, equally distributed around the plant. The Hub1 Expansion manning is assumed to be as follows: • 13 people will be in the administration/control room building during the day shift. • 37 people will be on site during the day shift, equally distributed around the plant. • 4 people will be in the administration/control room building during the day shift. • 6 people will be on site during the night shift, equally distributed around the plant. The personnel distributed around the plant are assumed to be indoors 50% of the time. These assumptions are based on information about the debottlenecking manning and discussions about the baseline manning in the HAZID meeting.	

We will discuss manning level assumption in a more detailed way in chapter 5. However, according to this assumption description, one could claim that the assumption requires further specification and it will not be enough just to classify areas into two categories of administration and on site and then assign a day and night value for manning.
The basis for these assigned values for manning levels and the distributions on a facility is normally historical data and past experiences. Nevertheless, care should be taken when actually assigning the manning values since manning plays an important and basic role in calculations of fatality risk indices and therefore influences the risk picture of a QRA to a great extent.

Final Discussions on assumption presentation in this DNV report

It is a good point that this report has dedicated a separate part for introducing and presenting the necessary assumptions. However, not all assumptions are listed as we have observed. There are several critical assumptions not outlined in the dedicated section and they are rather implied to in an implicit way during the report. This is something to be considered for future reports.

In addition, for the assumptions listed in the assumption section, they could be discussed more thoroughly and with more precision, rather than just being limited to the extent of the assumption description. As we will see in the next chapters, it is very useful to mention the relevant QRA parts to the assumptions made as well as their influence on the total risk picture, their duration of validity, and other probable available information and assessment about the assumptions. In that case, the reader (reviewer) would be given a brighter and clearer picture about the sources and basis of the assumptions and their potential effects on the risk results.
Consequently, an importance of an assumption could be established for further review and improvement of the assumption.

3.3.2 AKER SPITSBERGEN - RISK ASSESSMENT OF RISER OPERATIONS (Example 2)

Most of the definitions and descriptions for introduction has been extracted from the main Aker QRA report.[29]

3.3.2.1. Introduction

Scandpower is engaged by StatoilHydro to perform a risk assessment for various riser operations on Aker Spitsbergen in DP mode. The main scope of work is to establish the risk level for Aker Spitsbergen in DP mode when carrying out standard marine drilling riser operations. Dynamic positioning (DP) means to automatically maintain vessel position exclusively by means of the thruster force.[29]

Aker Spitsbergen is a DP semi-submersible drilling unit as shown in figure 3.7 below.

Figure 3.7 Aker Spitsbergen semisubmersible [29]

3.3.2.2 Assumption Presentation in Aker Report

In this report there is not a chapter especially dedicated to assumptions therefore the assumptions are not classified and listed as in the previous work. There is just one subsection mentioning some assumptions about DP systems and Riser Operations briefly. As a result, in the following chapter, we will outline some of the assumptions being implied in an implicit way in the report.
Once again, the related technical sections of the assumptions are not of interest in this chapter. The focus is basically on the way the assumptions are presented.

3.3.2.2.1 Indirect Assumption number 1

In the middle of introducing the fault tree structure for vessel drive-off, the following quote has been detected:
It is assumed in this study that the rig will operate in DP Class 3 mode for riser operations with all position reference systems and control stations operational at the time when the first failure occurs.[29]

In our opinion, it is useful to state the assumption rather than not to mention it at all, but this sudden way of mentioning an assumption without further references on ´DP class 3 ´ seems absurd, in our opinion.

There are several places where terms such as “It is assumed”, “It is considered”, and “It is assessed” have been used without any further references being mentioned. Most of these statements fit the description of assumptions and it would have been more practical for them to be listed as assumptions under their corresponding area of influence. Additionally, they are required to be provided by a degree of importance as we will further discuss in chapter 5.

Indirect Assumption number 2;
Considering the fact that in this chapter we only deal with assumption presentation, in this section we will mention some wordings used in the report for assumption presentation in different parts of the report.

***Conditional* Probability of Kick in Drive/Drift-off**
Based on the previous project experience, it is presumed the duration of a kick, i.e., the time to control the kick *is estimated to be* 1.5 days. And the average days for drilling and completion in contact with reservoir *are conservatively estimated as* 70 days per well. [29]
(Assumptions are based on experience, conservative experience-based estimation.)

Indirect Assumption number 3;
As an example of an analytical assumption, we could refer to this table of planned well activities. This will be used as the base case in the risk analysis.(The numbers are assumed)

Table3.6. Planned well activity [29]

Operation	Number of operations/wells	Total number of days
Drilling & completion (Development)	2	200
Testing	2	10
Workover	2	30

Drilling and completion activities using the standard marine riser will be performed in overbalanced condition. *It is conservatively estimated that* 70% of the drilling and completion time (conservative) will be spent in contact with the reservoir. Based on the above discussion, the time for riser operations in contact with reservoir *could be calculated.*[29]

In the above example some conservative assumptions have been made and serve as a basis for the rest of calculations. If the assumptions are not valid, the results may vary to a great extent.

3.3.2.2.2 Directly Addressed Assumptions
And eventually the assumption sub-section of the report is presented here for our review. In our opinion according to other extensive parts of the report, this assumption presentation is considered insufficient. We see the assumption section in Figure 3.8 below.

8. MAIN ASSUMPTIONS

8.1 DP System

- The analysis considers the impact on availability/frequency due to equipment and system failures in addition to human errors. Hence, it does not take into account the impact on availability from accidental events such as explosions, collisions, etc. Two exceptions to this are the risk of fire in the engine room and sudden weather change causing drift-off.
- No common mode failure is considered in this assessment except for common mode software failure and network failure.
- All equipments are assumed to be in a fully operable condition initially. No testing or maintenance unavailability is considered in this analysis.
- The rig is always operated in DP class 3. All position reference system and control stations are operational at the time when the first failure occurs.
- Only those failure modes which could lead to loss of DP in a short time are considered in the fault trees. Scenarios of position loss in a relatively long time is not included because crew on rig will have enough time to recover the faulty equipment to maintain DP or implement normal disconnection sequence to secure the well.
- Sufficient diesel supply is available for the diesel generator in the day tanks. Contamination of diesel will be eliminated by procedural means such as sample taking etc. hence is not considered in the analysis.
- During design, provisions are assumed to be made to ensure good maintainability of the equipment. This includes the provision and storage of a sufficient number of critical spares and necessary resources available. Critical equipment is assumed provided with spare parts onboard the vessel.
- Loss of two thrusters is assumed to be the maximum acceptable criterion for dynamic positioning in the worst weather condition.

Figure 3.8 Assumptions in Aker Report [29]

3.3.2.3 Discussions about the assumption presentation in Aker Spitsbergen riser operations QRA

As we discussed and reviewed some parts of the report, it is easily discernible that the assumption presentation in this report is somehow chaotic and does not follow a standard organized pattern. Some assumptions have not been mentioned unless they were needed in some sections for some calculations or to form a basis for further discussions. This might be confusing and decreases the value of a good report.

The terms *given, it is considered, assessed,* estimated, etc., have been used several times and that is mainly because the assumptions have not been classified and listed. In case of assumptions not being listed, the writer of the report has to pull his resources and addresses the necessary assumptions according to the requirement for each section. As a result, some assumptions might be mentioned several times while some others (maybe even critical ones playing a great role in risk analysis) could be totally ignored.

The positive point about this analysis is that most of the time the basis for assumptions (historical data, experience…) has been mentioned to avoid further confusion. However, the overall conclusion about the examples are that the assumption presentation needs to be more organized and all the assumptions could be categorized in one classified section dedicated for that matter.

3.3.3. Design Accident Loads and Concept Risk Assessment for the Statoil Bressay (Example 3)

We will not go through the depth of this study case, but we will only limit our work to find some forms of assumptions in the report. Since the report lacks the standard assumption section.

3.3.3.1Introduction to the facility [30]

Risktec Solutions Limited has been requested by Worley Parsons Europe Ltd. to prepare a Design Accident Loads (DAL) analysis and Concept Risk Assessment (CRA) for the Concept Bressay Offshore Platform, operated by Statoil.The objective of the DAL and CRA is to determine the best possible estimate of risk for the various concepts under evaluation.[30]

Facility Description

Concept design configurations are currently underway for the planned Bressay platform, a fixed jacket Production Drilling and Quarters (PDQ) platform located in the UKCS sector of the North Sea, standing in approximately 100m water depth.[30]

The Bressay platform briefly comprises a wellbay and manifold area, a central process tower, a process utilities area, a utilities and power generation area, a living quarters module, a drilling support module and drilling facilities as illustrated in Figure 3.9 below.

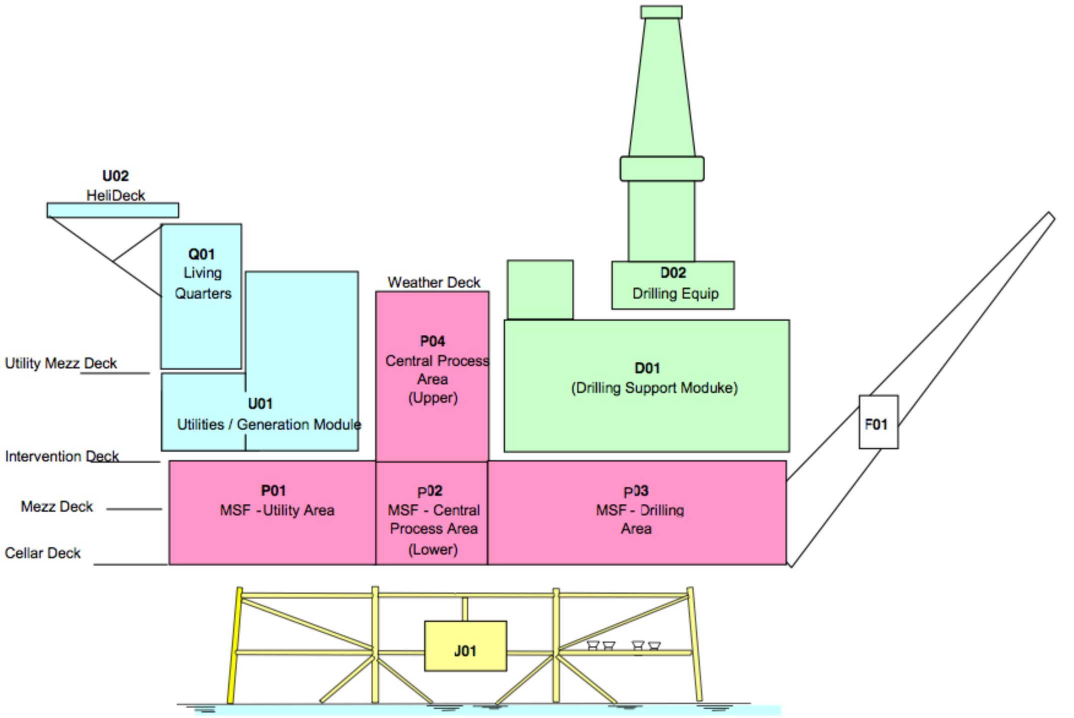


Figure3.9. Bressay Platform Layout [30]

3.3.3.2 Assumptions mentioned in this report

All assumptions provided in this report are considered indirectly mentioned assumptions since there has not been a separate section for assumptions and their importance analysis**.** We will point out some of them in this section. The assumptions are mainly established to serve as some inputs for the method used in the report. According to the report [30], PHAST requires a number of specific inputs and conditions to run models. The inputs have been explained below:

Assumptions regarding Inventory

The mass inventory used in the models is the mass that could be lost in an event of full bore release that lasts for 1 hour. *To remain conservative, no isolation credit was taken in the analysis*. Hence, *models were generated without any inventory limitations* to allow any potential release to reach its steady state conditions. This implies that release rate stays constant at the initial value. *This approach generates worst-case consequence results from inventory considerations.* [30]

The sentences in italics introduce a discreet way of presenting an assumption.

<u>Assumptions regarding Scenario Type and Location</u>

Releases from the pipework / equipment were modeled as leaks from four different hole sizes are as follows

- 3mm Pin hole leak
- 13mm Small leak
- 35mm Medium leak
- 105mm Large leak, including full bore ruptures[30]

The categorization for leaks is mainly subjective and thus needs to be mentioned. In the above examples, some inputs that had to be assumed for the PHSAT program have been mentioned to some extent. There might be still some other assumptions that the analysis has missed due to this not well-organized way of presenting assumptions.

<u>Assumption regarding Parts Count</u>

A Part count method was used to calculate an estimate of the leak frequency associated with each identified node. The numbers of major equipment items (i.e. vessels, heat exchangers, pumps and compressors) in each node *were initially counted based on the PFDs supplied by the project*.
However, *because no P&IDs were available at the concept stage an estimate had to be made to predict reasonable numbers for the pipe fittings, valves, flanges and instrument connections associated with each major equipment item*. [30]

This is a very important assumption dealing directly with the leak frequency, which is a major contributor to PLL and FAR values, and the underlying assumption here, which is the method for counting, has been introduced in a discreet way. If the reviewer misses this part, due to the assumption not being listed, the method and results of part count would be greatly confusing and may be even misleading when it comes to risk reducing measures and other recommendations. Since if the method for part count is not understood, the results of leak frequency calculations will be misleading

3.3.3.3. Discussions on Assumptions

The same conclusions on the previous example will apply for this case as well. Generally, it is very important how to address and present the assumption in a QRA since the report should be well comprehensible by all participants involved and not necessarily all of the reviewers are experts in risk analysis. And one way of making the report more organized and “user-friendly” is by stating all the relevant assumptions in a dedicated chapter as well as with their criticality and importance. Categorization will also be of great value since there might be some examples of assumptions directly affecting the other one, as we have now seen some examples of them in the sections above.

3.3.4. Kalundborg Refinery QRA by Scandpower (Example4)

On behalf of Statoil, a Quantitative Risk Analysis (QRA) of the Kalundborg refinery is performed. The QRA presents the risk picture during normal operation.

3.3.4.1 Introduction to Kalundborg Refinery Process and QRA methodology[31]

The Statoil refinery at Kalundborg in Denmark refines crude oil and condensate (light oil) to petrol, jet fuel, diesel oil, propane, heating oil and fuel oil.

Kalundborg refinery is located in the northwestern part of Sjælland in Denmark. The production capacity is 5.5 million ton oil products per year. [31]

A picture of the refinery is shown in Figure 3.10 below.

Figure 3.3: Picture of the Kalundborg refinery. The process area is in the lower left corner of the plant. The dock is in the upper part of the picture. The six tanks just visible in the far right of the picture belong to Foreningen Danske Olieberedskapslagre (FDO), but are operated by Kalundborg refinery[15]

Generally, the refinery processes crude oil and condensate into gasoline, diesel oil, jet fuel, fuel oil, propane and butane.

In the figure 3.11 below, a coarse schematic of the process material in Kalundborg refinery has been illustrated.

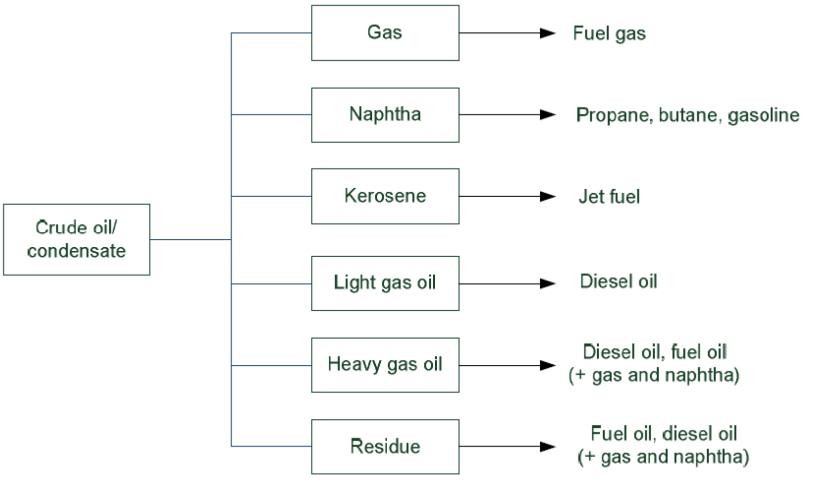


Figure 3.11. Process material and products in Kalundborg[31]

Methodology applied for this Risk Analysis

The main steps of this Quantitative Risk Analysis are shown in Figure 3.12 and are briefly explained below.

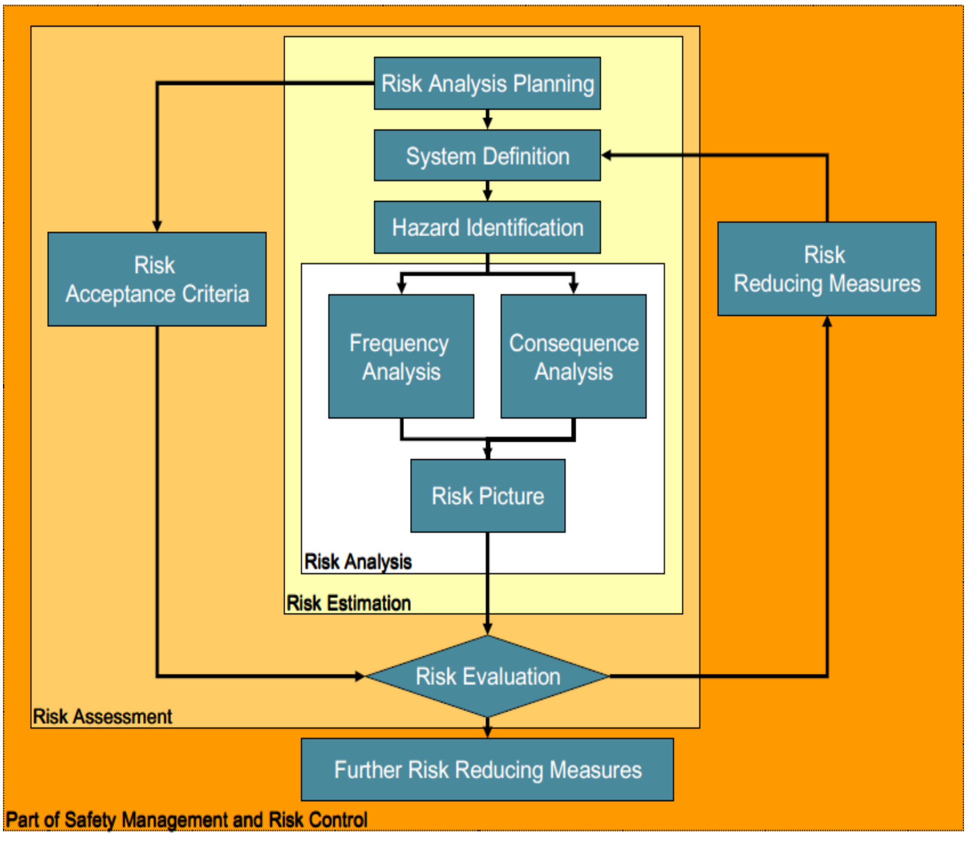


Figure 3.12. QRA methodology and steps in used for Kalundborg[31]

3.3.4.2 Examples of Assumptions in this report

This QRA report is considered to be one of the new and recent ones and separate independent chapters of assumptions are listed. Assumptions are listed according to their area of effect and do not comply with the categorization criteria presented in Statoil Gl0282 guideline.[10]

The assumptions listed in this report are mainly related to:

- Process leak Analysis
- Probabilistic fire and explosion model
- Accidents in offsite area

And other areas of the facility have not been listed under the assumption section.

We should also consider that Kaundborg refinery is an onshore plant and hence the general areas of the facility are different from those related to offshore facilities. This actually has a direct effect on manning distribution and therefore on the total risk picture; to be more precise, PLL values greatly differ from those of offshore platforms and so will the FAR and AIR values.(Personnel Risk Indices in general)

It is generally expected that in a refinery the process area dominates the other sections in terms of risk analysis and therefore process leaks are of great importance and a great deal of assumptions are usually associated in process leaks calculations as it is the case in this report.

Based on this mentioned QRA report, the Process leaks assumptions are categorized into two different groups:

- Process Leaks Frequency
- Process leak Duration

<u>Assumptions in Leak Frequency Estimation</u>

Leak estimation for Kalundborg is based on generic frequency data, counting of potential leak sources and on Kalundborg specific process data. During the segmentation and calculation of leak frequencies, several assumptions have been made. The most important assumptions are listed below. [31][33] [34]

The nature of the assumptions is based on previous experiences. Investigation of the validity or importance of the assumptions is not the topic of this chapter so the focus will be mainly on the presentation of assumptions.

As we can see in the table 3.4 below about examples of assumptions, there are two columns in the table; one describing the assumption itself and the other one is labeled as “criticality of assumption with respect to risk analysis” which ism basically the effect it has on the risk level of the report or the `importance` of the assumption that we will further discuss in chapter5.

Table 3.7 Assumptions in leak frequency estimation for Kalundborg[33]

No.	Description of assumption	Criticality of assumption wrt the risk analysis
3.1	The subsegments must be classified as either gas or liquid segments by segmentation. Some streams contain a mixture of gas and liquid. These lines are classified as liquid segments if the gas content is less than 50 vol %	This is only a problem for a fraction of the segments (only mixtures). If classified as liquid, the resulting initial leak rate will be higher than if classified as gas. It is judged that streams with gas fraction below 50 vol % also behave like gas leaks. Thus, the assumption can be considered conservative
3.2	The subsegments can only have one set of process properties such as pressure and density. For segments including process equipment giving pressure increase (pumps, compressors) or pressure drop in the segment, a conservative representation (i.e. not highest, but a weighed average towards the highest possible values) of the process properties are chosen	In most segments, the variance in pressure and density is moderate. Moderate change in these parameters has only minor effect on the result. However, using an upper estimate will ensure that the results are somewhat conservative
3.3	All instruments in lines are assumed to be ¾" in diameter	Normal procedure in risk analysis, not expected to influence the risk level
No.	Description of assumption	Criticality of assumption wrt the risk analysis
3.7	All leaks with initial leak rate > 0.1 kg/s that has occurred at Kalundborg the recent 7.5 years have been accurately logged in the Synergi database	Actual leaks not logged in the system and/or erroneous logging of data related to actual leaks (in particular the leak rate) will have significant affect on the overall risk picture and recommendations extracted from the established risk model
3.8	It has not occurred any leas with leak rate larger than 10 kg/s in the life time of the Kalundborg plant	The frequency for leaks > 10 kg/s is adjusted based on the assumption that no leaks with leak rate larger than 10 kg/s has occurred. If more than one such leak actually has occurred, then this will have significant effect on the risk picture and on recommendations from risk model

As with the first two examples, the assumptions have been identified as conservative; that is usually a term that have been used a reasonable amount of times in risk analysis parts. The term basically means that because we are not aware of the u certain event, we would usually try to choose the worst case scenario not to mention that surprising events might still happen but with the worst case, it is usually meant the worst case known up to now.

Assumptions in Leak Duration Estimation

Leak duration has a great effect on the future consequences of a possible leak, the longer the leak lasts, the higher the probability of ignition, heavier explosion and escalation of fire will be. Therefore, assumptions related for this section could be considered quite “critical”.

Table 3.8. Leak duration assumptions for Kalundborg [33]

No.	Description of assumption	Criticality of assumption wrt the risk analysis
3.9	- The response times received by Kalundborg are assumed to equal the time from the leak occurs until all enclosed control valves are closed. In TLT, the response times equal time to detection. - The response times received are used for shift period, while for day time the response times are a 1/3 of the response time for shift period. - The time to initiate ESD, defined by TLT, is assumed to be 2 seconds for all valves. - The valve closing time is assumed to be 10 seconds. - The blowdown valves are assumed to open at the same time as isolation of the segment	The response times are very important for the result in the risk analysis. The leak duration will affect the ignition probability (more fluid released implies higher probability for exposure of live ignition sources), the explosion loads (more released gas will on average result in more gas taking part in the combustion process in case of ignition) and the fire duration (the fire duration is important for the probability for escalation to equipment)

In the assumptions above for leak frequency and duration, the positive point is the assumptions are listed with respect to their area of effect but the shortages in the way of presenting them could be that they are not classified to which category of classification of assumption they belong. Other possible features that could possibly add to the value of assumption presentation might be: stating which other areas of the QRA report they have effects on/are affected with, the duration of their validity and the background source they are based upon. Some of these features are stated with only few examples only.

Indirect Assumptions in Kalundborg

Except for the assumptions presented in the assumption section there are some other assumption mentioned in an implicit and not classified way in the middle of the rest of the work and due to necessity. We will mention an example below. The indirect assumptions are presented in italics.

Equipment Counting

According to the report [34], the counting of different types of equipment was performed as part of the Kalundborg risk analysis work since a counting of equipment is necessary to provide the correct input for leak frequency calculations. The following components were counted:

- Flanges
- Valves (all types, both manual and actuated)
- Instruments

- Process vessels (drums, separators, scrubbers, columns)
- Pumps
- Compressors
- Heat exchangers (shell & tube, plate and fin/fan coolers).

For equipment present in two different sub segments, i.e. present in both a liquid and a gas sub segment (this would, for example, be the case for a separator); the count was divided by a factor of 2 to avoid the equipment being counted twice.
The estimated leak frequencies for the process area of Kalundborg were based on average values for various "large" equipment types, rather than a detailed equipment count.
It was regarded to be too time consuming to perform detailed counting for the entire Kalundborg refinery. Instead, detailed counting was performed for a selection of large equipment types. These results were then used as average values for similar large equipment types at Kalundborg. [33] [34]

The table below presents the estimated average number of valves, flanges and instruments for various types of equipment. *All similar equipment identified during counting was assumed to have the same amount of leak points as the average equipment presented in the table.*

Table 3.9 Average number of valves, flanges and instruments for various types of large process equipment established by counting of 5-6 items of each component for Kalundborg QRA [34]

Process equipment	Valves	Flanges	Instruments	**Total**
Exchanger/cooler	6.8	7.0	1.7	**16**
Pump	10.5	7.9	1.9	**20**
Stripper/column	18.4	15.4	12.0	**46**
Drum/separator	13.2	9.8	3.6	**27**
Strainer	12.7	8.0	1.2	**22**
Actuated valve	5.0	2.0	1.0	**8**

During the counting of leak points at Kalundborg refinery, there were identified several components that could not be classified as any of the equipment types below. *This equipment was counted in detail, or was assumed to be equal to other similar equipment.* Examples of such items are heaters and compressors. [34]

In the text above the sentences in italics represent another way of addressing assumptions in the report. The above examples are in fact important enough to be listed in a separate section. Since it could be quite challenging for the reader to get ahold of this assumption in the middle of the report.

For the equipment count, as we have observed in previous examples of different QRAs, it plays an essential role in leak frequency estimation and yet so far in none of the QRA reports were separately listed and fully discussed. As will later see in chapter 5 for Valemon examples, it is eventually listed under analytical group of assumptions with references to process leaks. The underlying assumption of the count is being mentioned to be P&IDs of the process facility.

3.3.4.3Discussion on assumptions presented in Kalundborg

In the section above mostly the description of the assumption has been stated. The areas affected are not exactly mentioned and there are some probability distributions assigned which are based on background knowledge and therefore may not be reliable for all time and need to be noted. Throughout the report, ambiguous terms such as small, medium and large have been used with no reference to the source

The assumptions in this QRA form the basis for the results of the analysis. Therefore, changes in the assumptions will have influence of the presented risk level. There were some positive and negative points to the way of presenting assumptions in Kalundborg. The main positive point is that some rather important and more observable assumptions related to process leak duration and frequencies were listed in a dedicated separate section.
The disadvantages could be stated that the assumption sections were not rather extensive. In most cases it was limited to only a sole description of the assumption however; some sections have come up with a criticality column as well, stating how important the nature of the assumption might be with respect to the presented risk level. But uncertainties and sources of background knowledge have not been stated. Generally a more detailed discussion and explanation of the assumption is more valued. Mentioning the related areas of effect the assumption, which has been done to quite some extent here, is also appreciated in a way of making the effected parts more traceable in case the assumption is not valid so that an improvement

3.3.5 General Comments about all the four examples:

Finally, our observations of these examples have been that most of the assumptions are listed and mentioned implicitly and indirectly in case of being needed only and not any time before that. Meaning no earlier classifications had been done in advance. The assumptions presented so far have been rather scattered and disorganized or not fully developed with respect to sources of background knowledge and areas of effect as well as associated uncertainties.

This general shortcoming has encouraged us to go through the Valemon TRA, which its assumption section is to a great extent established according to the mentioned standards and an acceptable classification has been done. It is not perfect, though and the aim of the following chapters is to mentions the flaws as well as learning from the advantages.

3.3.6.Valemon TRA Examples

As we have mentioned in the beginning of this chapter, we will not review the assumption examples of Valemon in this chapter and we have dedicated the next two chapters for introducing and discussing the examples of assumptions of Valemon. After reviewing the scattered and not organized examples of some assumptions mentioned discursively in the main report and out of necessity only, we reached to the conclusion that example 4 (Kalundborg) has provided the best examples of presenting assumptions so far. Yet, Valemon TRA has apparently been done in a lot better way (regarding assumptions) and the documentations of assumptions seem to be better and more effectively organized in this perspective. In addition Valemon report is more up-to-dated and hence is expected to out rule the other examples.

Therefore, we have chosen 5 examples of assumptions from the assumption section of Valemon and will in chapter 5 review the impacts of assumption on the whole QRA and will comment on the way they have been presented as well as the basis of their formation and some recommendations for improvement will also be provided. We will on top of all these, define an importance factor to each assumption based on their impacts on other parts of the QRA.

The selected examples are:

Group 1.Organizational/Operational
Group 2. Technical Assumptions
Group3. Analytical Assumptions

1. Annual number of supply vessel visits to Valemon
2. Lifting activity to/from supply vessel
3. Collision resistance of jack-up rig legs
4. Equipment count: Equipment count has been made on P&IDs. Main units, instruments and valves found are considered good estimates
5. Manning level and distribution

From the 5 chosen examples numbers 1, 2 and 5 belong to group1. Example number 3 belongs to group2 and example number 4 has been taken from group3.

The next chapter (chapter 4) is dedicated to Valemon field and TRA introduction. All selected examples of assumptions for investigating in this work have been selected from Valemon TRA. This is mainly because the Valemon TRA is one of the recent reports and complies to an acceptable extent with the Statoil guideline GL0282 [10]with respect to assumption documentation. The assumption section in this report seems quite extensive and the most thorough one of all the other examples we have already been through in this thesis. In chapter 5, we will have a discussion about the five examples chosen (mentioned above) out of the 65 officially listed ones in the Valemon report with respect to the objectives of this work and the discussions presented in chapters 2 about assumptions and uncertainties in QRAs.

Chapter 4

4. Introduction to Valemon field and TRA methodology

In this section Valemon field and facilities will be introduced. Since this chapter is mainly explanatory, most of the text has been extracted from the main Valemon TRA report, reference number [17]. Only minor discussions have been made and distinguished.

4.1 The Valemon field and installation (system Description)[17]

The development concept for Valemon will be a platform solution with process facilities with condensate export to Kvitebjørn and a rich gas export to Huldra-Heimdal pipeline (a tie-in on Huldra to the existing pipeline to Heimdal). The Valemon field development can be seen in Figure 4.1. The plan is to start drilling wells in 2012 with production planned to start in 2014

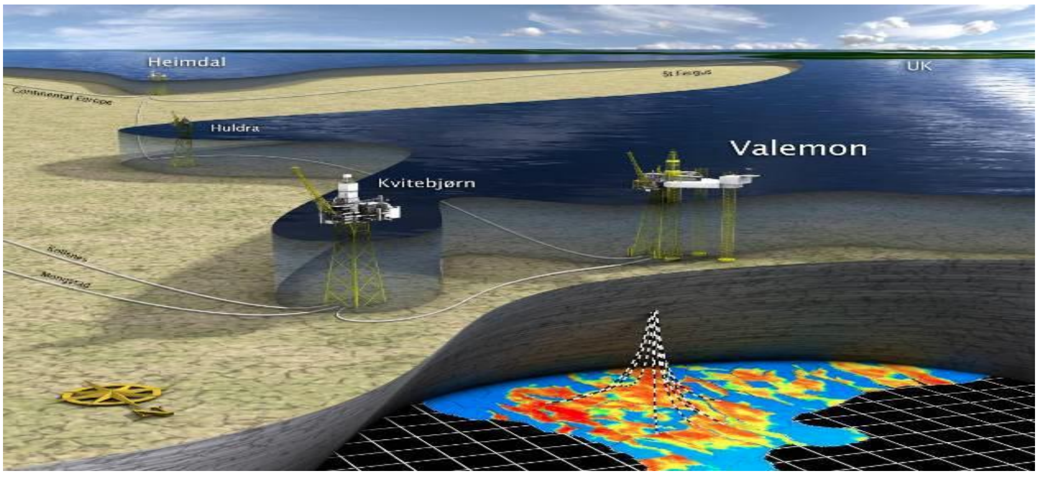


Figure 4.1 The Valemon field development, [17]

An overview of the Valemon topside layout is shown in Figure 4.2. The dimensions of the platform are 79 m x 26 m, excluding the LQ and including the cantilever on east side cellar deck. The height of the main deck is 15.5 m from cellar deck level. Platform west is the LQ side and east is the process & flare stack side. The jack-up rig West Elara shall be used for drilling operation on Valemon, using a cantilevered drilling rig above well intervention deck as seen in Figure 4.2.

The platform will be designed with a Living Quarter for 401 persons, a wellhead area for 20 slots, a process area with process equipment and space and weight allowance for installation of a compression module and future tie-ins. [17]

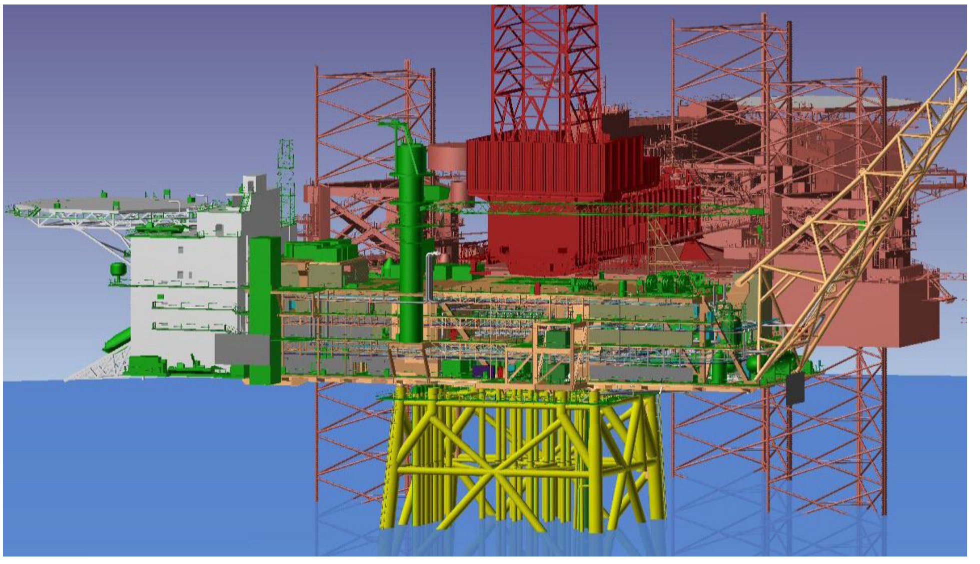


Figure 4.2: Valemon topside with jack-up rig [17]

4.1.1 Main areas and fire divisions on Valemon[16]

The term "main area" is used in Statoil's risk acceptance criteria, with reference to NORSOK Z-013. Based on this, the following main areas for Valemon must as a minimum be defined:

- Accommodation
- Utility area
- Wellhead area
- Process area including risers

Figure 4.3 shows a sketch of the main areas defined for Valemon.

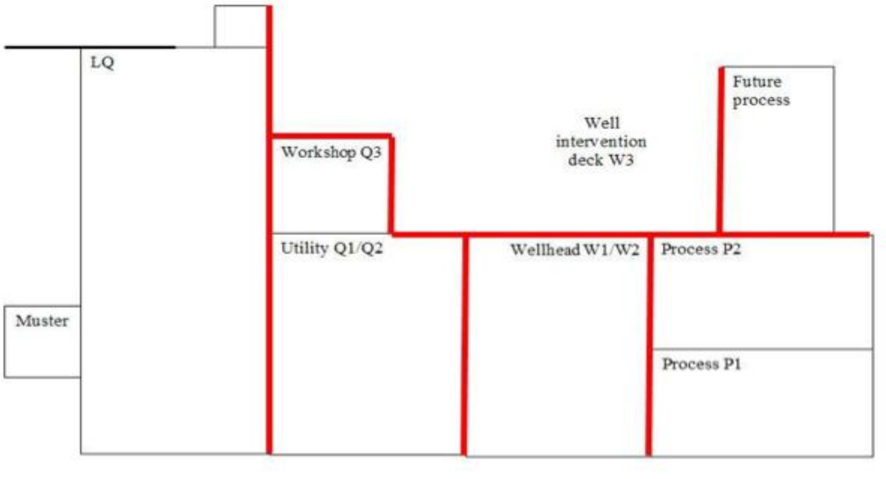


Figure 4.3 Main areas on Valemon. (H-fire rated decks/walls are marked red. Note that the utility roof is also H-rated north and south of the workshop area. P1 and P2 are part of same main area). [17]

There is a plated deck between the process cellar (P1) and process mezzanine (P2) levels, however, P1 and P2 is considered part of the same main area.

There will be a fire (and blast) division between the future process module and the process module below. There will also be a fire and blast division between the well intervention deck and the wellhead area below. Based on NORSOK[11], the future upper process area and the well intervention deck can be considered separate main areas. These areas have different functionality and risk level.

Hence, for this TRA, it is chosen to consider each of the areas divided by fire rated decks as main areas.

- LQ
- Utility area (including workshop) (Q1/Q2/Q3)
- Wellhead area (W1/W2)
- Well intervention deck (W3)
- Process area (P1/P2)
- Future process area (P31)

The future pig launcher area P11 located south of P1/P2 is considered part of the process area. (P1/P2).

4.2 Valemon TRA methodology and Steps[17]

A detailed quantitative risk analysis of Valemon has been performed in line with applicable regulatory requirements and Statoil requirements. A brief description of the applied risk analysis methodology is given in this section. The main elements of the methodology are as illustrated in figure 4.3.

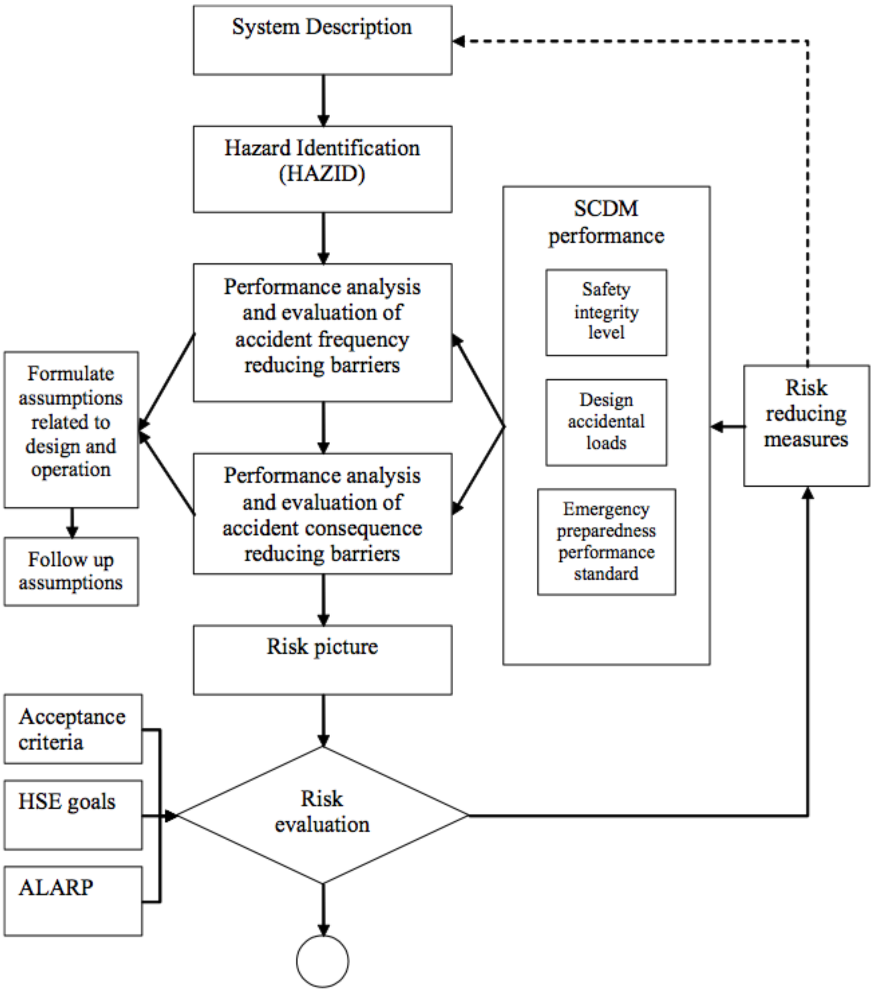


Figure 4.3. The Risk analysis Process for Valemon[17]

The risk quantification is shown as a two-step process. The first step is an analysis of the frequency of initiating events, and the effectiveness of the barriers implemented to prevent that failures and situations of hazard and accident will occur. In the second step analysis of the effectiveness of the barriers implemented to prevent accident escalation and to minimize the accident consequences is performed.

Identification and evaluation of possible risk reduction measures is performed until the risk acceptance criteria and HSE goals are met, and further risk reduction based on an ALARP evaluation is not practicable.

Risk reduction measures may represent fundamental changes to the system, or may be limited to improved performance of safety critical design measures such as increased design accidental loads or a higher safety integrity level. Improved performance may refer to increased capacity, reliability, availability, efficiency, and ability to withstand loads, integrity or robustness. In this way, the risk analysis serves as basis for establishment of the performance standards for safety barriers and emergency preparedness.

4.3. Framework for Valemon (Regulatory basis)[17][11]

The petroleum activity in Norway is based on the NPD Regulations of August 31st 2001 “Regulations relating to Health, Environment and Safety in the petroleum activities” (the Framework Regulations). “Regulations relating to design and outfitting of facilities etc. in the petroleum activities” (The Facilities Regulations) was issued by the Norwegian Petroleum Directorate September 3rd 2001 and last amended in 2007.
Several standards are referred in the NPD regulations, in particular NORSOK standards. Consequently, these are included as part of the regulatory basis. The NORSOK standards are developed by the Norwegian petroleum industry and are prepared and published with support of The Norwegian Oil Industry Association (OLF) and Federation of Norwegian Manufacturing Industries (TBL). The NORSOK standards are managed and issued by Standard Norge.[17]

It is also worth mentioning that all the TRA steps should be defined and implemented within a total framework which is basically defined by generally applied sets of standards such as standards set by PSA, OLF, HSE, NORSOK standards and also the expectation of an operator company the QRA is being presented to such as Statoil in this case which has prepared some guidelines on how different parts of a risk analysis should be presented. As an example of which we could refer to GL0282, guideline for risk and emergency preparedness analysis, mentioned in this report for assumptions and presuppositions section.

Figure 4.3 above could therefore be represented as the in the figure4.4.

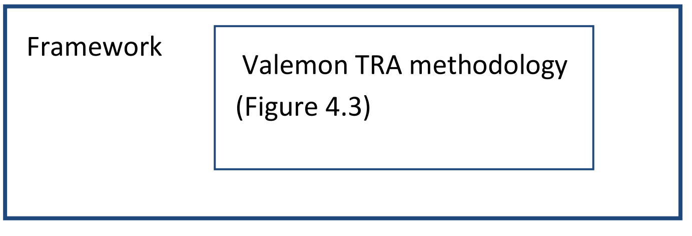


Figure 4.4. Framework versus TRA methodology stages

The framework therefore influences all parts of the analysis and usually sets the basis in risk evaluation for RAC. As underlying criteria all parts of the risk analysis have to comply with the set standards starting with the systems description to the risk evaluation step including any operations carried out on the facility. The same rule applies for our main topic of this work, assumptions. That is all the defined assumptions should not in any case be in conflict with the predefined framework of the analysis.

4.4 Hazard identification for Valemon[17]

The methodology used for hazard identification is in accordance with ISO 17776. This standard outlines a method for a systematic review of the design with the object of identifying all possible hazards associated with the systems and functional rooms. Those hazards considered to have the potential of developing into hazardous events are the starting point for quantification of personnel risk as reported here. Hazards considered having minor consequences and/or negligible frequencies of occurrence were identified and registered with hazard numbers but not evaluated further in the risk analysis. [17][18]

Identified hazardous events

The list of identified hazardous events that represent major accident risk or significant risk to personnel on Valemon is as follows: [17] [19]

- Dispersion of unignited gas (the toxic effect of hydrocarbon gas)
    - Fires from HC releases (heat and smoke exposure)
    - Gas explosions
- Blowout and well releases:
- Topside blowout
- Subsea blowout
- Riser and pipeline leaks
- Fire in utility areas
- Collision risk
    - Supply vessel traffic to Valemon and Jack-up rig
    - Passing vessels- and fishing vessels traffic to the field
- Dropped objects and swinging loads
    - Dropped objects due to material handling with main crane
    - Dropped objects from the Jack-up rig
- Helicopter accidents
- Extreme weather
- Structural failure
- Earthquake
- Subsidence
- Sudden drop/Punch through of jack-up rig
- Jack-up capsize
- Occupational accidents (personnel risk)
- Fire in living quarter [16]

We will later in chapter 5, investigate the relation of selected assumptions on these identified hazards. It is also worth mentioning that new hazards might be introduced during further development phases and one should not limit focus only to these hazards.

4.5.Risk Acceptance Criteria for Valemon [17]

The purpose of the analysis is to present the risk level for Valemon and whether it is within acceptable limits or not. *Acceptable here means that the Valemon risk acceptance criteria and regulatory requirements are met.*

Risk acceptance criteria (RAC) as given in framework are being described in this part in addition to how it applies to the Valemon installation.

Beyond meeting the risk acceptance criteria, the risk shall be reduced to a level as low as reasonably practicable (the ALARP principle). Risk reducing measures are then required for this purpose. Statoil's RAC are related to personnel risk and impairment of main safety functions.

Personnel risk[17][11]

The Valemon project's risk acceptance criteria with respect to personnel risk are as follows:

<u>Individual Personnel Risk (Manned Phase):</u>

The mean individual risk, expressed by the fatal accident rate (FAR) – must meet the criteria FAR < 10.

<u>Group Individual Risk (Manned Phase):</u>

For specially exposed groups (Operation, Mechanic, Electric / automation and Maintenance Contractor, or as defined in TRA / EPA), the mean group individual risk, expressed by the fatal accident rate (FAR) – must meet the criteria FAR < 25. The criterion applies for groups existing of personnel that together constitute of minimum 3 positions in ordinary, regular service on Statoil installations.

<u>Personnel Risk (Normally Not Manned Phase):</u>

For installations that are normally not manned, the PLL per year shall be below 4.0E-03, if annual manhours on the installation are less than 15000. If annual manhours exceed this, the FAR criteria shall apply.

Personnel risk is expressed as FAR – Fatal Accident Rate –number of fatalities per 100 million exposed hours. FAR is used as a measure for average risk, either for all personnel on a facility or for defined groups.

FAR= PLL*1E8/ N

where
PLL expected number of lives lost per year
n = number of people in the group
h = hours of exposure per person/position per year.
N = n * h = total number of hours of risk exposure per year

The criteria shall apply as a mean for any 12 month period. The FAR is a measure of the average risk for a group of individuals while they are offshore. The time off duty in the LQ and helicopter transport risk is therefore included.

Impairment of main safety functions [17]

This chapter describes how impairment of main safety functions is interpreted.
The main safety functions are described in the PSA Facilities Regulations section 7.[17]
The Facilities Regulations states:
Accidental loads and natural loads with an annual probability greater than or equal to 1x10-4 shall not result in loss of a main safety function. The requirement to loads applies to each individual type of load and not for the sum of these, as per guidelines to the Facilities Regulations, section 11.

Statoil's Design Basis, refers to NORSOK Z-013, edition 3 for definition of main safety functions. Further, it states:
The probability of loss of defined main safety functions shall be estimated per year, per safety function and per accident category, as given in Norsok Z-013, edition 3, annex B. Accidental events within each of these categories having combined probability ≥ 10-4 per year shall be considered dimensioning.

4.5.1 Interpretation for Valemon

This section presents how the RAC applies to the Valemon installation.

- **Personnel risk[17]**

The Valemon platform shall be normally not manned. It is however required to be manned during drilling, well interventions, pigging activities and maintenance. Hence, both FAR and PLL criteria may be relevant depending on the operational phase.

The relevant groups for calculation of Group Individual Risk for Valemon are assumed:

 Management
 Operation
 Mechanic
 Electric and automation
 LQ service

Calculation of FAR for Valemon is based on exposure when manned, thus N (total number of hours of risk exposure per year) is the number of manned hours per year. The criteria shall apply as a mean for each 12-month period. Hence, in this calculation, the PLL value is based on the same number of manned hours per year as for FAR calculation.

- **Assessment of loss of main safety functions for Valemon**

Valemon's risk acceptance criteria refer to NORSOK Z-013, on how to estimate loss of main safety functions. With respect to fire and explosion accidents, it requires that for each of these accidental loads,

a) The frequency for escalation from one main area to another main area shall be less than 10-4 per year. The requirement applies to each side of each division between two main areas.
b) The frequency for impairment of main load bearing structures shall be less than 10-4 per year. This is the sum for each type of accident for the complete installation, and not for each main area or structure.
c) The frequency for impairment of each room of significance for combating accidental events shall be less than 10-4 per year. This is the sum for each type of accident for each room.
d) The frequency for impairment of each safe area shall be less than 10-4 per year. This is the sum for each type of accident for the LQ and muster areas with lifeboats. [17]

4.6.Risk Picture of Valemon[17]

The total risk is presented on a format intended to facilitate comparison against the Statoil risk acceptance criteria. The base case activity level 5 (typical year 2024) has been presented which is the year expected to have the highest total risk level. Personnel risk in terms of FAR is presented area wise. In order to be able to interpret the results of analysis presented in this section of risk picture, one should be aware of the 6 predefined activity levels considered for Valemon. The activity levels serve as an underlying assumption for all risk calculations in this TRA report.

4.6.1. Activity Levels for Valemon

The Valemon platform shall be normally not manned. It is however required to be manned during drilling, well interventions, pigging activities and maintenance. Hence a total of 6 combinations of different activities are foreseen as defined below:

1. Simultaneous drilling and production (including jack-up drilling rig)
2. Normal production (stand-alone, no well intervention)
3. Simultaneous production and well intervention (stand-alone)
4. Simultaneous drilling, production and wireline well intervention (including jack-up drilling rig)
5. Stand-alone production including all known future modifications
6. Stand-alone production and normally not manned installation

The total risk picture is presented for the activity level with the expected highest total risk; Simultaneous production and well intervention, stand-alone (activity level 5, year 2024). This has been based on an evaluation of number of wells in production, number of drilling and well intervention operations, change in flowing wellhead pressure and inlet separator pressure during lifetime number of tie-in wells and introduction of future compression module.
Further, the personnel risk, Potential Loss of Life (PLL), is presented for the normally not manned (NNM), normal production stand-alone phase (activity level 6).

4.6.2 Personnel risk[17]

The total PLL and FAR values per area for activity level 5 and 6 are presented in Table 4.1 and Table 4.2.

Table 4.1Total PLL and FAR, activity level 5[17]

PLL	Average manning	FAR
$2.4 \cdot 10^{-2}$	41	6.73

As seen the FAR value is well within the risk acceptance criteria of FAR < 10 for activity level 5.

Table 4.2 Total PLL and FAR, activity level 6 [17]

PLL	Average manning	FAR
$8.4 \cdot 10^{-4}$	1.25	3.24

As seen the PLL value is well within the risk acceptance criteria of PLL < 0.004 for activity level 5.

The distribution of FAR between accident categories is shown in Figure 4.5.

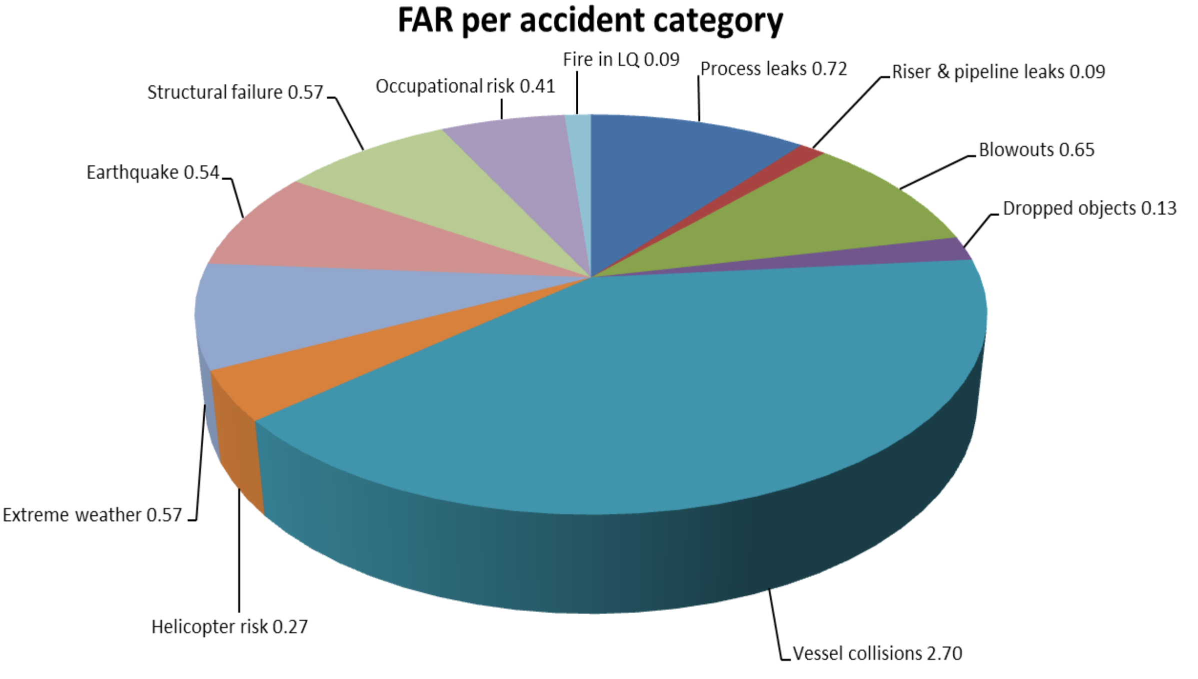


Figure 4.5. Distribution of FAR between accident categories [16]

It is seen that the vessel collision risk is high, since all personnel is assumed killed upon total loss of main structure. This is based on an impairment of main load bearing structure which is above the acceptance criteria. The figures for natural loads (earthquake and extreme weather) may be somewhat conservative, since no safety margins to the design criteria have been assumed.

This figure in presenting FAR values per accident category is considered very important and serves as a reference point for evaluating the different assumption examples on the total risk picture. This has been done in chapter 5.

4.6.3 Impairment of main safety functions

The relevant result of this part of the Valemon risk picture for the assumptions to be discussed in the next chapter is the main load bearing structure.

Impairment frequencies for main load bearing structure for activity level 1 (year 2019) are shown in table 4.3 below. Based on the RAC defined for Valemon, regardless of the accident load, the 1E-4 applies for all categories.[17]

Table 4.3 Impairment frequencies for main load bearing structure [17]

Accident load	Accident scenario	Impairment of main load bearing structure [per year]
Fires	Process	$1.0 \cdot 10^{-6}$
	Riser	$4.5 \cdot 10^{-6}$
	Blowouts	$6.6 \cdot 10^{-5}$
Sum fire loads		$\mathbf{7.15 \cdot 10^{-5}}$
Explosions	Process	$1.13 \cdot 10^{-4}$
	Riser	$3.7 \cdot 10^{-6}$
	Blowouts	$9.73 \cdot 10^{-6}$
Sum explosions		$\mathbf{1.26 \cdot 10^{-4}}$
Impact	Helicopter impacts	0
	Collision impacts	$2.36 \cdot 10^{-4}$
	Dropped objects	0
Sum collision/impact		$\mathbf{2.36 \cdot 10^{-4}}$
Environmental loads*	Extreme weather	$\mathbf{5.0 \cdot 10^{-5}}$
	Earthquake	$\mathbf{9.5 \cdot 10^{-5}}$
Structural failure**	Structural failure of Valemon	$\mathbf{9.90 \cdot 10^{-5}}$
	Jack-up capsize, cratering due to subsea blowout	$\mathbf{5.40 \cdot 10^{-6}}$

As it can be seen, the criteria are met for fire loads, environmental loads, and structural failures and jack-up capsize.

The criterion for main load bearing structure due to impact load is not met. This is due to vessel collision on the jack-up rig, and is based on the assumption that the jack-up legs only withstand a 14 MJ vessel collision impact. In appendix C, it is shown that in order to be within the criterion, the jack-up needs to withstand a 45 MJ bow impact. [17]

The risk acceptance criteria for impairment of main load bearing structures due to impact load will be met for stand-alone phases (activity level 2, 3 and 6). This is going to be further discussed in examples of chapter 5.

4.6.4. Summary of overall risk results for Valemon [18][17]

Personnel risk

The total FAR for Valemon in activity level 5 is 6.73. This is the activity level with the expected highest personnel risk. The total FAR for Valemon is well within the risk acceptance criteria of FAR <10 for personnel risk.

The personnel risk, expressed as PLL, for Valemon in activity level 6 (NNM) is 8.4 ·10-4 per year. The PLL value for Valemon is well within the risk acceptance criteria of PLL < 0.004 for personnel risk in NNM phases.

Impairment of Main Safety Functions

The dimensioning year related to the impairment of main load bearing structure, prevention of escalation, rooms of significance to combat accidents and safe area is chosen to be 2019, which represents activity level 1. The dimensioning activity level for impairment of escape ways has been activity level 5 (year 2024). [17]

We will only point out the topics under the impairment of safety functions in here.

- Prevention of escalation
- Main load bearing structure
- Rooms of significance to combat accidents
- Safe area
- Escape ways

The relevant parts of safety functions for each assumption example will be discussed in the next chapter in the discussions related to each assumption.

4.7. Uncertainties in Valemon TRA [17]

There is always a degree of uncertainty in the results from a risk analysis. Some of the uncertainties are related to the consequence models and statistical models used for calculating accidental loads, impacts and frequencies. Uncertainties will also be associated with design and operational assumptions, which are input for the study. Uncertainties related to generic accident data are also obvious when applying to a specific platform with its equipment. Some Uncertainty factors on this work have been mentioned below: [17]

A number of results in this TRA are associated with quite some uncertainties. The main uncertainties are listed in the following.

- The input on manning level and distribution on areas is highly uncertain. The manning study by Statoil has not been finalized. The manning distribution on platform areas is based on the FEED study. The assumptions made for manning is important for calculating personnel risk: among other total FAR, Group risk and PLL (the latter for normally not manned phase). The assumed manning level and distribution is found in appendix K, operational assumption number 1.2.

- Activity levels during lifetime: Production from the Valemon field is associated with a significant uncertainty. Therefore, there is uncertainties connected with production profile (and number of producing wells), required well intervention activities, required manning etc. Hence, as many as 6 possible activity levels have been defined for the period 2014 to 2027, considering drilling, well intervention, production profiles, number of tied-in wells and future installations. The combination of such activities within each activity level is decisive for which activity level will be dimensioning for the installation, when considering the risk acceptance criteria. This is important for among other the design explosion loads.

- Operational input on lifting activities in the different activity levels is uncertain. A number of operational assumptions have been made, like lifting routes, lifting heights, weights and number of lifts. Note also that it is uncertain whether the main deck above process area (or roof of the future area after this has been installed) needs to be used for storage. In particular, this is important for the structural design of the main deck (and possibly the assumed weight of the future module). It is also important for the conclusions on dropped object impact on subsea pipelines

- The jack-up legs have been checked to withstand a vessel impact of 14 MJ, which is an uncertain assumption. In order to meet the risk acceptance criterion for impairment of main load bearing structure due to vessel collision impact, with the current premises/assumptions for the calculations, the design load for the jack-up would need to be set to 45 MJ.

- Further, there are uncertainties in the underlying assumptions for vessel impact loads. Such uncertainties may be operational assumptions, like the number of supply vessel visits per year, or whether any other risk reducing measures to prevent collision with the jack-up or the jacket can be used.

These uncertainties are directly related to assumptions examples we are going to discuss in the next chapter. Therefore we will explain about them more in chapter 5.

4.8. Assumptions presented in Valemon

In line with the requirements on assumptions mentioned in chapters 2 and 3, the applied assumptions for Valemon QRA have been listed in one separate appendix. [18]

A total number of 65 assumptions presented in 3 categories have been addressed.

This section is normally supposed to include all assumptions and suppositions used in the report. However, as we will see in chapter 5, there are still some assumptions that are not listed in this chapter.

The 3 categories of assumption consist of:

1.Organizational/Operational
2.Technical assumptions
3.Analytical assumptions

The list of all assumptions presented in Valemon report is shown in table 4.4.

Table 4.4 Assumptions for Valemon TRA report[18]

4.9 Final Comments on Valemon Description and TRA Methodology

This chapter was an introduction to Valemon field and facility, the TRA method applied together with its final result of the risk analysis. Yet, there is a great deal of uncertainty involved in this report and some assumptions have been made and used. The assumptions made are based on background knowledge (experience) and there is always uncertainty hidden in application and interpretation of this background knowledge. This uncertain aspect of assumptions is quite challenging in the sense that invalidity or alteration of an assumption could lead to considerably different risk results.

All the assumptions in a QRA should be listed, considered and approved so that all involved participants could deal with the challenges of the risk level being influenced in case of assumptions not being valid.

In the next chapter, some examples of assumptions introduced in the table above will be discussed in order to help understand the importance of them in the QRA.

Chapter 5

5. Evaluation of Examples of Assumptions in Valemon Report

In this chapter we have selected 5 examples from the list of examples of assumptions in Valemon TRA and we will discuss the description, basis and different impacts of these assumptions.

5.1 List of Selected Examples of Assumptions in Valemon Field

Group 1.Organizational/Operational
Group 2. Technical Assumptions
Group3. Analytical Assumptions

1. Annual number of supply vessel visits to Valemon
2. Lifting activity to/from supply vessel
3. Collision resistance of jack-up rig legs
4. Equipment count: Equipment count has been made on P&IDs. Main units, instruments and valves found are considered good estimates
5. Manning level and distribution

From the 5 chosen examples numbers 1, 2 and 5 belong to group1. Example number 3 belongs to group2 and example number 4 has been taken from group3.

5.1.1 Reasons for selection of the examples

In selecting of the examples, the focus has been to include all three categories of assumptions. Another important factor in assumption selection has been the relation and impact the selected assumptions have upon one another. As we will see, some of the mentioned assumptions could be serving as an underlying assumption to others.

And finally we will discuss manning level assumption separately because of its different nature with respect to personnel risk. Another reason for setting this assumption aside so that it would be the last one has been that to be able to identify its impact on the other four examples more easily. This assumption will at the end of this chapter provides a situation for comparison between the manning level distributions in Kalundborg QRA as well.

5.2.The approach towards assessment of the assumption examples

According to the main title of this work which is importance analysis of assumptions, with this approach we would like to answer the following list of questions with respect to assumptions in our discussions:

- How important is the assumption?
- What are the effects of the assumption on the risk level? (Which areas are affected?)
- Why the assumption is being made in such a way (reasoning and background knowledge)
- Could it be made any other (better) way? And why? (Recommendations)
- What changes may occur as a result of the assumption being changed/misinterpreted/ignored/not valid?

The approach towards evaluating assumptions is that first assumptions shall be discussed in two different ways defined as follows and the proposed questions shall be answered in the following categories:

I. General Aspect

From this viewpoint, we look at the definition and explanation of the assumption in itself and the background the assumption has been based upon. The general impacts of the assumption are briefly addressed.

II. Integrated and interrelated aspect:

In this part we will evaluate the assumptions in an integrated level that is in comparison with other parts of the QRA and particularly the consequences and risk picture parts of the analysis.
The different steps of Valemon TRA has been introduced in chapter 4, section 4.3 as we could recall. We will discuss this part by explaining the impact of the assumption on each part.
The challenge might be that sometimes the parts of are so correlated that it is not simply possible to distinguish where exactly the assumption takes effect. The main point of breaking down the QRA to its components is to be able to realize the area of effect for the assumption so that we could trace the impacts of assumption in the analysis in case the assumption changes or will be invalid.

We then discuss how the variation, modification and misinterpretation of some assumptions could change the different aspects of risk level. We would comment on how the assumption affects and interacts with other parts of the assessment such as HAZID, cause analysis, consequences, risk picture and etc. In other words, which other parts of the analysis are influenced by the assumption and particularly what are the direct and immediate impacts of the assumption not being valid? This is mainly done to define a qualitative degree of uncertainty and sensitivity for the assumption.

The main steps outlined for Valemon QRA that the assumptions can be discussed upon are listed below:

1. Framework
2. System definition
3. Hazard identification
4. Cause analysis
5. Frequency and consequences analysis
6. Risk Presentation (Total Risk Picture)
7. Risk Evaluation with respect to Risk acceptance Criteria/ ALARP Principle
8. Uncertainties and Sensitivity analysis

5.2.1Dimensions of Risk

When evaluating the effects of assumption on some selected sections of the QRA, we shall always refer to risk in terms of:
1. Risk to Personnel
2. Risk to environment (presented as frequency and quantities of oil spills)
3. Risk to Asset (presented as frequency of accidents)

The following could also be included:

4. Frequency of impairment of main safety functions
5. Escalation potential towards Valemon from incidents on jack-up drilling rig also to be addressed; e.g. falling loads, ship collision giving collapse of jack-up rig, structure faults and earthquake. [16]

5.2.2. Ranking of assumptions according to uncertainty and sensitivity

In section 3.2(components of risk description QRA) we have introduced for this work, Probability, Consequence, Uncertainty, Background knowledge and Sensitivity as main components of risk in a QRA. We are therefore intending to evaluate our selected assumptions (uncertainty factors) in light of these components.
In chapter 2, we had a through discussion for probabilities and consequences and we reasoned why we always have to look beyond the expected values and probabilities describing risk.
We introduced the concept of background knowledge when some epistemic (knowledge)-based probabilities are assigned to some events which analysts have lack of knowledge about.
In this chapter, while evaluating assumptions we would like to focus on uncertainty and sensitivity corresponding to each assumption. The intention is to provide some results about scoring uncertainty and sensitivity along with the risk

picture to basically look beyond the mere probability values and also provide an additional basis for decision support for managerial review. Therefore, in evaluating the assumptions which count as uncertainty factors, we will eventually rank the importance of assumptions according to their corresponding uncertainty and sensitivity based on our own background knowledge and supporting arguments and discussions that we shall provide after introducing assumptions.

In line with Flage and Aven [6], the uncertainty analyses cover the following main tasks:[7]

- Identification of uncertainty factors. (here assumptions)
- Assessment and categorization of the uncertainty factors with respect to degree of uncertainty.
- Assessment and categorization of the uncertainty factors with respect to degree of sensitivity.
- Summarization of the uncertainty factors' importance.

The approach we will use for importance analysis of assumptions is based on uncertainty and sensitivity analysis and according to Aven [s1] is called a semi quantitative approach:

To reflect uncertainty factors such as assumptions we suggest a semi-quantitative method adjusted to include consideration of both risk and vulnerability. By vulnerability we understand the two dimensional combination of consequences and associated uncertainties. The effect on risk and vulnerability depends on two dimensions:

- *Degree of uncertainty.*
- *Sensitivity of the relevant risk and/or vulnerability indices to changes in the uncertain quantities.*

For example, a high degree of uncertainty combined with high sensitivity could lead to the conclusion that the uncertainty factor has a significant effect on risk. However, if the degree of uncertainty is high but the risk and/or vulnerability indices are relatively insensitive to changes in the uncertain quantities, then the effect on risk could be minor or moderate. The category classifications (low, medium, high) will be case-specific and subject to judgment by the analyst, but the following descriptions provided in table 5.1 could serve as a guideline [6]

Eventually, after discussing all the features above for each assumption, we will present a table with the assumption description and its corresponding uncertainty and sensitivity. In this table each assumption and its underlying assumptions are given a score according to the discussions about them. The scores and their descriptions are adopted from tables 5.1 and 5.2 below [6][7][8]
We will focus on uncertainty, sensitivity and the importance factor of the assumption.

The scores are chosen from three subjective categories of Low, Medium and High. As mentioned above other classification is also possible but for this work we have chosen to consider these three categories based on Aven[6]. They are mainly based on the author`s opinion and our background knowledge and the discussions we have provided for the example.

Table 5.1 . Degree of uncertainty rankind checklist [6]

Uncertainty	Description
Low	- The assumptions are seen as very reasonable - Much reliable data are available - There is broad agreement/consensus among experts - The phenomena involved are well understood; the degradation models used are known to give predictions with the required accuracy
Medium	- The assumptions are seen as somewhat reasonable - Some reliable data are available - There are variations in the consensus of experts - The phenomena involved are well understood, but the degradation models used are simple/crude
High	- The assumptions made represent strong simplifications - Data are not available, or are unreliable - There is lack of agreement/consensus among experts - The phenomena involved are not well understood; degradation models are non-existent or known/believed to give poor predictions

Table 5.2 Degree of sensitivity ranking checklist[6]

Sensitivity	Description
Low	- Unrealistically large changes in base case values needed to alter the outcome - Low degree of uncertainty
Medium	- Relatively large changes in base case values needed to alter the outcome - Medium degree of uncertainty
High	- Relatively small changes in base case values needed to alter the outcome (e.g. exceeded risk acceptance criterion) - High degree of uncertainty

The uncertainty- and sensitivity factors' grading (low, medium or high) are scores of how significant the particular components are in relation to the entire system. A summarization of these factors' importance is performed. The importance is the average of the score from the uncertainty and sensitivity. [9]

The suggested approach introduced above is how we will rank the assumptions upon with respect to their degree of uncertainty and sensitivity. According to Aven [8] combining the uncertainty score with the results of the sensitivity analysis, the importance score is obtained. When the scores for the two dimensions are say H and M we just indicate the average importance score as H–M. It is different than M–H. The point is not to make a precise ranking of all factors but to identify the factors that are most critical for the result of the quantitative analysis.[8]

And finally that is how we answer the question of "how important" an assumption could be considered. But for reaching to this point i.e. assigning scores to uncertainties and sensitivities, we need to evaluate the assumption establishment based on proposed sources, impacts and our own background knowledge.

5.3. Supply vessel visits (Example1)

In this section, we will evaluate the assumption related to the number of supply vessel visits from the different aspects we mentioned in 5.2.

Table 5.3 Annual Number of Supply Vessel Visits to Valemon [18]

1.10	Annual number of supply vessel visits to Valemon
Description	The number of supply vessel visits to Valemon is 24 per year in the normally not manned phases (activity level 6) and 52 per year in the normal production (manned) phases (activity level 1-5).
Influence on risk level	Increased number of supply vessel visits increases the risk from ship collisions and/or may increase the design load on Valemon jacket. Furthermore, the supply vessels are also ignition sources and increased number of visits also increases the overall ignition probability.
Relevant RA sections	Appendix B; Blowouts Appendix C; Ship collision risk Appendix D; Riser and pipelines Appendix F; Process
Lifetime	Yes, ref, Table 2.1.

Table 5.4 Annual number of supply vessel visits to jack-up rig[18]

1.11	Annual number of supply vessel visits to jack-up rig
Description	The number of supply vessel visits to jack-up is 120 per year. This is based on 2-3 visits per week when drilling and during workover operations.
Influence on risk level	Increased number of supply vessel visits increases the risk from ship collisions. Furthermore, the supply vessels are also ignition sources and increased number of visits also increases the overall ignition probability.
Relevant RA sections	Appendix B; Blowouts Appendix C; Ship collision risk Appendix D; Riser and pipelines Appendix F; Process
Lifetime variation	Yes, ref, Table 2.1.
Simplification? If yes; influence on risk level	
Information source	Statoil
Comment	
Status	

Both tables can be represented as in one with respect to different activity levels. The results are shown in table 5.5 below:

Table 5.5. Assumed number of vessels with respect to activity levels

Activity level	Description	Number of visits to Valemon per year	Number of visits to jack-up per year
1	Simultaneous drilling and production, no well interventions	52	120
2	Normal production, no drilling, no well interventions	52	-
3	Simultaneous production and well interventions	52	-
4	Simultaneous drilling, production and wireline well interventions	52	120
5	Normal production, workovers, well interventions	52	120*
6	Valemon stand-alone, normally not manned	24	-

5.3.1 General Aspect of the assumption

<u>About the tables</u>

From the table above we can see that the number of vessels to Valemon in manned levels (52 visits) of activities (1-5) is more than twice the number of visits in unmanned level 6(24 visits). The numbers are given per year period and as in manned levels the basic assumption has been that one vessel trip is being carried out weekly during the whole 52 weeks in a year resulting in the assumed number of 52 visits per year. In activity level 6 a twice per month visit has been considered. The numbers are based on historical data and similar experiences giving a coarse amount of the required supplies and the information source is stated to be Statoil database. This statement seems vague, as it might not be clear which exact source at Statoil is meant. According to the size of the platform and other descriptions mentioned in the system description section, the values seem reasonable. But the values are not necessarily true. For example a once a week visit to Valemon during activity levels 1-5 might change in later phases of production. In addition, in our opinion, it would have been better to distinguish between activity levels 1,4, 5 and 2,3 due to a jack up rig being present in activity levels 1, 4 and 5. However, one might claim that this effect has been added by a total number of 120 visits to the rig annually but still the two topsides are integrated and the suggestion, as a more conservative assumption, is to consider higher values vessel visits during activity levels 1, 4 and 5.

On the other hand, one should pay close attention to the difference of values in normally manned and unmanned phases of the platform. Compared to activity level 6 (unmanned phase), there are more activities that are required during simultaneous production, drilling, well intervention, etc. (activities level 1-5) such as numerous lifting and transportation due to there are personnel being present on the platform and different activities being carried out.

The number of supply visits to jack-up drilling on the other hand has been assumed to be annually 120 visits, based on another assumption that an average of 2-3 visits per week are required for drilling and workover operations. The assumed numbers would be in a range of 104 to 156 and here an average of 120 has been considered. Once again, the numbers are only assumptions based on some background knowledge and uncertainties are always present in interpretation of the results of past experiences.

About the general consequences

Having reviewed what the assumption it in itself and what grounds for such assumed numbers, it is time to answer how important he assumption is by considering what the possible consequences might be if the mentioned numbers of supply visits deviate from the presented and estimated numbers above.

It seems that the decrease in the numbers of visits in reality would have no or at least fewer unwanted consequences rather than a dramatic increase in number of supply vessels. The increased number of vessel visits could cause a lot of consequences the first of which would be the possibility of collision risk both between the vessel-platform and vessel-vessel collision in the vicinity of the platform. It is worth mentioning that there are different types of vessels such as passing, fishing, supply, as well as different types of collisions such as vessel-vessel and vessel-platform., vessel-rig, etc. The main focus for this example would be supply vessel-Valemon and supply vessel- jack up collision risk.

In case of a collision to the Valemon jacket, another potential consequence could be the extra load that will be imposed upon the Valemon jacket due to impact energy of the probable collision between the vessel and the platform. The same explanation applies for jack up rigs while being present. This would be related to impact loads caused by either ship collisions or dropped objects that are considered one of the contributors in defining the design accidental loads and would be discussed further in the examples 2(Lifting operations) and 3 (Design load for Jack up rigs)

Another issue to be considered in case of increased number of supply visits is the increased probability of dropped objects since more lifting activities are then in action due to increased number of supply visits. Increased lifting activities increase the risk for dropped objects, which are considered one of the impact loads and have several other consequences, which we shall discuss in the next section (example 2)

In addition, supply vessels serve as ignition sources due to the fuel and engine system they sail upon. So if there would be any leakages in the vicinity of the platform, with these vessels being on site, the probabilities of potential fires and/or explosions are enhanced.

5.3.2 Interrelated Aspect of Assumption

The impact (relation) of this assumption with respect to other parts of the total risk picture/level and with other parts of the TRA itself has been discussed in the following sections.

5.3.2.1.Framework

This framework is general and applies to all parts of the assessment as discussed earlier. The main concern is that it is necessary the assumptions made be in line with the framework i.e. they should not contradict any of the applied standards and regulations.

With respect to framework for this example one could claim that the assumed numbers of visiting vessels are acceptable and not conflicting any regulations. It is known that supply vessel visits are necessary for different purposes during the life of the platform and the assumed numbers are then based on past experienced numbers of visits to platforms with more or less similar conditions.

5.3.2.2HAZID

We have introduced the HAZID phase and its different methodologies as part of a QRA in chapter3. Now we would like to mention how/if this assumption of number of supply vessel visits being not valid or misinterpreted would be identified as or associated with a potential source for some hazardous event.
As we can remember from section 4.3 one of the hazardous events listed in the HAZID section is defined as follows:

- Collision risk
    - Supply vessel traffic to Valemon and Jack-up rig
    - Passing vessels- and fishing vessels traffic to the field

It can be shown that the collision risk due to increased number of visiting, passing and fishing vessels is one of the contributors to the major accident risk.(see figure 4.5)This example, however, is limited mainly to supply vessels only. These vessels are important due to their intended approach towards the facility and their being present on site for some time. The speed is normally not the main issue for supply vessel but the importance generates from the fact that in case of a supply vessel being on a collision course, the probability of evacuation before the collision is very low. From this point of view collision risk appears to be one of the dominant risk contributors based the FAR value pie diagram presented in the risk picture of Valemon. (Figure 4.5.)

The main hazard associated with this assumption would then be the impact it has on ship collision risk (collision frequency) as the risk of collision is greatly influenced by any major alteration in the assumed number of vessel visits. The increased number of vessel visits to the platform will directly influence the potential frequency of vessel collision, as we will see through the rest of sections of this assumption.

Another important hazard that could be derived from this assumption is the structural failure or any kind of damage to the asset (Valemon platform, jacket, jack up rigs,..) due to collision impact energy. This is mainly a design issue and we will discuss this further in example 3.

As a recommendation, it would be better to list another hazard of supply vessel-vessel collision risk to be identified if the number of visits is increased due to higher ingress of vessels in the area. The potential hazards depend on not only the number of supply vessel visits but also to their speed and size. But they are not relevant for this case here.

For identifying hazards, focus should normally be on major accidents risk and the basic goal for HAZID therefore is to identify accidental events with the potential for personnel risk and impairment of main safety functions.

Identified hazardous events regarding vessel collisions were:

- Supply vessels when approaching or attending either Valemon or the jack-up rig (when present)
- Supply vessels hitting the conductors or risers inside the Valemon jacket
- Supply vessels hitting the underside of topside (including LQ) and lifeboats

5.3.2.3.System Description

For the system description, it should be noted that the change in values of the assumed numbers of visits of supply vessel does not change the system characteristics. The effect is somehow in the opposite way, meaning that the system description might have an impact of defining the required numbers of visits due to the size and other properties of the system.

The assumption that the number of visits to jack up rig is considerably higher than the annual visits of to the platform itself can be justified with the fact that there exists more required activities during the drilling phase which requires more lifting and supplies. However, the increase in number of the vessels could cause collision and dropped objects risks which should be avoided to an acceptable extent.

We refer to different activity levels assumed for Valemon once again, in support of the statement that : " 6 different activity levels have been defined but only activity level 1, 4 and 5 are assumed dimensioning for supply vessel risk." That is mainly due to jack-up presence for drilling, well intervention or workover purposes. If we consider the above statement as another assumption for the vessel collision risk, the impact of it would be on defining the number of supply vessel visits per year for each activity level and thereby the supply vessel collision frequency, in other words, the number has to be defined according to the activity levels and the assumed amount of work which has to be estimated depending on the definition of each activity level. This is exactly the description of our assumption in this section.

The assigned numbers are based on background knowledge of the analysts, therefore there is a possibility that they might deviate from what actually will happen and in that case, the main concern would be to predict the different consequence scenarios.

In order to be better able to detect the effect of the assumption to collision risk, a partial system description is presented related mainly to supply vessel locations and the corresponding collision risk. [20]

According to the system description of Valemon field, there are several approaches for the vessels to come in the vicinity of the jack-up drilling rig and Valemon itself. (Figure 5.1) The location of supply vessels with respect to each other could be another matter in determining whether the vessel is on the collision course or not. But that is not. This aspect is not quite relevant to the assumption at this level.

On Valemon, there is one main pedestal crane, located on the south side of the installation. Supply vessels to Valemon will therefore be operating on that side. Supply vessels to the jack-up rig can operate on two different sides of the jack-up. Figure 5.1indicates the possible positions of the supply vessels. [19][20]

Another point to be mentioned is that in case of a collision, the conductors and risers are located within the jacket structure, therefore a protection has been provided against ship collision. There is still a risk that they could be hit by a supply vessel, so this is considered in this analysis.

As, one can see system description has a considerable effect on how the assumption of number of vessels would lead to different consequences.

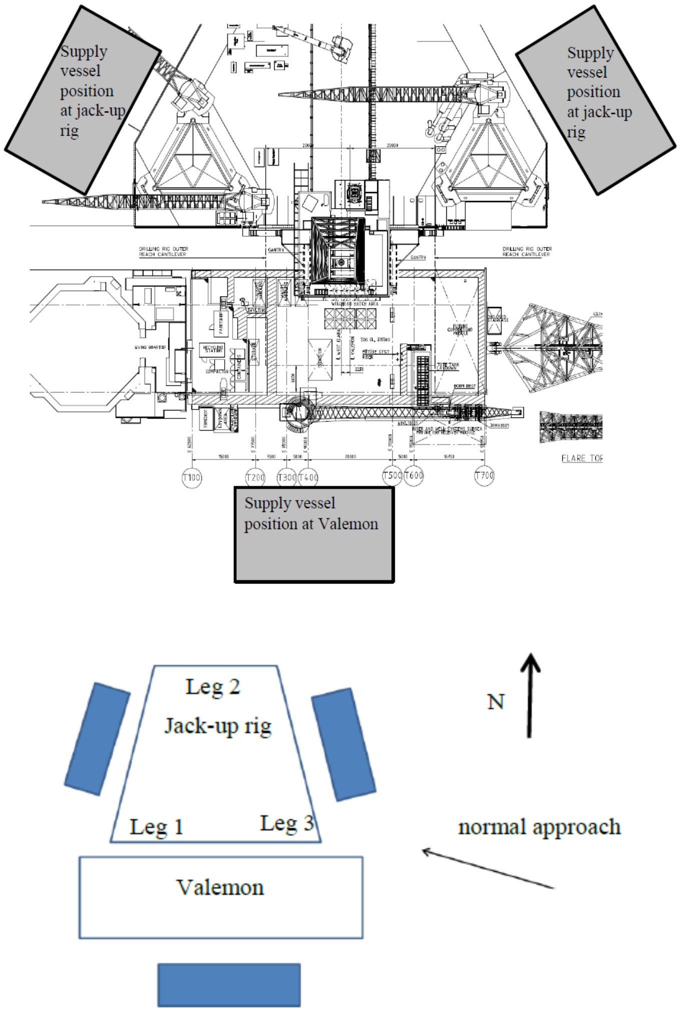


Figure 5.1 Supply vessel positions relative to the installations [20]

5.3.2.4 CAUSE ANALYSIS (Including a hazard frequency analysis)

It is normally the case for each cause analysis of a QRA to investigate the requirements for the initiating events to occur or in other words, to point out the causal factors.
Having developed a general idea of the causal factors, the frequencies or probabilities of the hazards (in this example the collision frequency) can be estimated. Often the analyses have a main focus on this estimation.[2]

By defining the vessel collision as a hazard, in this section of the assessment, one should be able to track and sort out the different causation of the mentioned hazard. As for this specific assumption we are discussing, the increased number of the vessel visits is then serves as an important cause of the collision risk. And therefore our assumed values have a direct influence on the cause analysis; the more vessels on the collision path, the higher the frequency of the collision risk.

There is a methodology used in this report for collision frequency calculation [18] and according to the equation 5.1, the direct impact of assumed numbers of vessels on collision frequency can be observed.

For supply vessels the collision frequency is established from historical data instead (background knowledge), achieving a probability of collision per supply vessel visit. The factor P collision per visit of 2.0·10-4 is then included in this historical based probability. (This is also another assumption)[18][20]

F collision = N visits per year · Pcollision per visit · P2 eq.5.1 [20]

A value of P2 being 1.0 has been considered for vessels maneuvering nearby Valemon. Note that all these assigned probabilities are knowledge-based probabilities and therefore cannot be objectively calculated. (another calculation assumption)

5.3.2.5. Consequence Analysis

In the consequence analysis we study the effects the initiating events may have on human beings, the environment and financial assets (or something else that humans value). [2]
In this example, we would like to study the possible consequences of alteration of the assumption in the QRA. The main question is: What would happen if the number of supply visits increase/decrease? What are the possible consequences? To answer this question, we should one more time consider the main hazard identified with this assumption which was the ship collision risk.

Increased Collision frequency

As it has been presumed in this study the increased number of supply visits to Valemon contributes directly to ship collision risk in terms of increasing the value of assigned probability of collision per visit and eventually increasing the collision frequency. (eq. 5.1)

Collision frequency variation seems to be the most common consequence associated with this assumption. According to the report for ship collision risk provided for Valemon, the method for calculating collision frequencies is as follows:

Combining the historical collision frequencies (background knowledge) with number of visits (this assumption) and conditional probabilities of hitting Valemon (knowledge-based probabilities) and jack-up rig, the resulting frequencies can be estimated.[19]
In Table 5.6 the collision frequencies for activity level 6 has been mentioned.

Table 5.6 Collision impairment frequencies for Valemon and jack-up rig, activity level 6 [19]

Visits to Valemon	Collision frequency [per year] Valemon
Approaching supply vessel resulting in high energy impacts	$4.18 \cdot 10^{-5}$
Attending supply vessels resulting in high energy impacts	$1.20 \cdot 10^{-4}$
Attending supply vessels resulting in low energy impacts	$2.74 \cdot 10^{-3}$
Other attending vessels resulting in	$3.57 \cdot 10^{-4}$

Once again, one should note that the values presented in the tables are based on historical data and some other underlying assumptions applied. The noticeable point is they might look quite accurate in a value, but there is high probability they are not correct. The values are accurate in terms of mathematical calculation not in terms of uncertainty description.

It might be useful to refer to this statement:
Probabilities are expressions of uncertainty based on particular background knowledge. There is a great deal of uncertainty in terms of interpretation of this background knowledge and relating it to future events between different individuals. However, for a given background knowledge the probabilities are not uncertain. [6]

Impact to risers, conductors and underside of deck

In addition to structural impairment, vessel collisions can also lead to severe consequences if hydrocarbon risers or other critical equipment is impaired. It has been identified a potential of visiting supply vessels hitting the risers and conductors even though they are located within the jacket. The gas export and condensate export risers are mostly routed inside the jacket, but also routed underneath the cellar deck partly outside the perimeter of the jacket.

In addition to the number of vessels, the size and shape of them are also important in potential consequences.
Many supply vessels have become larger during the last 10 years. The HAZID identified a possible risk for supply vessels to hit underside of topside deck, including risers routed underside the process deck (outside the jacket perimeter), and also possibility of hitting the lifeboats. Figure 5.6 shows an example of such a situation. [19][20]

Figure 5.2 Supply vessels at Statfjord A, [19]

Size of the supply vessels determines the displacement of vessels, which directly has an effect on collision impact energy. Larger displacement gives increased impact energy given a collision, and thereby increased risk.
Of other factors related to supply vessel visits that could influence the collision risk, one might refer to the presence time of supply vessels as well as their arrival speed at Valemon or the jack-up. There are specific assumptions listed with respect to this matter, but we limit our discussion only to the number of supply visits that influences the frequency of collisions.

<u>Oil spill to sea</u>

One of the consequences could be collision to risers and pipelines and therefore considerable oil spill to sea.
In the event of a riser and pipeline leak, the full inventory is assumed released.

<u>Availability of rescue vehicles</u>

An increase in number of supply vessels visits can have a positive consequence as well; should there be an accident on the platform or the rig, since there is always a vessel present it means that there is always a rescue boat (vehicle) present and the chances of survival of personnel is accordingly higher. The supply vessels can also help get people out of the water and they are much safer and bigger than the simple lifeboats on board.

Usually, in consequence analysis relevant for each accident scenario, different methods are used such as modeling, estimation, assigned probabilities, etc. for establishing event trees. During these steps a lot of assumptions and simplification are made that are not included in the main reference list.

As an example, through some calculations and modeling of ship collision risk, appears to be some knowledge-based probabilities conditional assigned for simplification and the modeling of collision risk. These assumptions are only are mentioned implicitly in vessel collision risk calculations. See appendix E. As a recommendation, in our opinion, it would have been an option to include another category to the main categories for stating the *calculation assumptions*.

5.3.2.6. RISK PICTURE

With respect to this section of the TRA, Risk picture of the Valemon has been presented in terms of Personnel risk (PLL and FAR) values as well as Impairment of main Safety Functions.
For the personnel risk we can compare the calculated (and estimated) values of FAR and PLL for different activity levels and compare it with the values presented in the assumptions for the number of supply vessel visits. We could see that the FAR and PLL values are far less in level 6 than those of related to activity level 5 and so is the number of supply visits. We may then coarsely conclude that the number of supply visits might be one of the main FAR contributors.
If we take a look at Figure 4.5, we could trace the consequences of increased vessel visits in vessel collision (main contributor according to the picture), Dropped objects (indirectly and more relevant to the second example) , Blowouts, riser and pipeline leaks, structural failure.(all indirectly).

Impairment Frequencies
As for Impairment frequencies for main load bearing structure, it is also observable that collision impacts of 2.36 *10E-4 per year is considerable compare to other accident scenarios.[20]
In both cases the consequence of vessel collisions due to increased number of vessel appears to have an important impact in all parts of the TRA.

The increased number of supply vessel visits adds up to FAR value and frequency of impairment of safety functions on a facility as shown in table 5.6.

Table 5.7 Impairment frequency of main load bearing structure on Valemon[20]

Activity levels	Impairment frequency [per year]
1,4 and 5	
Passing vessels	$1.63 \cdot 10^{-6}$
Supply vessel collisions	$2.34 \cdot 10^{-4}$
Fishing vessels	Negl
Total	$2.36 \cdot 10^{-4}$
Activity level 2 and 3	
Passing vessels	$4.41 \cdot 10^{-7}$
Supply vessel collisions	$3.83 \cdot 10^{-5}$
Fishing vessels	Negl
Total	$3.87 \cdot 10^{-5}$
Activity level 6	
Passing vessels	$4.41 \cdot 10^{-7}$
Supply vessel collisions	$2.03 \cdot 10^{-5}$
Fishing vessels	Negl
Total	$2.07 \cdot 10^{-5}$

Personnel risk

Personnel risk due to passing vessels and supply vessel collisions, causing total loss of Valemon is presented in the tables below for activity levels 1, 4 and 5, activity levels 2 and 3, and for activity levels 6. For supply vessel collisions, it has been *conservatively assumed* that all personnel are killed. *It is assumed* that for passing vessels, all personnel will have evacuated before impact, i.e. no fatalities, which is a very non-conservative assumption, since 100% evacuation might not be possible at all.[20]Ensuring that the vessels reduce the speed within the safety zone is determining for reducing the consequences associated with collision. [19]

The contribution to personnel risk associated with collisions is determined by whether the installation has been evacuated prior to the impact or not. For collisions with attending vessels it is not likely that personnel have evacuated prior to impact, as the vessels are supposed to be approaching the installation or operate in the vicinity of the installation and a collision may come as a result of some fault in the vicinity of the installation without pre-warning or without leaving sufficient time to muster and evacuate. For these collisions, the personnel risk contribution may be rather high.
That is the reason why even if the speed of the attending/visiting vessels to the facility is not considered to be dangerously high, the fact there is in fact no time for evacuation of the personnel adds up to the other fact these vessels usually travel considerable to/from the facility (adding up to the collision frequency) and then as a result, there would be a considerable potential risk to personnel.[20]

Table 5.8 PLL and FAR due to passing vessel and supply vessel collisions causing total loss of Valemon - activity level 1, 4 and 5 [20]

PLL	Average manning	FAR
$9.7 \cdot 10^{-3}$	41	2.69

Table 5.9 PLL and FAR due to passing vessel and supply vessel collisions causing total loss of Valemon - activity level 2 and 3 [20]

PLL	Average manning	FAR
$1.6 \cdot 10^{-3}$	41	0.44

Table 5.9 PLL and FAR due to passing vessel and supply vessel collisions causing total loss of Valemon - activity level 6

PLL	Average manning	FAR
$2.6 \cdot 10^{-5}$	1.25	0.24

As a result, one could see that based on many assumptions and underlying assumptions the FAR value for activity levels 1,4 and 5 is the highest and has the least value in activity level6 due to platform being NNM. The PLL has also the lowest value in activity level 6, which is acceptable given the discussions above.

5.3.2.7.Risk Acceptance Criteria

We will only comment on this section of the TRA that the effect of increasing number of vessels will cause the FAR values to reach or even be higher than the set acceptance criteria.
According to the Valemon main report RAC mentioned in section 4.4, the criteria for FAR value have been presented. Comparing the results of personnel risk the previous section with the RAC mentioned here, one could see that the FAR values related to supply vessel collision risk is within accepted region 2.96< 10.

5.3.2.8 Uncertainties /Sensitivities

There are uncertainties in the underlying assumptions for vessel impact loads. Such uncertainties may be operational assumptions, like the number of supply vessel visits per year, or whether any other risk reducing measures to prevent collision with the jack-up or the jacket can be used. [17]

Taking into account the uncertainties of the results of the QRA (Expected values, assigned probabilities, assigned numbers and distribution and etc.), it should be noted that the final results of any QRA are not always the ultimate results and therefore cannot be the mere basis for decision-making. In other words, safety related decision-making is risk informed, not risk-based. [2]

A good risk analysis is not complete without a sensitivity analysis part. During the process of risk analysis, one is confronted with a great deal of uncertainties about the input to the system. There have been made a lot of assumptions, and a great deal of subjective and knowledge and experience-based probabilities have been applied to set the basis for the inputs of a QRA in order to fill in the gaps for unknown events and give a baseline to the necessary calculations.
Among all these different inputs with assigned probabilities, distributions or assumed values, some of them are considered more important, i.e. have a greater role in the overall results of risk picture. These variables are called the most sensitive ones. Any small alteration in the value of these variables as an input to the system, results in a great alteration as an output (the risk picture results in this example).

Therefore, sensitivity analysis is required to find the more “important” inputs or assumptions to be better prepared in managing the corresponding uncertainty factor or maybe dedicating a greater value in terms of budgeting and time to that area.

Sensitivity analysis is usually considered to be one of the main parts in economic risk assessment such that the variable with most critical influence on the economic measure would be identified such as oil price so on. However, there are different methods in standard QRAs that sensitivity analyses are being carried out, such as presenting spider diagrams, or radar diagrams or some semi-quantitative criteria we have chosen to comply with in this work. For more information on sensitivity analysis see section 2.6.

5.3.3. General discussion on this Assumption

Underlying Assumptions

Based on table 5.5, one could claim that the number of supply vessel visits per year for each activity level and thereby the supply vessel collision frequency is directly defined based on the 6 activity levels considered for Valemon making the activity level assumption the underlying assumption for this number of visits assumption.
According to the report [17], 6 different activity levels have been defined, but activity levels 1,4 and 5 are dimensioning for supply vessel risk.

In many cases the assumptions itself are interrelated or based on another assumption, we would like to call them an underlying assumption. In this case, for example, the numbers assigned to supply vessel visits are based on the assumption of considering 6 activity levels for the lifetime of Valemon field. This assumption, may later need to be updated when Valemon is actually going to be operated and so it will necessary to update all the assumptions and input data to the whole analysis

The selected assumption presents an estimation of the required number of supply vessel visits to Valemon and to the jack up rig based on different activity levels.
Activity levels 1, 4 and 5 are when jack-up is present due to some drilling, well intervention or workover. Therefore a n average number of 120 vessel visits per year adds up to the number of assumed supply vessel visits to Valemon and that contributes directly to the increased collision frequency and the also takes effect in the total FAR value related to ship collisions in the mentioned activities(discussed in risk picture section). Another effect on the risk picture is that the increased number of vessels would also increase the collision frequency of both Valemon and the jack-up rig.

Background Knowledge

The important thing we would like to emphasize on is as we have observed some calculations (collision frequency, impairment frequency, impact energy…) and therefore estimations are based actually on these assumed numbers and the historical data. If the data is misinterpreted or the assumed numbers are not valid for the case, all the calculations will be flaky and would not be a wise choice to rely on the results. So assumptions might be just some numbers or values, but they serve as a starting point for all the calculations done in the assessment such as the role the initial conditions play when solving an equation of some order. If they are not valid, so will not be the results!

Assumption Presentation

Additionally, one can conclude that this assumption seems to be completely documented and all the relevant parts that may be affected by the assumption are also listed, basis for

background data has been documented and the results are clear in terms of presentation.
One of the recommendations to be considered in the way the assumption has been presented would be the row that is labeled as “lifetime variation”. It might not be crystal clear for the reader which lifetime is the case. If only the lifetime of Valemon is meant, it could have been better had it just been mentioned so.
Another recommendation is to include another group of assumptions, probably labeled as calculation assumptions and in there all assumptions with respect to calculations such as simplifications, safety factors, and correction or compensation factors should be documented.
One unclear item seen in the assumption presentation of number of supply visits is that it has been write `Statoil` as the source. Yet it has not been exactly stated what/who is meant by Statoil. It could be a person, a database, a suggestion and etc. But the source of information should be clear so that the information can be verified if necessary.

Impact on Other Parts of the Analysis

One conclusion is that the number of supply vessel visits contributes directly to the increased frequency of collision and normally increases the risk of ship collision in terms of frequency. On the other hand, the increased number of supply vessels means increased lifting activities and therefore creating more possibilities for risk of dropped objects and so on. The advantage of having more supply vessels in the vicinity of the platform, however, is the increased number of lifeboats present (and possibly escape vessels) in case an emergency evacuation is required.

Based on the discussions above, this assumption of number of supply vessel visits serves as an underlying assumption for vessel collision risk and even indirectly for dropped objects risk and therefore serves as an underlying assumption for the rest of the assumptions as we will observe it in the next examples. In that case the assigned numbers are considered to be important in that case.

Moreover, one should always bear in mind that although assumptions are listed separately with their corresponding areas being defined, it is almost always the case that alteration to an assumption requires some other considerations and modifications to be done with respect to other assumptions. In simple words, all assumptions are related to one another and some of them act as an underlying assumption for the others and the combination of these assumption serves as the whole input to the system and in case of a hazard, any wrong input or any wrong combinations of inputs could have been identified as a cause.

From the argument above, one could realize the importance of clarity and traceability criteria for assumptions presentation that was mentioned in Statoil`s GL 0282.
The close correlation between all the assumptions in a QRA should always be considered in all aspects.

Finally, we would like to present the `importance ranking table` for this assumption based on all the discussions above.

Table 5.10. Importance ranking of the assumption example 1

Assumption Description	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance
Number of supply vessel visits	H	M	H-M

Based on the discussions above and according to criteria mentioned in table 5.1, the degree of uncertainty for this assumption is considered to be high since it is based on strong simplifications (once a week visit) and lack of agreement among experts have been noted as well.

In case of sensitivity, the immediate effect of relatively inconsiderable changes do not seem significant but if the alterations are large enough then the impacts of this assumption n total risk picture is considerable. This is because of this assumption is closely related to other assumptions we will discuss in the following sections. Therefore a medium sensitivity has been assigned for this assumption.

Finally an overall index of H-M has been considered for this assumption based on the arguments we have presented for evaluating this assumption.

5.4 Lifting activities (Example2)

In this section we will discuss the assumption regarding lifting activities to/from supply vessels to Valemon. This example belongs to the first category of assumptions i.e. operational/organizational assumptions. The description of the assumption is presented in table 5.9.

Table 5.11.Assumed Lifting activities are shown in tables below [18]

1.19 Lifting activity to/from supply vessel	
Description	Lifting activity is assumed as shown in table 7
Influence on risk level	Increased lifting activity increases the frequency of dropped objects, and may impact the design load for dropped objects at relevant areas and/or increase the risk from dropped objects.
Relevant RA sections	Appendix G: Dropped objects
Lifetime variation	
Simplification? If yes; influence on risk level	
Information source	
Comment	
Status	

It is also worth taking a look at the total external and internal lift distributions presented in tables 5.13 and 5.14 below. The tables have been presented for two activity levels 5 and 6. Activity level 5 has been assumed to be the dimensioning activity level due to multiple numerous and simultaneous activities (see 5.4.1). Activity level 6, on the other hand, is normally not a manned phase and has been presented for comparison.

<u>**Valemon activity levels and lifting activities**</u>

Activity level 1:

Simultaneous production and drilling. Jack-up drilling rig present (no well intervention operations are included in this activity level).

Activity level 2:

Normal production phase. No jack-up drilling rig. No well intervention operations.

Activity level 3:

Simultaneous production and well interventions. No jack-up drilling rig.

Activity level 4:

Simultaneous drilling, production and wireline well intervention (including jack-up drilling rig)

Activity level 5:

Stand-alone production including all known future modifications. Jack-up drilling rig at times present for Workover.

Activity level 6:

Stand-alone production and normally not manned installation.

We will use activity levels as basis for developing further assumptions. The table 5.12 might give us an insight about the activities going on in different levels and thus justify the assumed and assigned lift numbers for each activity level to some extent.

Table 5.12. Activity levels and different operations

Operation	Activity level 1 1)	Activity level 2 1)	Activity level 3 1)	Activity level 4 1)	Activity level 5	Activity level 6
Drilling operations	2	0	0	2	0	0
Completions	2	0	0	2	0	0
Production wells 3)	17	11	11	17	17	17
Workover	0	0	0	0	2	0
Coiled tubing operations	0	0	2 2)	0	2 2)	0
Wireline operations	0	0	7 2)	7	7 2)	0
Well Clean-up	5	0	0	2	0	0

Table 5.13External and internal lifts for activity level 5

Lifting route	Platform area affected	Drop to sea possible	Annual lifts (1-20 tons)	Annual lifts (> 20 tons)
Vessel to LQ laydown area (Workshop roof)	Utility	Yes	624	0
Vessel to Waste handling area	Utility	Yes	312	0
Laydown area on main deck east of workshop to Laydown area, Cellar/mezz/upper mezz south of process	Utility + laydown south of platform	Yes	260	0
Laydown area on main deck south of workshop to Laydown area on main deck east of workshop	Utility	No	520	0
Vessel to Laydown area on main deck east of workshop (lifts > 8 tons)	Utility	Yes	6	0
Vessel to Laydown area on main deck east of workshop	Utility	Yes	1040	0
Vessel to Laydown area, Cellar/mezz/upper mezz south of process	Laydown south of platform	Yes	104	0
Vessel to Laydown area, Cellar/mezz/upper mezz south of process (lifts > 8 tons)	Laydown south of platform	Yes	4	0
Laydown area on main deck south of workshop to Laydown area, Cellar/mezz/upper mezz south of process	Laydown south of platform + south part of utility and LQ	Yes	260	0
Vessel to Laydown area on main deck south of workshop	Laydown south of platform + utility and LQ	Yes	416	0
Vessel to Tote tanks area	Process	Yes	208	0
Vessel to Well intervention deck (heavy lifts > 8 tons)	Well area	Yes	112	16
Total number of annual lifts			**3866**	**16**

Table 5.14 Internal and External lifts for activity level

Lifting route	Platform area affected	Drop to sea possible	Annual lifts (1-20 tons)	Annual lifts (> 20 tons)
Vessel to LQ laydown area (Workshop roof)	Utility	Yes	52	0
Vessel to Waste handling area	Utility	Yes	52	0
Laydown area on main deck east of workshop to Laydown area, Cellar/mezz/upper mezz south of process	Utility + laydown south of platform	Yes	52	0
Laydown area on main deck south of workshop to Laydown area on main deck east of workshop	Utility	No	156	0
Vessel to Laydown area on main deck east of workshop (lifts > 8 tons)	Utility	Yes	6	0
Vessel to Laydown area on main deck east of workshop	Utility	Yes	52	0
Vessel to Laydown area, Cellar/mezz/upper mezz south of process	Laydown south of platform	Yes	104	0
Vessel to Laydown area, Cellar/mezz/upper mezz south of process (lifts > 8 tons)	Laydown south of platform	Yes	4	0
Laydown area on main deck south of workshop to Laydown area, Cellar/mezz/upper mezz south of process	Laydown south of platform + south part of utility and LQ	Yes	52	0
Vessel to Laydown area on main deck south of workshop	Laydown south of platform + utility and LQ	Yes	52	0
Vessel to Tote tanks area	Process	Yes	208	0
Vessel to Well intervention deck (heavy lifts > 8 tons)	Well area	NA	0	0
Total number of annual lifts			**790**	**0**

Comments on the tables of assumed numbers of lifts:

As one can observe from the tables above, the assumed number of lifts are based on the first example we have discussed; the number of supply vessel visits. This is because normally an increase in the number of vessel visits leads to more lifting activities. The underlying assumption that has not been defined here is that the size of the vessels has been assumed the same. Since the number of lifts could change for vessels of different size due to their various capacity for equipment that are intended to be lifted.

Considering this relation and referring to the assumed number of vessel visits for activity level 5 (52 vessel visits a year per; once a week during a year), we can see that most of the assumed numbers of lifts are basically multiplications of the number 52. That shows the relation between this assumption and the number of vessel visits. Based on the operational activities required for different parts of the platform, different routes have been considered in the assumption and different ratios of 52 have been assigned.

For example if we look one lift route from the vessel to laydown area on main deck east of workshop which has the highest number of lifts in the table in activity level 5 (1040 lifts), it is based on the assumption that there would be 20 lifts per week (20*52 weeks per year). That is 20 lifts of each vessel visiting Valemon is assumed to belong to this part. Finally, almost all numbers in columns have been based on a weekly supply vessel visit, which in our opinion seems a very coarse and rough basis since there are also challenges and uncertainties with assumed number of vessels as we had previously discussed.

In tables 5.13 and 5.14 categorization of lifting routes have been mentioned which is normally a good point for giving a more clear and detailed view for the assessment of lifting activities. Lifts have been categorized as both internal and external that is inside the different layers of the platform itself and from/to the supply vessels to/from the platform respectively. The possibility of drop to sea is also considered (probability not assigned)

Lifts have been divided into to categories according to their mass; over and under 20 tons. This is mainly due to the different hit energy the possible dropped objects could create. But one recommendation would be to narrow the weight of lifting objects further down maybe into 3 categories of 0-10, 10-20 and over 20 in order to provide better and more detailed insights into the consequences the dropped objects would lead to. However, with respect to this assumption we are more interested in the frequency of dropped objects rather than the hit energy they might lead to.

5.4.1General aspects of the assumption

The study of dropped objects analysis for Valemon is mainly based on Valemon activity levels and lifting activity levels. The activity levels could therefore serve as an underlying assumption for lifting activities (the selected assumption here) here.

Dropped Objects

The direct and immediate impact of increase in number of lifts would normally be increased dropped object frequencies. It is usually the case that the more lifting activities and simply the higher number of lifts would eventually result in the increased frequency of dropped objects. The indirect effect of the assumption would be the impact on the design accidental loads for relevant areas due to hitting energies of dropped objects.

In other words, the numerous numbers of lifts usually leads to higher frequencies of dropped objects, which will have other consequences such as the influencing the main load bearing for relevant areas that are subject to numerous lifting activities. The hit energy would be of concern in the design load case.

The number of lifts contributes directly to the calculated frequencies of dropped objects as we see in the formula below:

Frequency of dropped objects = Probability of drop per lift *Number of lifts eq.5.2

However, we should always take into consideration that the increased number of the lifting operations for example up to twice the value assumed does not necessarily double the risk (here frequencies of dropped objects). What we are trying to convey is that the relation is not totally linear. As lifting activities become more in number, there are other interactions between the cranes, vessels, loads, etc that affects the result. Hence, the system does not work as a linear system. The main point is these activities are all related and therefore cannot be considered as independent phenomena. They influence each other.

Underlying Assumptions

There are some underlying assumptions with respect to this lifting assumption that might not be clear enough in the first glance. We could for example trace back and relate estimated number of lifts to the number of supply vessel visits to Valemon presented in example 1. Again there are underlying assumptions such as :

The assumption has been based on the fact that all vessels are of the same size and shape.

Additionally, the number of equipment included in each vessel and the crane capacity per lift has been assumed the same for all lifting activities.

These assumptions are necessary to be mentioned when we use the supply number of vessel visits as the basis for estimating the required number of lifts. (which is the case for Valemon as we will further discuss.)

And in situations like this, when these assumed numbers of lifts serve as building blocks for the rest of calculations for establishing the risk picture for dropped objects, care should be taken for considering the underlying assumptions as well.

Undocumented Assumption

The following assumption regarding dropped objects have been made and it is very important to base the probabilities upon but has not been listed in the main part for assumptions and we have encountered it during the calculation and estimation of dropped objects in an appendix for the main report. In our opinion it should have been stated separately as well. According to Valemon report for dropped objects [25], we have the following assumed data:

For main crane lifts from e.g. supply vessels to the installation a 30% probability of hitting the sea and 70% of hitting the installation is proposed. All internal lifts and from other lifting devices are assumed to hit the installation. The drops distributes among dropped load (90%), falling crane boom (8%) and fall of crane (2%). [19] These are conditional probabilities based on background knowledge of the analyst(s).

It is worth mentioning that out of the assumed 70 percent probability of drops hitting the installation, one might consider drop onto the supply vessel as well, but since the most unwanted consequences happen when dropped loads hitting the platform itself, probably that is why I has not been mentioned.

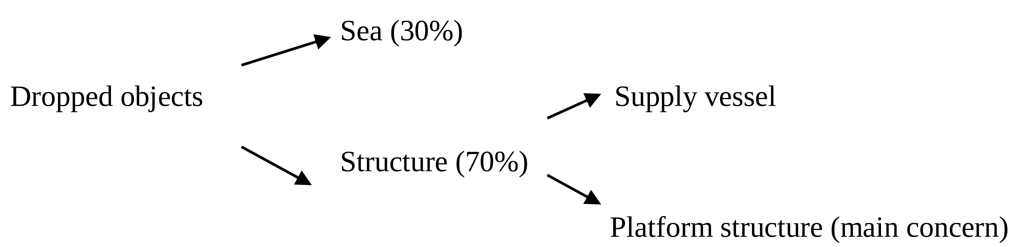


Figure 5.3. Dropped objects falling diagram

Each of the mentioned possible drops could lead to different consequences, which we will later define. But since the main concerned has been assumed to be the drops onto the platform structure, in the tables above, we can see that the affected areas have been listed as `Platform area affected`

In general in analysis of dropped objects, is involved with frequency of dropped objects (probabilities) and consequences. We will discuss this further in the following section.

5.4.2.Integrated Impact of the Assumption on the QRA[25][26]

We will continue our discussion according to the Risk Assessment Process as in the previous example.

5.4.2.1 Framework:

There are several rules, standards and guideline established for marine lifting activities. And therefore, all activities should be within that framework. Relating the number of lifts to/from supply vessel visits, it seems that the assumed numbers are complying with the standards.

5.4.2.2 System Description

In order to help visualize the following assumption (especially for the lifting routes mentioned above), the reader is encouraged to take a look at the main areas on Valemon Platform: (See figure 4.3)

And further to better understand this example of assumed lifting numbers assumption, we would like to introduce briefly lifting facility and lay down areas on Valemon. Based on the Valemon report, we have:

Pedestal crane

The Valemon platform is equipped with one pedestal deck crane, located on the south side of the platform as illustrated in Figure 5.8.

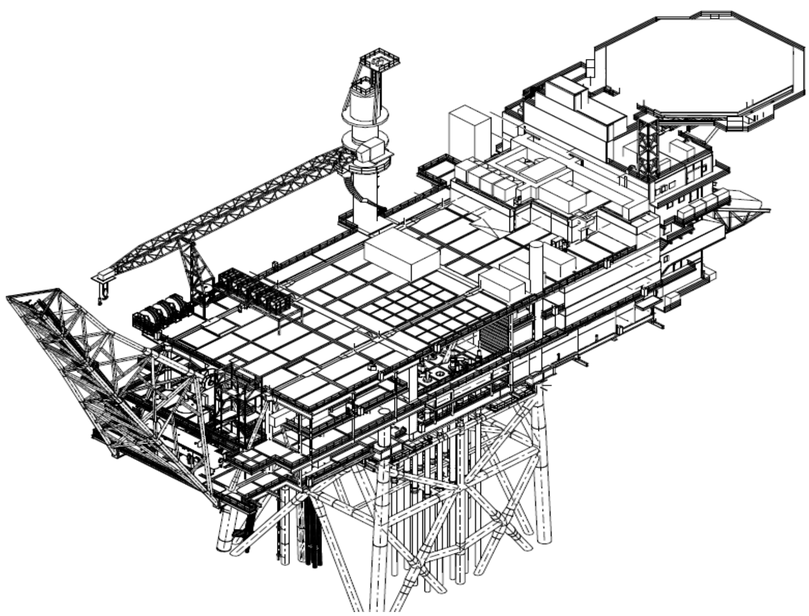


Figure5.4. Valemon with pedestal crane at the south side [25]

This pedestal crane will mostly be used to on/off loading between Valemon and supply vessels.

Laydown areas on Valemon

Dropped object hazard for the Valemon platform is mainly connected to pedestal crane lifts between vessels and laydown areas at platform. The most frequent lifting operations are container and tote tank lifts to/from supply vessels. [26]

Supply vessels will arrive at south side of Valemon and consequently the laydown areas will be at the same side. There are laydown areas for each level on the platform. The roof on the workshop module will also be used as a laydown area, mostly for LQ containers. Waste handling area will be used as laydown area for containers with waste. Figure 5.6 illustrates the laydown areas on Valemon.

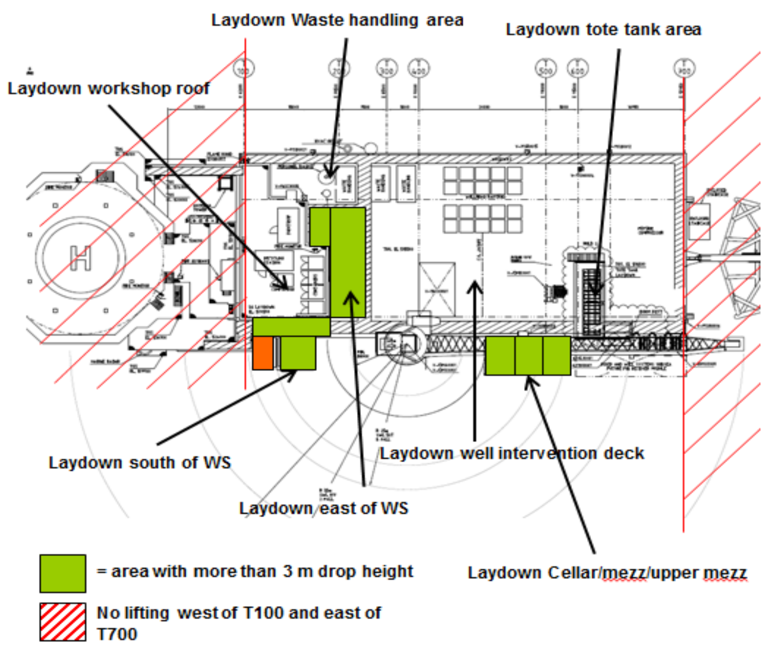


Figure 5.5: Laydown areas on Valemon[25]

Sometimes assumptions are defined according to the system description. Assumptions are actually extra added (not necessarily valid) information to some parts of the system description based on the assessor's background knowledge.

5.4.2.3 HAZID

One of the hazardous events known in the HAZID process of the TRA has been identified as

Dropped objects and swinging loads

- Dropped objects due to material handling with main crane
- Dropped objects from the Jack-up rig

The identified hazards can be the direct result of extensive crane and lifting activities. Therefore, the dropped object risk due to increased and/or improper lifting operations is one of the contributors to risk level and could cause damage to personnel, environmental and asset.

In the Valemon report, potential hazards are evaluated and risks are then further assessed and quantified. This is done through an assessment of the crane activity, which then is combined with historical failure data, local hit probabilities, and an evaluation of the hit consequences in various locations. There are uncertainties with almost all calculations and information provided, therefore, a lot of assumptions have been made and need to be considered.

Other hazards indirectly related to tis assumption could be riser and pipeline leaks in case the dropped object hits the jacket (the risers are routed inside the jacket) and structural failure if the hitting energy of dropped object would be above the deign load bearing of the structure.

5.4.2.5Cause analysis

Having identified dropped objects as the main hazard associated with this assumption, one should then be able to track the causation of this hazard according to the definition of required steps of risk analysis in Norsok z03 [10].The main cause of the Dropped Objects as mentioned before is the increased crane and lifting activities.

Another concern in the cause analysis section of a QRA is to define a frequency for the hazard after having understood all the causation. Without the frequency analysis of the dropped objects, establishing a complete risk picture is not possible.

In the report related to dropped objects for Valemon [25] , the frequencies and impact energy of the dropped objects have been calculated/estimated based on some assumptions. Going through the methodology of the calculations in detail is not the main focus of this thesis work, however these frequency and energy impact of the dropped objects loads are important parts of cause and consequence analysis for this hazard. Therefore, we will briefly introduce the dropped objects frequency estimation as part of this section and the impact energy of the dropped objects in the next part (consequence analysis).

<u>Dropped object frequencies</u>

For calculating the frequency of dropped objects in the Valemon report there has been established two parts:

- Historical failure data and (hard data for establishing drop probabilities)
- Valemon lifting activity (expert judgment for establishing number of the lifts)

*And eventually: Frequency of drop = probability of dropped objects per lift *number of lifts*

Note that the calculated frequency is then divided between the all parts of the installation itself, the supply vessel and the sea. Based on the assumption above drop frequency (probability per lift multiplied by the number of lifts) should be split between fall on the deck (~70%) and into the sea (~30%). (This assumption is also based on previous observations) [26]

Historical failure data is presented based on previous experiences and serves as background knowledge to establish the new frequencies for this report. We can see the results in the tables below:

Table 5.13 Generic dropped objects probabilities for NCS [26]

Load	Lifting device	Drop probability per lift
Moderate (1-20 tons)	Main crane	1.3E-05
	Drill derrick	1.2E-05
	Other	2.3E-05
Heavy (>20 tons)	Main crane	2.0E-05
	Drill derrick	3.8E-03
	Other	3.6E-05

Table 5.14 Drop probabilities for routine lifts with platform cranes (historical data)[26]

Type of load	Weight of lifted object	Drop probability per lift
Load fall	Moderate (1-20 tons)	1,17E-05
Load fall	Heavy (> 20 tons)	1,80E-05
Crane boom fall	Moderate (1-20 tons)	1,04E-06
Crane boom fall	Heavy (> 20 tons)	1,60E-06
Fall of crane	Moderate (1-20 tons)	2,60E-07
Fall of crane	Heavy (> 20 tons)	4,00E-07

This historical data serve as basis for assigning probabilities for dropped objects probabilities per lift. . And as we know there is a great deal of uncertainty related to application of this data in order to establish new data. Therefore some assumptions have been made that are documented and are very critical when it comes to frequency calculations. One of the assumptions regarding lift frequencies are dividing the lifts into two categories of “heavy” and “moderate” which seems a bit coarse, in our opinion.

Assumed number of lifts is another parameter important for the formula above. We have discussed this part in section 5.4.1 considering the tables presented for the number of lifts.

Finally, combining the historical dropped object frequencies with assumed number of lifts and subjective and conditional probabilities of hitting different areas, the resulting newly established frequencies would then be estimated.

Based on the equation above for calculating the frequency of dropped objects, one could observe the direct impact of number of lifts in the frequency analysis of the dropped objects for Valemon.

5.4.2.6Consequence analysis

The consequences of dropped objects are mainly depending on the impact energy of the falling loads. And in determining the impact energy of a fall, the drop height and terminal velocity are major factors. Dropped objects have potential of personnel injuries, material damage and hydrocarbon releases. In the worst-case scenario dropped objects may threaten main safety functions in the event of e.g. an ignited hydrocarbon release. Also Dropped objects to sea may hit the jacket, risers or the subsea pipelines and lead to HC leaks.

Some common consequences of dropped objects with their conditional probabilities are listed below. One should remember that the assigned probabilities are knowledge-based (based on hard historical data and/or expert judgments) and therefore the existence of uncertainty in them is undeniable. One should note that regarding assigning the following conditional probabilities, the background knowledge is usually not mentioned and simply some new assumptions have been made. We believe it is a wiser choice to list these assumptions in the relevant part as well as their information source they are established upon.

Damage on structures (asset risk)

According to the data dossier for Valemon [], for main crane lifts from e.g. supply vessels to the installation a 50% probability of hitting the sea and 50% of hitting the installation is proposed. All internal lifts and from other lifting devices are assumed to hit the installation. The probability of severe material damage could be assumed to be about 2%.[]

Hydrocarbon releases (environmental risk)

Based on previous data, the probability of a hydrocarbon release given a dropped object may be estimated to be between 1.5% and 2%. This low figure is probably due to restrictions such as no lifting over hydrocarbon equipment. In the event of a hit of a load above the design load on a deck, the probability of a hydrocarbon leak and immediate ignition may be high.[25]

Injuries to Personnel

The injuries/fatalities the dropped objects may cause to personnel should be considered as well. We have mentioned the FAR results in the risk picture section**.**

The above suggested probabilities are based on observed data on NCS and yet serve the basis for further calculations in the rest of the report. In other words, the past experiences and probabilities derived from them, serves as background knowledge for assigning new probabilities to future uncertain events(here dropped objects). There is uncertainty in applying this background knowledge and that has to be mentioned and considered.

There are several scenarios that where the object being carried falls. In this report for example three scenarios have been considered:[26]

- Topside : main deck above process, utility area, well intervention deck
- Crane boom and pedestal fall, swinging objects
- Dropped objects into the sea

For each of these scenarios there has been a different calculations of frequency and impact energy and as a result different consequences with respect to risk to personnel, asset and environment. As we have mentioned before, the main approach for consequence analysis of dropped objects would be to calculate the hit energy of dropped objects. And the calculation of impact energy requires different modeling and calculations for each scenario. One limitation to modeling methods according to Vinnem []is that available models for the assessment of dropped objects hazards are generally too simplistic in the sense that differences in operational procedures and crane protection are not usually taken into consideration.

Eventually, each scenario would then come up with different consequences and eventually different impacts on risk picture.

As we can conclude the number of lifts does not affect the impact energy directly. It however, has great influence of frequency and the therefore affects the risk picture by influencing the frequency of the hazard (dropped objects).

5.4.2. 7 Risk Picture and Risk Acceptance criteria

One of the very important features of a risk analysis is presenting the risk picture and we would like to present how the assumption of number of lifting activities would influence the total risk picture for Valemon

With respect to the impacts of the assumption on the risk picture, we are concerned in the following three areas:

- Personnel Risk
- Impairment frequency of main safety functions
- Risk to environment , mainly oil spill (frequency and expected amount)

Usually an evaluation is also included with respect to the set RAC for the project. Referring to chapter 4 where we have introduced the RAC for Valemon, we recall:[17]

The probability of loss of defined main safety functions shall be estimated per year, per safety function and per accident category, as given in Norsok Z-013, edition 3, annex B. Accidental events within each of these categories having combined probability ≥ 10-4 per year shall be considered dimensioning. And,

The mean individual risk, expressed by the fatal accident rate (FAR) – must meet the criteria FAR < 10.[17][10]

The risk picture in the Valemon report is presented by means of:

- Impairment of the main safety functions
  - Impairment of prevent of escalation
  - Impairment of main load bearing structures
  - Impairment of rooms of significance to combating accidental events
  - Impairment of safe area o Impairment of escape

- Personnel risk in terms of FAR
- Material damage
- Oil spill to the environment

And we would like to know about the impacts the assumption on these mentioned areas.

Impairment frequency

All dropped objects exceeding the dimensioning loads are assumed to cause impairment/penetration of the deck and hydrocarbon leaks in the wellhead area due to accident escalation. For Waste handling area, Workshop roof and Laydown area east of workshop impairment/penetration of the deck could result in fatality amongst employees working underneath the exposed area. However, the probability for penetration of process area is negligible all the time we only have lifts of tote tanks with maximum weight of 6 tons. The frequency of crane boom fall is higher than 1.0E-04 for all the above mentioned areas. But is assumed that main deck is dimensioned for crane boom fall. [25][26]

Comment

Based on the discussions provided, one could observe that this assumption in number of directly affects the impairment frequency due to the dropped objects consequences and from this perspective is considered critical. As we can see, there are some assumptions stated about dimensioning and design during presenting the risk picture.

Personnel Risk

The total FAR value corresponding to dropped objects fatalities, according to figure 4… has been estimated to be 0.13 out of the total FAR of 6.73 for Valemon in activity level 5.

We will not go through the details of calculations of FAR value for this example. Yet, it should be noted that for considering the risk to personnel it is important to notice where the dropped objects actually fall and cause further consequences and escalation. And the risk to personnel then would be depending on the normal manning level of that area.

In addition, one could consider two different outcomes of a falling object event affecting the potential loss of life (PLL): fatality due to ignition of released hydrocarbon and fatality due to energy impact from falling object. It is assumed that no employees are working beneath hanging load. Fatality due to energy impact from dropped object is only expected to be an issue in wellhead if the falling load exceeds DAL.[25]

Due to some criticalities of risk to personnel, lifting over some areas is then prohibited. In conclusion the increased number of lifts could affect the PLL and FAR values in some special areas. Manning level is very important for this mater. We will discuss this further in example number 5.

Material damage

Another impact of the increased number of lifting could be the damage to material (asset). According to table 5.10, there are 3866 annually lifts < 20 tons and 16 lifts >20 tons for activity level 5. All lifts > 20 tons and 3346 lifts < 20 tons have the possibility to be dropped to sea. Table 5.11 show the annually lifts applicable for activity level 6. Of 790 lifts, 634 have the possibility to be dropped to sea. The frequencies of damage to asset has been estimated and presented in table 5.14 below.[25]

Table 5.15: Material damage frequencies due to dropped objects[25]

Event	Annual frequency	
	Activity level 5	Activity level 6
Dropped objects < 20 tons on topside	3.17E-02	6.47E-03
Dropped objects > 20 tons on topside	2.02E-04	NA
Dropped object from Valemon to sea hitting pipeline	6.57E-05	1.24E-05*

Oil spill to the environment

Oil spill as an ultimate result of dropped objects will mainly be due to falls into the sea hitting the condensate export pipeline. The impact on risers compared to this one is negligible since risers are protected inside the jacket.[26]

And the number of lifts in the relevant areas with a possibility of drop into the sea could increase the frequency of oil spill and depending on where the fall is actually taking place the impact energy influences the estimated leak rate and consequently amount of oil spill.

5.4.3. Final remarks and discussions on this assumption

The main hazard identified with the numerous lifting activities is the risk of dropped objects. We have reviewed the cause and consequences for dropped objects and observed that lifting heights and lifting routes will together with lifting activity have great impact of the outcome of dropped object risk assessment.

The important issue to be acknowledged here is that in order to be able to perform an efficient analysis on dropped objects, a great deal of inputs are necessary and they have all been based and assumed on historical data, similar past experiences and expert judgments. So the assumed lifting numbers presented in tables 5.13 and 5.14 are, in a way, considered as building blocks of all the calculations made regarding dropped objects to get a clearer picture of risk of dropped objects. Therefore it is very important that the background knowledge applied for establishing these assumptions be mentioned and valid to the possible extent.

To comment on the tables presenting the assumption one could claim that they appear to be very comprehensive and informative. It has been wise to mention the affected area on the platform in addition to probability to sea drop. But to an expert on lifting activities, it might lack a great deal of necessary information and underlying assumptions. As an example, one could state that the size(shape) of the objects being lifted have not been mentioned though they are considered an important factor when considering the consequences of dropped objects. Also, the weight of load contributes directly to the impact energy and the impact energy is considered dimensioning for design accidental loads. Therefore it would have been better to narrow the division range down into more detailed and smaller intervals.

Conclusions for example 2

In conclusion one should pay attention to the following. The assumed numbers should not be deceiving. We should consider the underlying assumption. Number of visits of supply vessels, number of equipment to be lifted, the size of the vessels, different areas of approach and lifting routes should also be considered.

The numbers are based on some uncertain knowledge and could change during operation due to alterations to some underlying assumptions.

Therefore it is essential that we do not rely on the mere numbers and calculations. One should be able to see beyond just the assumed numbers .The emphasis has to be on the source and background of the assumption.

And eventually, the relation between assumptions has been brought into attention. As we have observed the number of supply vessel visits are in close relation with the assumed numbers of lifting. So, it is very important to bear in mind that if one of the assumptions is proved to be not valid, the other one is also influenced and the whole results of risk picture might be compromised.

Finally, we would like to present the importance-ranking table for this assumption based on all the discussions above.

Table 5.16. Importance ranking for assumption in example number 2 (lifting activities)

Assumption Description	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance
Lifting activity to/from supply vessel	M	H	M-H

Based on the discussions above and according to criteria mentioned in table 5.1, the degree of uncertainty for this assumption is considered to be moderate since the phenomena is well understood but the models used are considered simple/crude for calculating lifting risk especially for modeling drops to see. (see appendix G)
However, some reliable historical data are available and have been used as generic dropped objects frequencies. This assumption is mostly based on the previous one presented in example 1.

With respect to the degree of sensitivity, we have assigned a high score to this assumption since any minor change in lifting activities are reflected directly in risk of dropped objects and hence increasing fatality and impairment risk as discussed in sections above.

Finally an overall index of M-H has been considered for this assumption based on the arguments we have presented for evaluating this assumption and its total impacts on other parts of the analysis.

5.5. Collision Resistance of Jack-up rig (Example 3)

In this part, we will evaluate an example of assumptions from the design category.

Table 5.17. Assumed collision resistance of jack-up rig [18]

2.12	Collision resistance of jack-up rig legs
Description	Collision impact capacity for the jack-up rig legs has been checked for 14 MJ
Influence on risk level	A ship collision exceeding the design load for jack-up legs is assumed to cause jack-up to fall over Valemon and thereby impairment of the main safety function "main load bearing structure" for Valemon
Relevant RA sections	Ship collisions
Lifetime variation	
Simplification? If yes; influence on risk level	
Information source	
Comment	
Status	

5.5.1 General notes about the assumption

According to the Valemon report [17], structural failure can result from overload of the structure (structure exposed to loads exceeding its design loads). Such accident loads could be due to for example:

Collision impact
Fire exposure
Gas explosion loads
Sea bed cratering due to blowout outside casing
Extreme waves
Extreme wind

The main concern for this example is the structural failure due to vessel collision impacts. One of the underlying assumptions would then be the increased number of vessel visits (example1) and the shape and size of the vessels that might lead to different frequency and impact energy of collision.

Generally structural response studies cover a wide variety of studies which are aimed at predicting the performance of the structural elements when subjected to accidental loads arising from accidental events such as vessel collision, explosion, extreme weather etc.[21]

This example of assumptions varies in nature from the first two examples mentioned before in sections 5.3 and 5.4 since it is selected from the design category of assumptions of Valemon. The design load for jack-up rig legs which is the main focus of this example, is directly related to vessel collision study that we have discussed in example 1. However, in the first example, we were mainly concerned with the frequency of supply vessel visits as we were discussing the impact of increased numbers of supply vessel visits to both Valemon and the jack-up rig. In this example, on the other hand, the emphasis should be directed to the impact energy for vessel collisions to the rig. And this is very important because this impact energy is considered to be an input to DAL for the report.

Note that the ship collision risk itself is based on a set of operational assumptions. For example an increase of number of supply vessel visits to Valemon may result in unacceptable risk with the current design loads. (example1)

According to the assumption description the design criteria for the rig legs is to stand in 14 MJ. [18]However, the assigned probabilities, expected values or some assigned values based on past experience and background knowledge are just epistemic-based expressions of uncertainty and conceal a great deal of uncertainty within themselves. Hence, we should look beyond these numbers and evaluate the uncertainties that may cause deviation from this assumption.

5.5.2. Integrated effect of the assumption

In this section we will discuss the relation of this assumption with different areas of QRA. Since this assumption is about design issues, the approach would be to focus on supply vessel potential collision impact energies.

5.5.2.1 Framework and RAC

According to the framework and set standards, structures should be able to maintain a certain amount of impact loads called the main load bearing (design load)for structures. According to the NORSOK standards z013 [10], the RAC for impairment frequency of main load bearing structures has been set to be less than 1E-4 per year [17].

With respect to RAC, however, the assumption needs to be modified and it has been shown that the design load of 14MJ is not sufficient for maintaining the structural integrity of the jack-up and it has been provided the calculation for modifying the assumed design load to be 45 MJ so that the impairment frequency of jack-up legs would meet the RAC (that is the impairment frequency of less than10-4 per year)

Referring to risk results of Valemon report, [17], is has been documented that :

The frequency of "impairment of main load bearing structure" due to ship collisions onto the jack-up rig has been calculated, and it becomes $2.36 \cdot 10^{-4}$ per year. This is based on that the jack-up legs have been checked to withstand a vessel impact of 14 MJ, according to input from Statoil. As a consequence of the jack-up rig being impaired by ship collisions, Valemon will also be affected. Hence, the risk acceptance criterion "impairment of main load bearing structure" is not met for Valemon with a design impact load of 14 MJ for the jack-up rig.

A short sensitivity on ship impact load and frequencies, shows that in order to meet the risk acceptance criterion "impairment of main load bearing structure" for Valemon, the design load for the jack-up needs to be set to 45 MJ .[20]

We can easily observe that the criteria for jack-up legs impairment has not been met due to vessel collision impact energy.

That is an important thing to mention about the documentation of the assumption. If one from a superficial observation decides to design the legs for 14 MJ as mentioned in the assumption description, due to other assumptions and calculations of vessel impact energy, (which is outside the scope of this work) the structure would collapse causing major destruction to both the rig and the Valemon.

5.5.2.2 HAZID

Reviewing the hazard identification according to FEED phase of the Valemon report, some related hazard identified related to these design assumptions might be:

- Collision risk
- Structural failure
- Jack-up capsize

The first hazard mainly serves as causation for this assumption as we have mentioned in 5.5.1. And the rest are considered consequences of not complying with design load for the rig. Nonetheless, the main theme for evaluating this assumption lies in the impact energy of supply vessels visiting the jack-up rig.

5.5.2.3 Cause Analysis

The main cause for impairment of jack up rig seems to be the collision between the supply vessels and the rig. The increased number of visits, would affect the impairment frequency that we had discussed in example one. And the calculation of Impact energy defines the required design load for the jack-up legs.

Therefore, here, we briefly mention the calculation method for impact energy of vessel collisions.

The basic equation for evaluating total impact energy due to a vessel collision is s follows []

$$E = 0.5 \cdot m \cdot (1 + dms) \cdot v^2$$ equation 5.3

where

E = total impact energy [MJ]

m = vessel displacement [tonnes]

dms = added mass (0.1 for bow/stern, 0.4 for sideways impact)

v = velocity at impact [m/s]

The total impact energy is distributed between collision damage of the installation and remaining kinetic energy for the impacting vessel (for an example where the supply vessel suffered large deformations). [20]

Ensuring that the vessels reduce the speed within the safety zone is determining for reducing the consequences associated with collision. However, collisions that exceed the design accidental load for the jack-up rig legs are considered to have the potential to cause impairment of main load bearing structure.

According to the equation 5.3, one could conclude that the size of the vessel is of great influence for calculating the impact energy which is dimensioning for the design load of the jack-up legs in this example and therefore needs to be acknowledged in our opinion.

5.5.2.4Consequence Analysis

The focus for this section would be on design collision loads.

The consequences of structural failure being the jack-up rig for this example, besides the material damage to itself, is that it might fall on the Valemon structure and cause impairment of safety functions and escape ways. It could also lead to damaging critical areas such as the process areas and eventually cause fire or explosions. In addition, it is a threat to personnel risk as well. In the worst case scenario, the whole structural impairment would be the loss of main support structure (Valemon) and it is a major risk resulting in damaging all the safety functions and eventually capsizing the platform. Some experienced jack-up structural failure has been shown in table 5.18.

Table 5.18.Experienced jack up failures [21]

Date	Description	Illustration
2003; September	Rig: Parker 14-J Location: GOM Break failure during jacking operation caused a jack-up structural failure	
2000; April	Rig: Al Mariyah Location: Saudi Arabia During cantilever skidding operations, the main deck of the jack-up collapsed, causing the cantilever deck to tilt over. The rig floor fell on to the platform below, damaging the helideck and topside module, whilst the derrick fell into the sea and sank.	
1996; November	Rig: Maersk Victory Location: South Australia Cause: Collapse due to punch through. During pre-loading (with about 2m air gap), the rig suddenly listed down to starboard.	

According to the Valemon report [17], as one ultimate consequence it has been stated:

Failure of jack-up leg is assumed to result in structural impairment of the Valemon Platform. 2 out of 3 legs will give 100% impairment, whereas 1 out of 3 will give 50% impairment.

The above explanation is also considered another assumption which has not been documented in the main assumptions list. This could be important in clarifying what is meant by “impairment” of the rig in the report. This assumption then serves as an underlying analytical assumption.

5.5.2.5 Risk Picture

For evaluating the relation between the design assumptions, we are interested in its possible impact on the impairment frequencies, personnel, asset and environmental risk.

Impairment of main safety functions

Vessel-structure collisions may occur from different types of vessels with various frequencies of occurrence and consequence potential. The risk contributions from each type of vessels are summed up and presented in the following and represent the total risk ship collision risk.

Vessel collisions on the jacket or the jack-up legs above the design loads are estimated to give impairment of main load bearing structure. In such cases, it is not considered of interest to at the same time sum up impairment of the other main safety functions, since the whole installation is lost in such cases.

The total impairment frequency of main load bearing structure on Valemon due to ship collisions for the different activity levels has been presented in the table 5.19.

Table 5.19 Impairment frequency of main load bearing structure on Valemon[20]

Activity levels	Impairment frequency [per year]
1,4 and 5	
Passing vessels	$1.63 \cdot 10^{-6}$
Supply vessel collisions	$2.34 \cdot 10^{-4}$
Fishing vessels	Negl
Total	$2.36 \cdot 10^{-4}$
Activity level 2 and 3	
Passing vessels	$4.41 \cdot 10^{-7}$
Supply vessel collisions	$3.83 \cdot 10^{-5}$
Fishing vessels	Negl
Total	$3.87 \cdot 10^{-5}$
Activity level 6	
Passing vessels	$4.41 \cdot 10^{-7}$
Supply vessel collisions	$2.03 \cdot 10^{-5}$
Fishing vessels	Negl

Personnel risk

Personnel risk due to passing vessels and supply vessel collisions, causing total loss of Valemon is presented in the tables below for activity levels 1, 4 and 5, activity levels 2 and 3, and for activity levels 6 separately.

According to Valemon report, for supply vessel collisions, it has been conservatively assumed that all personnel are killed. It is assumed that for passing vessels, all personnel will have evacuated before impact, i.e. no fatalities. [20]

One should note that again this is an assumption not listed anywhere else but has been implied indirectly in an appendix. This is based on degree of belief of the analyst(s) and is therefore necessary to be documented for other reviewers in order to shed light on the calculations of fatalities.

Table 5.20. PLL and FAR due to passing vessel and supply vessel collisions causing total loss of Valemon - activity level 1, 4 and 5[20]

PLL	Average manning	FAR
$1.6 \cdot 10^{-3}$	41	0.44

Table 5.21. PLL and FAR due to passing vessel and supply vessel collisions causing total loss of Valemon - activity level 6 [20]

PLL	Average manning	FAR
$2.6 \cdot 10^{-5}$	1.25	0.24

Calculation of FAR value Valemon with jack-up present [20][19][27]

According to the previous data and calculations provided in data dossier for Valemon [19] a frequency of structural failure of 8.9·10-5 per year has been documented for jack up rig. *Conservatively assuming* that all structural failures of the jack-up rig also leads to collapse of Valemon, the impairment of main structure due to structural failure becomes:

1·10-5 + 8.9·10-5 = 9.9 ·10-5 per year

The FAR value is quantified *assuming 50% survivability of personnel*:

$$FAR = \frac{1.0 \cdot 10^{-5}}{365 \cdot 24} \cdot 10^{8} \cdot 0.5 = 0.06$$

The underlying assumptions need to be noticed since they play a great role in defining the FAR values. Without knowing these underlying assumptions, the results are not just more than some numbers.

A summary of the quantified risk for each activity level (Valemon operational phase) is presented in Table 5.22.

Table 5.22: Risk summary – structural failures [20]

	Activity level 1 and 4: Simultaneous production and drilling phase, jack-up rig present	Activity level 2,3,5 and 6: Normal production phase (Valemon as a stand-alone)
Structural failures – Impairment of main load bearing structures	9.9E-05	1.0E-05
Structural failures – Personnel risk presented as FAR	0.57	0.06

According to figure 4.5(Valemon total FAR contributors), the FAR value contributor due to structural failure to the total FAR is considered the third major contributor with the value of 0.57 out of the total value of 6.73.

The value complies with the RAC for Valemon but the effect of underlying assumption on this value is not negligible due to possible major consequence of structural failure and capsizing which will lead to loss of main support structure and conservatively loss of all personnel on board.

5.5.2.6 Uncertainties

Impairment of main load bearing structure of Valemon is above the criterion of 1·10-4 per year. This is mainly due to supply vessel collisions onto the jack-up rig. The jack-up legs can withstand a collision impact of 14 MJ, and the impairment of main load bearing structure due to impact load is not met. If the jack-up shows to withstand more than 45 MJ (calculations are outside the scope of this work), the risk acceptance criterion can be met. [20] [21] However, there are several underlying assumptions for the vessel collision risk which is important to follow up further, there are uncertainties in the underlying assumptions for vessel impact loads. Such uncertainties may be operational assumptions, like the number of supply vessel visits per year, or whether any other risk reducing measures to prevent collision with the jack-up or the jacket can be used.

5.5.3 Final Remarks and discussion for this example

- An important point to be considered in this assumption is again the relation and interdependency of assumptions to each other. If this assumption were to be evaluated independently, would have never been proven to be invalid. However, when one considers the underlying assumptions made for vessel collisions, a conclusion is reached that in order to comply with the RAC the assumption has to be modified. As for this example, for instance, the dependency between the underlying assumption, in number of supply vessel visits to jack-up has been considered and due to consideration of that assumption, and with a sensitivity analysis of impact energies and frequencies which is outside the scope of this work, it has been proven hat a 45 MJ resistance for jack-up legs is required rather than coarse assumed value of 14 MJ resistance.

- **A word on design**: Finally, another point that is also worth mentioning here, when evaluating the design basis for structures, some information on design criteria is required. Normally, after several tests have been applied and the necessary experiments have been done, normally a safety factor is also considered for ensuring to be on the safe side. It is used as a measure to fill in the gap of what is calculated and expected and what really happens in reality; but this safety factor is also subjected to uncertainties and there are usually standard values defined for it according to which area of the design is being dealt with.

The application of safety factor is rather conservative in most cases but it has been considered necessary for design issues since there are always uncertainties with the tests and in other inputs for calculating the design loads. This safety factor would work as a compensation for some of the unnoticed uncertainties. However, there have been arguments about the values of these safety factors for each design category and therefore there is still a degree of uncertainty in the assignment of the value in itself. But we are not intending to go further in this matter for this work.

For more information about design loads and limit states see APP.F.

Finally, we would like to present the importance table for this assumption based on all the discussions above.

Table 5.23. Importance ranking of example 3, Collision resistance of jack-up legs

Assumption Description	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance
Collision resistance of jack-up rig legs	H	H	H

Based on the discussions above and according to criteria mentioned in table 5.1, the degree of uncertainty for this assumption is considered to be high since models for design are believed to give poor predictions. According to the report the assumed 14MJ impact capacity has been proved to be coarsely and carelessly calculated and other interactions have been neglected and therefore test results of sensitivity analysis in the report documented that the capacity should be improved to 45 MJ for design basis. Additionally there has been a lack of agreement between the experts.

With respect to the degree of sensitivity, also a high score has been assigned to this assumption since a small deviation from the base case could lead to excessing design load for jack-up legs could then cause jack-up to fall over Valemon and hereby impairment of the main safety functions for Valemon.

Finally an overall index of H has been considered for this assumption based on the arguments we have presented for evaluating this assumption and its total impacts on other parts of the analysis. This assumption is considered to be critical in design criteria.

5.6. Equipment Count (Example 4)

This assumption falls into the analytical category of the assumptions and hence, differs in nature with the three previously discussed examples.

Table 5.24. Assumption description for equipment count [18]

3.19 Equipment count	
Description	Equipment count has been made on P&IDs. Main units, instruments and valves found are considered good estimates. Flanges and pipe lengths are quite uncertain and the following assumptions have therefore been made:
	Most valves are assumed flanged. Number of flanges counted has been multiplied by 1.5 to assure conservatism since flanged connections on piping are not seen on P&IDs. Length of main process piping is solely estimated based on equipment plot plans. Length of small bore piping is set twice number of flanges. E.g. if there are 3 off 2" flanges, it is assumes 6 meters of 2" piping.
Influence on risk level	Flanges and pipe lengths contribute significantly on leak risk and thus on all risk measures.
Relevant RA sections	Process accidents
Lifetime variation	Minor, but when equipment in changed out, additional flanges are often introduced.
Simplification? If yes; influence on risk level	Yes. The assumptions made are believed to be on the conservative side.
Information source	P&IDs
Comment	
Status	

5.6.1. General Description of the assumption

The main importance of equipment count in QRAs is the hazard it is associated with; leak frequencies. Flawed equipment especially main process equipment could be a source a leakage in the system. And normally, the more equipment in the system, the greater will be the leak frequencies simply because of the greater number of sources of errors. That is the reason why critical equipment contributing to leak frequency should be counted and documented. Now, the main question would be: how to count the equipment in a normally complex system like an offshore platform including process units? Is it possible for the personnel to actually go into the process unit for example and count the equipment one by one? Or are there other methods that have been applied in current industry?

We are going to discuss about the method used in the Valemon report for counting equipment and evaluating the pros and cons of it.

According to the description of the assumption in this section, the Valemon equipment count has been based on P&IDs. A P&ID consists of various elements. Some special equipment contributes more to leak frequencies and the emphasis has been made on establishing an acceptable method for their count. According to the Lillleaker TRA report in equipment count for Valemon[24]:

Main units, instruments and valves found are considered good estimates (for equipment count). Flanges and pipe lengths are quite uncertain and the following assumptions have therefore been made:

Most valves are assumed flanged. Number of flanges counted has been multiplied by1.5 (to assure conservatism since flanged connections on piping are not seen on P&IDs. Also they are considered as sources of leaks.

Length of main process piping is solely estimated based on equipment plot plans.

Length of small bore piping is set twice number of flanges. E.g. if there are 3 off 2" flanges, it is assumes 6 meters of 2" piping.

As one can see, there are several assumptions mentioned above such as introducing a coefficient of 1.5 for total calculation of number of flanges. This coefficient (or a compensation factor if we may call it that), has been made for the calculations to be on the safe side. The assumption has been claimed to be conservative meaning normally the calculated result is higher than what the number of flanges usually are.

One might ask why a factor of 2 for example has not been chosen. Well, this goes back to the discussions we have made in chapter2; this value has been made according to some assessor(s) ` background knowledge on similar situations. Another more conservative analyst for example could have simply chosen a factor of 2. Any number assigned would in any case include epistemic-based uncertainties and there is no reference for these numbers but the background knowledge. Another important issue would then be how any possible alteration of these assumed numbers would affect the leak frequency and the ultimate risk picture in the end.

5.6.2.Integrated Effect

In this section, we are going to discuss the relation of this assumption example with the rest of the system.

5.6.2.1 HAZID

One of the very important hazards identified in any oil/gas platform including process facilities is the risk of process leaks or generally leaks from any source. Hydrocarbon releases (HCR) may occur from the process, the wells and from the risers and pipelines. There could be different reasons for a release and the release could also take place at different locations. 'This assumption of equipment lift is mainly affecting the process risk which is limited to leaks occurring inside the platform modules during normal operation.

The above assumption has a very direct effect on leak risk in terms of frequencies as increased number of equipment (or increased length in pipelines etc.) could normally initiate more leak possibilities. The important case here is not to misjudge this effect as being totally linear; as if the twice the number of equipment or length of a pipe, the twice greater the risk (frequency) of the leak rates would be.

Once again we should bear in mind, that in all selected examples, we are not dealing with a linear and independent system as there are many dynamic and integrated parts in the system interacting with each other. The whole system is integrated and changing each and every part of the system could result in other interactions.

This interaction should to some extent be noticed and discerned by the analyst and that is why one of the requirements for the way assumptions in a QRA should be presented (according to Statoil guideline GL0282)[11] was mentioned to be traceability of the assumption to its possible sources and areas of influence.

5.6.2.2Cause (and frequency) Analysis

The number of possible leak sources per process unit need to be identified in order to calculate the annual leak frequencies. These leak sources include flanges, valves, instruments, pumps and other process equipment like pressure vessels and heat exchangers. The identification of these sources is mainly done by using the P&IDs. [23][24]

The normal method for establishing leak frequencies is to multiply the probability of leak per equipment by the corresponding number of equipment.

As one can infer from the mentioned method, there are uncertainties with both the assigned and conditional (on background knowledge) probabilities of leak for each equipment and the number of equipment themselves.

For this selected example of equipment count, the focus is on the number of flanges and the pipe lengths since they seem to be subject to large uncertainties and need to be estimated or assumed. The basis for the assumption or the underlying assumption – in other words- is the P&ID of the platform. First a (safety) factor of 1.5 has been assumed to be multiplied by the counted flanges. That seems reasonable since there are great amount of joints on piping which are flanged and yet are quite indiscernible from a P&ID plot. It is not a fixed and proven number, it is just based on the background knowledge of the assessor, and however, the number might be less or even more up to twice the counted number depending on different case.

It is therefore quite necessary to state which assumption has been preferred and applied in calculating and presenting risk for leak frequencies. Since the number of flanges is associated directly to leak frequencies and could eventually cause irreversible severe damages.

The second assumption is the length of piping in the system. In this report piping has been divided into the main process piping which is merely estimated on equipment plot plans and small bore pipes which is assumed to be twice the number of estimated flanges.[24] Therefore there is a direct relation to the assumed number of flanges and the small bore pipings; the dedicated length considered between each flange is hereby assumed to be 2 meters (one meter from each side). (Note that the diameter should be the same of course for the pipe and the required flanges along the flow path).

This seems to be a reasonable assumption assuring that there is at least a meter distance from each side of the flange to maintain some distance between the equipment. But what is this assumption based upon? Again the answer is the standard design requirements and of course the knowledge of the assessor in this matter.

In all the above cases, the underlying assumption could be well challenged, should man rely on P&IDs to form the estimation for the required number of valves, flanges, other equipment and even the length of piping?

If this assumption is not valid or for example not being approved, an alternative to P&ID-dependent equipment count might be to carry out some manual *spot checks* to get the idea of how many equipment is really in practice. Even the compensation factor assigned to be multiplied by the observed number of flanges could then vary based on the inspector´s check results and his/her method of counting observation.

It might however be argued that in today`s practice it is not such a wise idea to send personnel in the vicinity of the process area (or risers and pipelines) for a long time (since real counting requires time) to actually count the equipment due to risk to personnel, safety reasons and the process being really time consuming. In addition, the results of manual count would not even be 100% reliable due to involved human errors.

According to Espen Fyhn Nilsen, Risk Analysis Specialist at Statoil, currently there have been some calculations and presentations of leak frequency estimates in terms of leak frequency per installation. The numbers are basically derived based on similarities between a new and previously operated installation that have been considered more or less the same.

In our opinion, even though this approach saves a lot of effort for time consuming calculation, the uncertainties involved with it is even higher than the previous approach of equipment count. Eventually a compromise has to be made to find a method that works well for the installation.

5.6.2.3Consequence Analysis

As discussed in the previous section, the validity of this assumption has a direct effect on process leaks. The more the number of flanges and valves (equipment in general) or the more length of piping, the more it will possible for a leak to appear in the system due to corrosion, required maintenance, bad joints, different pressure and temperature discrepancies etc. But as in the other cases discussed so far, this relation between the number of equipment and the probability of leak (or leak frequency) does not follow a linear and straightforward pattern. Interdependencies and hidden sources of uncertainties should also be considered in leak frequency and estimations. The events are not considered independent and therefore the relation can be almost close to linear to some extent with one by one increase of the equipment but as the added number of equipment goes higher in amount, some uncertainty factors represent themselves in terms of nonlinear behaviors of the system.

Some of the common consequences and identified hazardous events due to leaks from process equipment and piping are:

- High gas concentrations in the modules)
- Jet and pool fires
- Gas explosions

The ultimate consequences of the leaks that would later are ignited and lead to fire and explosions could be loss of main support structure, personnel fatalities and even oil spill to sea.

5.6.2.4 Risk Picture

The influence of this assumption on risk level could be defined as :

Flanges and pipe lengths contribute significantly to leak risk (especially frequency and location) and thus on all risk measures.[24]

Personnel risk

This assumption plays a considerable role in the presented risk picture for the whole platform. According to figure 4.5 (the Valemon total FAR distribution per accident category), the process leaks are major contributors to FAR and PLL values. The Far value for process leaks has been estimated to be 0.72 out of the whole 6.73 FAR value for the whole platform in level 5 which makes the process leaks the second major contributor to fatality risk (after vessel collision risk).

According to the Valemon report (process leaks) [23]:

Process equipment may leak in different areas, all with different frequency of occurrence and consequence potential. The risk contributions from each main area are summed up and presented in the following table and represent the total risk from process accidents.

The distribution of this .72 FAR value can be shown in the table below:

Table 5.25: PLL and FAR contribution from each area (activity level 5) [23]

Leak source area	PLL			Average FAR
	Total	Immediate loss	Escape loss	
Wellhead area	1.6E-03	1.5E-03	5.7E-05	0.45
Process area	9.3E-04	7.2E-04	2.1E-04	0.26
Future process area	3.7E-05	2.6E-05	1.1E-05	0.01
Grand Total	2.6E-03	2.3E-03	2.8E-04	0.72

According to the table, it is seen that the majority of loss of life occurs “immediately”, i.e. due to direct exposure from heat and blast. About 11 % is due impaired escape routes.

The major contributor to risk is from leaks in the wellhead area.[23]

Impairment of main safety functions

The leaks, if ignited could lead to fire /explosions with high pressures that might cause structural failure and hence could also influence impairment of main safety functions such as escape routes, safe rooms and main support structure.

<u>Oil Spill</u>

Condensate leaks from large process inventories can result in oil spill to the sea. All condensate spills related to process accidents can be assumed to have relatively short duration.[23] Leak frequencies are therefore very important to be estimated on a reasonable and reliable basis. Another assumption in this report is that only leaks with initial rate larger than 20kg/s are assumed to lead to spill to sea.[23] Only this scenario is considered which should have been stated in the assumptions list for Valemon.

5.6.2.5 System Description for equipment count

Before we further discuss the importance of this assumption, it would be worthy to take a look at the process diagram for Valemon to se what serves as a basis for all leak frequency calculations.

A P&ID is a complex representation of the various units found in a plant. A schematic of the process system for Valemon is shown in Figure below. The wells are classified HPHT.[17]

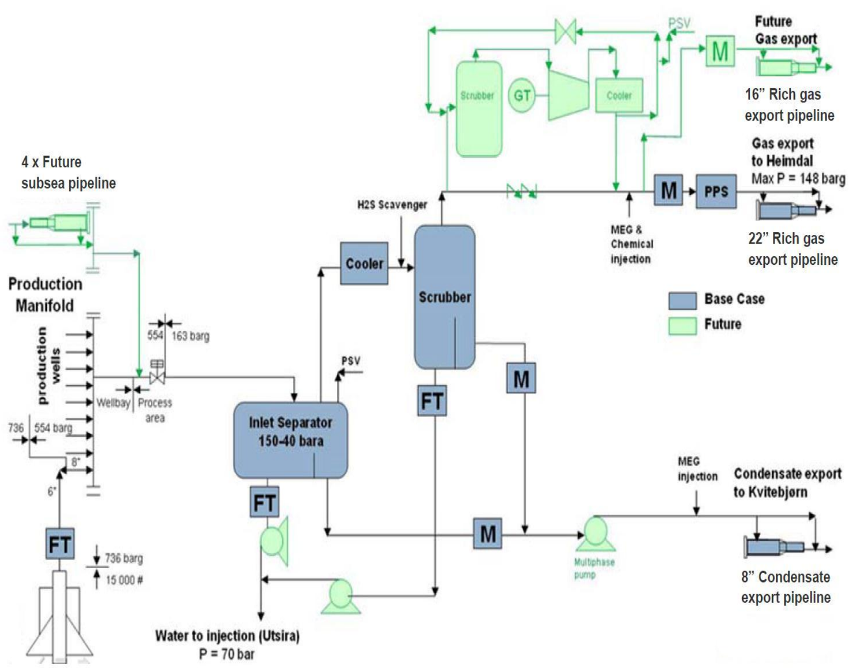


Figure5.6 The process diagram for Valemon platform [17]

These kinds of P&ID diagrams are currently considered building blocks for equipment count in order for leak frequency estimation.

According to the report, the number of possible leak sources per process unit need to be identified in order to calculate the annual leak frequencies. These leak sources include flanges, valves, instruments, pumps and other process equipment like pressure vessels and heat exchangers. The identification of these sources is mainly done by using the P&IDs. [24]

An example of equipment count sheet has been provided here in Table 5.23 below for consideration.

Table 5.26 Equipment count data sheet sample [24]

Unit	Equipment	Dimension	Count	Factor
US choke E				
	Flanged connections	1	1	12
	Flanged connections	6	5	12
	Instruments:	Pressure	7	8
	Piping (in m):	1	2	8
	Piping (in m):	6	30	8
	Manual, choke valve	6	1	4
DS choke E				
	Flanged connections	8	5	12
	Instruments:	Pressure	5	8
	Piping (in m):	8	10	8
	Manual, block valve	8	1	8
	Manual, check valve	8	1	8
	Manual, choke valve	8	1	8
Production manifold				
	Flanged connections	1	3	1.5
	Flanged connections	2	3	1.5
	Flanged connections	4	1	1.5
	Flanged connections	8	20	1.5
	Flanged connections	16	4	1.5
	Flanged connections	>16	2	1.5
	Instruments:	Pressure	2	
	Piping (in m):	1	6	
	Piping (in m):	2	6	
	Piping (in m):	4	2	
	Piping (in m):	16	30	
	Piping (in m):	>16	15	
	Actuated, blowdown valve	4	1	
	Actuated, ESDV valve	>16	1	
	Manual, block valve	1	3	
	Manual, block valve	2	3	
	Manual, block valve	8	1	
	Manual, check valve	1	1	
	Manual, check valve	8	1	
Future import manifold				
	Flanged connections	12	3	1.5

For further information about P&ID and equipment count, see Appendix G.

5.6.3 Discussions on Equipment Count Example

So far we have identified the leak frequency estimations as the main challenge associated with the number of equipment and we have discussed the possible consequences and the influence the equipment count assumptions may have on the total risk picture. In this discussion part we are going to bring into attention some points about this example that need to be noticed.

- By now, one should be encouraged enough to think of the underlying assumptions for this example. One common underlying assumption for almost all the examples mentioned so far for Valemon has been identified as the different the activity levels assumed for Valemon (see 5.4…..). The importance is because for each phase defined for the field there are different activities being implemented and the number of equipment changes in time according to a change in the number of wells and other modifications required in time.

According to the Valemon report for process leak risks[23]:

The leak frequency in each area will change with time for several reasons;

- Number of wells in production
- Number of drilling and well intervention operations
- Change in flowing wellhead pressure
- Change in inlet separator pressure
- Number of tie-in wells
- Introduction of future compression module

The personnel risk and impairment frequencies may in general be considered to increase with increasing leak frequency and the year of highest leak frequency should therefore be chosen as basis for the risk analysis (it has been chosen to be a year during activity level 5, 2024 maybe according to the report) [23]

- Another underlying assumption has been considered to be the methodology for counting equipment. One could challenge using P&IDs for basis of count due to several reasons for example not being extensive and accurate enough. We have suggested some alternatives and modifications for this such as spot checks and manual counts, and dedication of a compensation factors to critical and redundant equipment such as valves or flanges. (See sections 5.6.1 and 5.6.2.2)

- Another issue to be considered in consequences of equipment count is that for easier equipment counting normally segmentation is being carried out and the equipment for each segment is counted and documented. In that case the location of the leaks is also detectable to some extent. And the consequences would be more predictable, if we know the leak frequency as well as leak location, it would be easier to predict the potential explosion pressure. If the leak happens in a more congested area due to the higher number of equipment the explosion pressure would be much higher than if an explosion happens due to a leak in area with very few equipment. And that is another effect of equipment count (complexity of system) might have on the risk level.

- Finally, a comment on the presentation of the assumption of equipment count based on the Table 5.21(Assumption description) is that so far it has been the most detailed assumption presented. Almost all the fields in the table are filled out in the description of the assumption including the lifetime variation of the assumption, which was mentioned in this section as well. According to the table the assumptions have been again assumed to be conservative. However, there is uncertainty to what extent this assumption is reliable and it has not been mentioned that on what grounds the assumptions are considered conservative.

Assuming that to be valid, being conservative with respect to this assumption, means that the results are most probably not going to be worse than the presented risk picture, with respect to great deal of uncertainty existent in the world, surprises might also happen and this is something that cannot be shown by the results only. One might be able to see beyond the results of a risk analysis.

And finally, we like to present the importance score table for this assumption.

Table 5.27 Importance ranking of Equipment Count Example

Assumption Description	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance
Equipment count	L	M	L-M

Based on the discussions above and according to criteria mentioned in table 5.1, the degree of uncertainty for this assumption is considered to be low because the models for equipment count (P&IDs) are believed to give predications with acceptable accuracy. In addition, assumptions with equipment count and compensation factors, which are mentioned in the discussions of assumption, seem conservatively reasonable. And so far there has been agreement on this method of count between experts though we have challenged this method in this work.

With respect to the degree of sensitivity, a medium score has been assigned to this assumption since relatively large changes in base case values needed to bring about altered conclusions. The effect of alterations in this assumption is reflected in the risk picture by changing the leak frequency as discussed in previous sections but a small deviations of equipment count can be compensated by other measures introduced in sections above and dies not leak to immediate change in leak frequencies.

Therefore an overall index of L-M has been considered for this assumption based on the arguments we have presented for evaluating this assumption and its total impacts on other parts of the analysis.

5.7. Manning level and distribution (Example5)

In this section we will discuss the manning distributions for different activity levels for Valemon:

Table 5.28. Manning level and distribution for Valemon [18]

1.2 Manning level and distribution	
Description	Manning level and manning distribution will be different for each operational phase. Refer to Table 2.2 for manning level and Table 2.3 to Table 2.8 for manning distribution.
Influence on risk level	Increased manning means increased potential loss of lives. Increased manning in high risk areas increases overall FAR value.
Relevant RA sections	All
Lifetime variation	Manning level differ significantly between the operational phases due to the different activities being performed in each phase.
Simplification? If yes; influence on risk level	
Information source	Statoil manning input
Comment	
Status	

This example of assumption is different from many aspects with the previous four examples that have already been discussed mainly because it involves human beings. In addition, uncertainties with this assumption are considered higher. This is due to the fact that Valemon has not been built yet and the activity levels defined below that serve as an underlying assumption for manning distributions are quite uncertain in themselves. According to the Valemon report about uncertainties with this respect:

There are some uncertainties with respect to manning distributions and activity levels [17] :

- The input on manning level and distribution on areas is highly uncertain. The manning study by Statoil has not been finalized. The assumptions made for manning is important for calculating personnel risk: among other total FAR, Group risk and PLL (the latter for normally not manned phase).

The assumed manning level and distribution and its impacts are the main issues to be discussed in this section.

- Activity levels during lifetime: Production from the Valemon field is associated with

a significant uncertainty. Therefore, there is uncertainties connected with production profile (and number of producing wells), required well intervention activities, required manning etc. Hence, as many as 6 possible activity levels have been defined for the period 2014 to 2027, considering drilling, well intervention, production profiles, number of tied-in wells and future installations. The combination of such activities within each activity level is decisive for which activity level will be dimensioning for the installation, when considering the risk acceptance criteria.
This uncertainty influences the manning level and distribution, which we shall consider during all discussions related to this issue.

It is worth mentioning that this assumption belongs to the operational/organizational category of assumption, however, the reason why we have chosen to discuss this after all the other assumptions is that to be able to see the previous examples reflections in this assumption.

The importance and criticality of this assumption originates from the fact that the assumed numbers for manning serve as the direct input for calculating personnel risk in presenting the risk picture. And since any miscalculations or misjudgments in this matter lead to direct loss of lives, great care has to be taken when assuming the manning levels for different areas and different activity levels. Normally, the tendency should be towards choosing conservative assumptions due to criticality of the consequences.

In this section, first we will review the total manning for each activity level and then the detailed distribution of manning in different areas of the platform is considered. We will discuss and comment this mainly for activity level 5 which is been documented to have the dimensioning status (due to various simultaneous activities) and also activity level 6, which is the normally not manned activity level. Table 5.12 shows the total manning for each activity level.

Table 5.29. Manning level for each operational phase[18]

Operational phase/Activity level	Manning	Working schedule	Total annual number of hours on Valemon
1. Simultaneous drilling and production (including jack-up drilling rig)	13*	Normal rotation	365 *13*24= 113 380
2. Normal production (stand-alone, no well intervention)	13	Normal rotation	365 *13*24= 113 380
3. Simultaneous production and well intervention (stand-alone)	40	Normal rotation	365*40*24= 350 400
4. Simultaneous drilling, production and wireline well intervention (including jack-up drilling rig)	48**	Normal rotation	365*40*24= 350 400
5. Stand-alone production including all known future modifications	40	Normal rotation	365*40*24 = 350 400
6. Stand-alone production and normally not manned installation	7	Working 5 days out of 14 days at Valemon, 9 days out of 14 days at Kvitebjørn***	(5/14)*7*365*12= 10 950

* In addion, 1 drilling personell assumed present in wellhead area per day, as an average.

** 8 persons assumed for drill crew, spending 1/8 of the work day in wellhead area per day, as an average. It is a conservative assumption, since it is only relevant for 4 months a year.

*** Note that this may be changed to 2 weeks on Valemon, 6 weeks off-duty (giving 2/8*7*365*24= 15 330 manhours on Valemon).

Before further of the assumption, we shall first encourage the reader to remember the 6 activity levels defined for Valemon (Section.5.4) due to their great influence on manning distribution patterns and assumptions. Once again, note that the tables presented for manning are associated with significant uncertainty, since the manning study for Valemon has not been finalized yet.

5.7.1 Some comments on the assumption:

Increased manning means increased fatality risk and potential loss of lives since the number of exposed people becomes higher. Increased manning in high-risk areas increases overall FAR value. It is worth reminding about FAR and PLL values which represent the fatality risk in the risk picture.

PLL= The expected number of fatalities (normally) per year

FAR= The expected number of fatalities per 100 million exposed hours

Note that PLL is just and indicator for group risk, while FAR represents individual risk. And if the manning is assumed the same for calculations of PLL and FAR, the FAR is simply a ratio of PLL and the main indicator would be PLL. However, it is useful and dives the reviewer a good insight to present both values of FAR and PLL in the total risk picture.

Manning distribution deals with the number of people working or being present at different areas of on the platform. And one of the main concerns of offshore accidents is to avoid or reduce the risk to personnel. Therefore any assumption with respect to this matter is considered of great importance and has to be studied carefully and treated sensitively.

Another area of effect of the manning level distribution would be the alterations in leak frequency value. It is usually the case that the more people working on different areas (except for LQ for this case), the higher the probability of initiating a leak due to potential activities in maintenance, hot work, check-ups and manual manipulation of the system intentionally or unintentionally by personnel. Although it might be challenging to see the immediate results of difference in manning distribution in leak frequency, it is more convenient to observe the results in presented and calculated PLL and FAR values.

The immediate and direct effect of alterations in the manning level would lead to change in potential loss of lives and fatal accident risk calculations with respect to risk analysis. The mentioned parameters play an important role in presenting the total risk picture of any facilities, so care should be taken when dealing with manning distributions since they serve as a basis for these calculations. The challenging part here is that the Valemon platform has not yet been built however, the calculation of risk picture parameters is necessary for the preliminary TRA of the platform for the participants. As a result a totally knowledge and experienced-based probability distributions are assigned to manning distributions.

In typical manning level tables of a QRA the tables have been classified according to working group (personnel group) meaning the role and responsibility they have in the system and different areas of the platform.

A night and day shift separate sheet is sometimes included. In this report however, since the platform has not been built and operated yet, and there are therefore a great deal of uncertainty with it, as mentioned in the beginning of this section, there has been assignment of different activity levels which is also listed as one of the main and basic assumptions for the whole TRA and here therefore plays the role of underlying assumption for the manning distributions assigned. These levels were introduced above.

In the section below, we will focus on manning distributions in activity level 5 which is considered to be one of the populated levels including both production and intervention as well as all future modification (jack-up present for workover only) and activity level 6 (normally not manned production phase)

5.7.2.Integrated impact of the assumption

Some issues to be considered here is that the manning differ greatly in different operational phases (activity levels) as well as in different areas of the platform (Process, Wellhead, LQ ,…) and also according to day and night shifts.

The following tables are just solely assignments of knowledge-based values by the analysts. Given the numbers are basically epistemic probabilities they are quite uncertain and so great care should be taken while assigning these probabilities. Since they would then serve as a basis for the next steps in many different calculations for the QRA report and will eventually have a great impact on the presented risk picture of the platform.

In this example, we will not go very deep in reviewing all the assumptions (the detailed percentage of manning distributed on the whole platform according to the proposed tables for each activity level). Our main concern would be the effect of changing this assumption (the assigned probabilities) on different parts of the QRA especially HAZID, cause and consequence analysis and more importantly the risk picture (level).

The basis for our discussions would be table 5.12 with general manning classified according to activity levels. The detailed distribution is also available in the following tables 5.27-5.33.

5.7.2.1 FRAMEWORK:

It is necessary the manning level and distribution would be in line with the set standards. There have been some regulations with respect to acceptance criteria for Valemon:

Based on the report: [17]

The acceptance criteria for Individual Personnel Risk (Manned Phase):

The mean individual risk, expressed by the fatal accident rate (FAR) – must meet the criteria FAR < 10.

For specially exposed groups (Operation, Mechanic, Electric / automation and Maintenance

Contractor, or as defined in TRA / EPA), the mean group individual risk, expressed by the fatal accident rate (FAR) – must meet the criteria FAR < 25.

Personnel risk for Valemon:

The Valemon platform shall be normally not manned. It is however required to be manned during drilling, well interventions, pigging activities and maintenance. Hence, both FAR and PLL criteria may be relevant depending on the operational phase.

The relevant groups for calculation of Group Individual Risk for Valemon are assumed:

- Management
- Operation
- Mechanic
- Electric and automation
- LQ service

Calculation of FAR for Valemon is based on exposure when manned, thus N (total number of hours of risk exposure per year) is the number of manned hours per year. The criteria shall apply as a mean for each 12 month period. [17] Hence, in this calculation, the PLL value is based on the same number of manned hours per year as for FAR calculation.

5.7.2.2 SYSTEM DESCRIPTION:

The system description has an influence on the overall manning level and also the number of people assigned for each position and being present at each position at specific places. The assumption of manning is based on the capacity of different areas and the requirement for work on those areas. Proper assignment of manning level in a platform would result in efficient use of the safety functions such as safe rooms and escape routes. Additionally, the number of people present at a time of an accident at different modules could contribute greatly to PLL calculations and contours.

According to Vinnem [4], a risk assessment should always start with a system description. A precise definition of the system being analyzed assists both the analyst and more importantly those who will review or evaluate the study and the results. The system description should include:

- Description of technical system, relevant activities and operational phases
- Statement of the time period to which the analysis relates
- Statement of the personnel groups , the external environment and the assets to which risk assessment relates
- Capabilities of the system in relation to its ability to tolerate failures and its vulnerability to accidental effects[4]

As we see, statement of personnel groups is considered important and part of system description, however, assigning the distribution and numbers is part of the assumptions.

The purpose of the system description is to make the analysis sufficiently transparent, so that other participants are able to review and comment on it.

5.7.2.3.HAZID

Reviewing the identified hazards for this report mentioned in section…, the manning level assumption could be associated with the following hazards:

- Process leaks
- Fire in utility areas
- Occupational Accidents
- Fire in Living quarters

5.7.2.4CAUSE ANALYSIS

The causes of the above hazards are either directly or indirectly associated with the personnel (manning). The more people are working in the area the more probable that different types of fire or leak occur (or any other occupational accidents). That is mostly due to the deliberate or undeliberate modification and interventions human beings are normally involved with while working. The personnel involved, are either entitled to do some modification/justification according to their job or it might be case that some alterations happen by mistake. Human error has always been an inevitable aspect in every system operated by/consists of humans.

According to the report, occupational accidents are defined as accidents that are not caused by technical failure (hardware or operational related) of process equipment. Occupational accidents are accidents with no potential to cause fatalities outside the immediate area of the incident. They will be addressed by statistical analysis of previous accidents

It can be gathered by the given definition of the occupational accidents that human error is one of the main reasons for initiating these events. And the relation between the number of human errors and the actual number of people present at an area (manning) should normally be obvious enough!

5.7.2.5 CONSEQUENCE ANALYSIS

Having defined the relation between the manning distribution assumption to the mentioned hazards and their causes, one might be then interested to evaluate the consequences of the mentioned hazard and the role of this assumption being relevant here.

The consequences for leaks and fires are quite extensive and could range from minor injuries, to complete impairment of safety functions, and structure failure, explosions, loss of lives, oil spill, etc.

The assumption we are dealing with here, has a great influence on the consequences of almost all hazardous events in terms of risk to personnel. We could refer to process accidents, fire and explosions, leaks, structural failure, dropped objects, collision risk and so on.

The effect of manning level will be recognized in the calculated/estimated PLL and FAR values either directly or indirectly. When an accident happens, the more exposed people available would certainly lead to more potential casualties.

In the following discussion we will first review some points regarding the risk picture of Valemon and the role of manning in it in terms of FAR and PLL values and then review the manning distributions especially in activity levels 5 and 6 for gain better insight in understanding the results of the total risk picture.

5.7.2.6 Risk Picture and Manning Distributions

Personnel risk

According on Valemon1 report here is the total result of the risk picture:

The total FAR for Valemon in activity level 5 is calculated to be 6.73. [17]This is the activity level with the expected highest personnel risk. The total FAR for Valemon is well within the risk acceptance criteria of FAR <10 for personnel risk.

The personnel risk, expressed as PLL, for Valemon in activity level 6 (NNM) is 8.4 ·10-4 per year. The PLL value for Valemon is well within the risk acceptance criteria of PLL < 0.004 for personnel risk in NNM phases.[17]

Manning distribution Tables for Valemon Platform [18]

Table 5.30.Personnel distribution for activity level 1: Simultaneous production and drilling phase (jack-up drilling rig present, no well interventions) (per 24 hour) [18]

Personnel group	Number of persons	Fraction of time in area:								Sum
		LQ incl. helideck	Utility areas	Workshop module	Wellhead area	Well intervention deck	Process area		Future process module	
							Cellar	Lower		
Management	1	85.0 %	4.5 %	1.5 %	1.5 %	1.5 %	3.0 %	3.0 %	-	100%
Operation	2	67.5 %	2.5 %	1.5 %	7.5 %	1.0 %	10.0 %	10.0 %	-	100%
Mechanic	4	67.5 %	5.0 %	2.5 %	5.0 %	5.0 %	7.5 %	7.5 %	-	100%
Electric and automation	4	67.5 %	10.0 %	7.5 %	1.0 %	10.0 %	2.0 %	2.0 %	-	100%
LQ service	2	100.0 %	-	-	-	-	-	-	-	100%
Drill crew	1				100%					100%
Total manning	**13+1**									

The table above is considered for the activity level 1 which is considered to have a total average manning of 13.

It is seen that 6 group of personnel have been distributed into the 7 divided main areas on the platform. The assumption is mainly based on the fact that the greatest percentage of manning of all groups is located in the LQ and the LQ service personnel are considered to be located there all the time.

The process area which is considered to be the high-risk area is mostly occupied by operation and mechanic people which seems to be an acceptable assumption based on our background knowledge but still not certain at all.

The only drill crew considered for drilling (since level 1 is a drilling phase as well) stays at the wellhead area on the platform for all time. The assigned percentages for the well intervention could have been assumed less than the ones we actually see since there assumed to be no well intervention at this phase. However, manning level assumptions should above of all be conservative assumptions.

Table 5.31: Personnel distribution for activity level 2: Normal production phase (no jack-up drilling rig, no well intervention) (per 24 hour) [18]

Personnel group	Number of persons	Fraction of time in area: LQ incl. helideck	Utility areas	Workshop module	Wellhead area	Well intervention deck	Process area: Cellar	Lower	Future process module	Sum
Management	1	85.0 %	4.5 %	1.5 %	1.5 %	1.5 %	3.0 %	3.0 %	-	100%
Operation	2	67.5 %	2.5 %	1.5 %	7.5 %	1.0 %	10.0 %	10.0 %	-	100%
Mechanic	4	67.5 %	5.0 %	2.5 %	5.0 %	5.0 %	7.5 %	7.5 %	-	100%
Electric and automation	4	67.5 %	10.0 %	7.5 %	1.0 %	10.0 %	2.0 %	2.0 %	-	100%
LQ service	2	100.0 %	-	-	-	-	-	-	-	100%
Total manning	**13**									

For this activity level, there assumed to be no drilling activities anymore and there will be only normal production of the field. As one could easily observe, there has been no difference between this distribution and the previous one related to activity level1 except for the drilling crew that is not needed in this phase anymore. Still no well intervention considered for this phase so the numbers seen in the intervention deck column might be reconsidered.

Table 5.32: Personnel distribution for activity level 3: Simultaneous production and well intervention (no jack-up drilling rig) (per 24 hour)[18]

Personnel group	Number of persons	Fraction of time in area: LQ incl. helideck	Utility areas	Workshop module	Wellhead area	Well intervention deck	Process area: Cellar	Lower	Future process module	Sum
Management	1	85.0 %	4.5 %	1.5 %	1.5 %	1.5 %	3.0 %	3.0 %	-	100%
Operation	2	67.5 %	2.5 %	1.5 %	7.5 %	1.0 %	10.0 %	10.0 %	-	100%
Mechanic	3	67.5 %	5.0 %	2.5 %	5.0 %	5.0 %	7.5 %	7.5 %	-	100%
Electric and automation	4	67.5 %	10.0 %	7.5 %	1.0 %	10.0 %	2.0 %	2.0 %	-	100%
LQ service	2	100.0 %	-	-	-	-	-	-	-	100%
Well intervention crew working mostly in offices in LQ	14	95.0 %	1.0 %	-	1.0 %	3.0 %	-	-	-	100%
Well intervention crew working mostly outdoor	14	67.5 %	1.5 %	1.0 %	5.0 %	25.0 %	-	-	-	100%
Total manning	**40**									

In activity level 3, there will be both production and intervention and as a result the number average manning will increase greatly due to the added intervention crew working both in LQ and outdoor which is considered to be 14 for both cases adding up to the total manning from 13 up to 40.It is then seen that the percentage of people working at intervention deck has been increased. The outdoor working intervention crew still spends most of their time (67.5%) in the Living Quarters.

Table 5.33: Personnel distribution for activity level 4: Simultaneous production, drilling and wireline well intervention (jack-up drilling rig present) (per 24 hour) [18]

Personnel group	Number of persons	Fraction of time in area: LQ incl. helideck	Utility areas	Workshop module	Wellhead area	Well intervention deck	Process area: Cellar	Process area: Lower	Future process module	Sum
Management	1	85.0 %	4.5 %	1.5 %	1.5 %	1.5 %	3.0 %	3.0 %	-	100%
Operation	2	67.5 %	2.5 %	1.5 %	7.5 %	1.0 %	10.0 %	10.0 %	-	100%
Mechanic	3	67.5 %	5.0 %	2.5 %	5.0 %	5.0 %	7.5 %	7.5 %	-	100%
Electric and automation	4	67.5 %	10.0 %	7.5 %	1.0 %	10.0 %	2.0 %	2.0 %	-	100%
LQ service	2	100.0 %	-	-	-	-	-	-	-	100%
Well intervention crew working mostly in offices in LQ	14	95.0 %	1.0 %	-	1.0 %	3.0 %	-	-	-	100%
Well intervention crew working mostly outdoor	14	67.5 %	1.5 %	1.0 %	5.0 %	25.0 %	-	-	-	100%
Total manning	**40**									

Activity level 4 is almost the same as level 3 with the only difference that the jack up rig is also present in this phase for further drilling and wireline well intervention so it might have been a more conservative assumption to dedicate higher percentages to personnel in well head area and well intervention deck for this level.

Table 5.34: Personnel distribution for activity level 5: Simultaneous production and well intervention including all known future modifications (jack-up present for workover only) (per 24 hour)[18]

Personnel group	Number of persons	Fraction of time in area: LQ incl. helideck	Utility areas	Workshop module	Wellhead area	Well intervention deck	Process area: Cellar	Process area: Lower	Future process module	Sum
Management	1	85.0 %	4.5 %	1.5 %	1.5 %	1.5 %	2.0 %	2.0 %	2.0 %	100%
Operation	2	67.5 %	2.5 %	1.5 %	7.5 %	1.0 %	8.0 %	8.0 %	4.0 %	100%
Mechanic	3	67.5 %	5.0 %	2.5 %	5.0 %	5.0 %	6.0 %	6.0 %	3.0 %	100%
Electric and automation	4	67.5 %	10.0 %	7.5 %	1.0 %	10.0 %	1.5 %	1.5 %	1.0 %	100%
LQ service	2	100.0 %	-	-	-	-	-	-	-	100%
Well intervention crew working mostly in offices in LQ	14	95.0 %	1.0 %	-	1.0 %	3.0 %	-	-	-	100%
Well intervention crew working mostly outdoor	14	67.5 %	1.5 %	1.0 %	5.0 %	25.0 %	-	-	-	100%
Drill crew working in wellhead area	8				12.5%					100%
Total manning	**48**									

Activity level 5 is considered to be one of the most populated activity levels and contributing mostly to the FAR and PLL values. (According to the report, dimensioning level). There appears to be an extra manning of 8 drill crew working in wellhead area.

However, in this activity according to the main report, no drilling is being done, and the jack up is only present for well intervention and workover. Due to this definition, we think these extra added drill crew might be more relevant to be considered in activity level 4.Even discarding this issue, activity level 5 still seems eligible to be regarded as a dimensioning level. And the manning levels for this activity level serves are the basis for calculation and distribution of FAR values presented in the risk picture between the accident scenarios and areas. One should be very conservative and cautious for this distribution of manning.

Table 5.35: Personnel distribution for activity level 6: Normally not manned production phase (no jack-up drilling rig, no well intervention) (per 24 hour)[18]

Personnel group	Number of persons	Fraction of time in area:								Sum
		LQ incl. helideck	Utility areas	Workshop module	Wellhead area	Well intervention deck	Process area		Future process module	
							Cellar	Lower		
Management	1	85.0 %	4.5 %	1.5 %	1.5 %	1.5 %	3.0 %	3.0 %		100%
Operation	1	67.5 %	2.5 %	1.5 %	7.5 %	1.0 %	10.0 %	10.0 %		100%
Mechanic	2	67.5 %	5.0 %	2.5 %	5.0 %	5.0 %	7.5 %	7.5 %		100%
Electric and automation	2	67.5 %	10.0 %	7.5 %	1.0 %	10.0 %	2.0 %	2.0 %		100%
LQ service	1	100.0 %	-	-	-	-	-	-		100%
Total manning	**7**									

This activity level is considered to normally not manned so the number of manning has been dramatically reduced to 7 but according to table 5.18 we should note that these people are only working 5 days out of 14 days at Valemon (12 hours a day). The total number of exposed hours is shown in the table 5.12 for each activity level. Exposed hours of all personnel are specifically needed in calculations of FAR values. Below we can compare the results of FAR and PLL for activity levels 5 and 6.

Table 5.36 Total PLL and FAR, activity level 5 [18]

PLL	Average manning	FAR
$2.4 \cdot 10^{-2}$	41	6.73

Table 5.37 Total PLL and FAR, activity level 6 [18]

PLL	Average manning	FAR
$8.4 \cdot 10^{-4}$	1.25	3.24

As seen the FAR value is well within the risk acceptance criteria of FAR < 10 for activity level 5.

As seen the PLL value is well within the risk acceptance criteria of PLL < 0.004 for activity level 6.

For activity level 6, it is worth mentioning that according to the framework defined for Valemon report: [18],

Personnel Risk (Normally Not Manned Phase):

For installations that are normally not manned, the PLL per year shall be below 4.0E-03, if annual manhours on the installation are less than 15000. If annual manhours exceed this, the FAR criteria shall apply.

And according to table 5.15, one could see that the total exposed hours for activity level 6 has been calculated (based on the assumptions only) to be 10,950 hours, which is less than 15,000. Therefore the PLL criteria of 4.0E-03 shall apply for this activity level. [18]

If one compares these two presented tables of the results of FAR and PLL values with the manning distributions for activity levels 5 and 6 provided in tables 5.31 and 5.32 respectively, it can be concluded that the pattern the personnel distribution between the modules of the platform contributes directly to the risk picture since for every individual or group of personnel, it is very important that how much exposed hours they are working and how safely they are located. Eventually there are two factors that matter with respect to fatalities and manning patters. First, is the sole manning level (how many people) and second is the nature of distributions between different areas. Some areas are considered high-risk areas and having more personnel being exposed to those areas may lead to higher fatalities. In case of a major accident the personnel should be able to be evacuated through the escape routes and make their way to the lifeboats or be relocated to safe rooms and so on. Therefore having more personnel in the vicinity of process or wellhead area normally results in more fatalities rather than having the same number of personnel all located in LQ and safe rooms for most of the time.

Manning level and fatalities per accident category

Since the FAR distribution between accidents is considered to be important here for comparing the results of manning that we are discussing in this section, we shall once again present the level 5 FAR value distribution in pie diagram in Figure 5.8 below :

The distribution of FAR between accident categories is shown in Figure 5.7

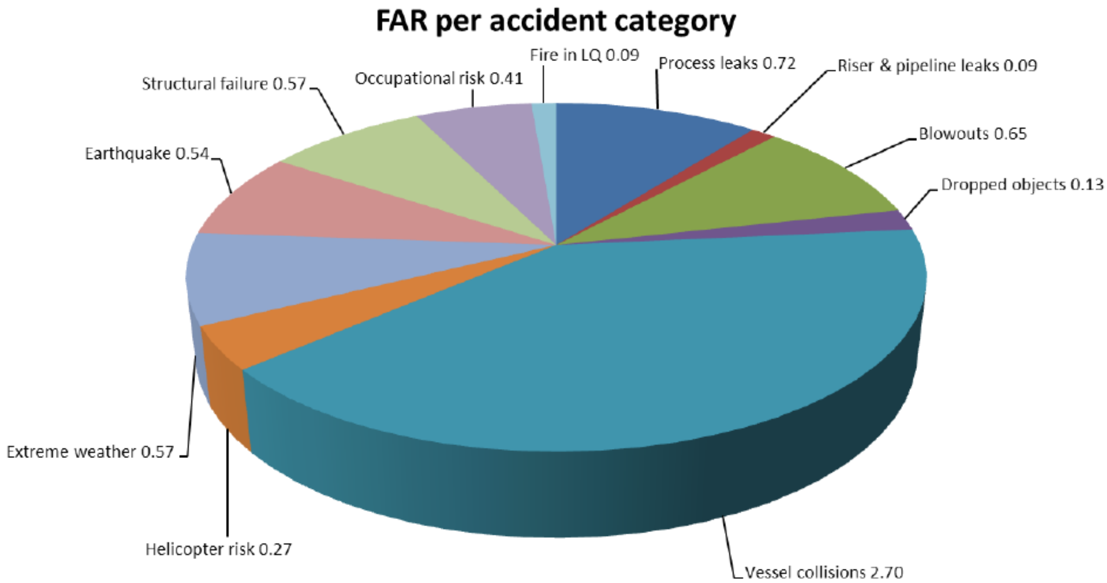


Figure 5.7. Distribution of FAR between accident categories [17]

We could easily observe that the major contributor to FAR value in level 5 is the vessel collision fatalities.

It is seen that the vessel collision risk is high, since as a result of a conservative assumption all personnel are assumed killed upon total loss of main support structure due to collision accidents with impact energies above the acceptance criteria that will lead to impairment of main load bearing structure. Given this argument, one should be able to relate the higher manning levels for platform to the higher fatality rates.

Process leaks and structural failure are considered the second and the third (respectively) major contributors to fatality risks in level 5 as seen from Figure 5.8.We have discussed the severity and consequences of these two accidents based on examples discussions of 1,3 and 4.

5.7.3 Final Discussions on this assumption

Given the discussions above, manning level has a great impact on the risk picture since the increases number of manning usually leads to increased fatalities.

According to the main Valemon report, calculation of FAR for Valemon is based on exposure when manned, thus the total number of hours of risk exposure per year is the number of manned hours per year. The criteria shall apply as a mean for each 12 month period. Hence, in this calculation, the PLL value is based on the same number of manned hours per year as for FAR calculation meaning the manning values have been fixed and locked. As a result FAR would proportional to PLL values. And this fact makes it easier for the reviewers to compare the results.[17]

The main point for this manning level assumption has been that the assumed manning distributions are subject to great uncertainties since the platform has not been built and operated yet. However, the results of manning level could contribute directly or indirectly to the risk picture, FAR or PLL values in the sense that the more populated an area is, the more risk to personnel and potential number of fatalities is created. As a result the personnel fatality risk as a consequence for each accident scenario increases. The increased manning level could on a different level serve as causation in creating more leak frequencies that will lead to possible ignition, explosion, and structural impairment etc. Any of these assumed consequences would then have fatality risk.

Finally, as one can see, the whole assumption on manning with respect to cause and consequences are interrelated. The more people involved the higher the probability of initiating hazards and the more hazards the more expected fatalities.

And finally, we like to present the importance score table for this assumption.

Table 5.38 Importance ranking of manning level example

Assumption Description	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance
Manning level and distribution for Valemon	H	H	H

Based on the discussions above and according to criteria mentioned in table 5.1, the degree of uncertainty for this assumption is considered to be extremely high since the phenomena involved are not well understood and models are non-existent and believed to give poor predications. This is mainly because the Valemon platform has not been built yet and thus the assumed numbers are very uncertain and enough data is not available.

Regarding the degree of sensitivity, a high score has been assigned to this assumption as well since even small changes in manning distributions would directly and immediately alter the results of risk pictures, especially in calculations of fatality risk to personnel.

Therefore, an overall index of H has been considered for this assumption based on the arguments we have presented for evaluating this assumption and its total impacts on other parts of the analysis especially fatality risk in the total risk picture.

Recommendations

Regarding the presentation of the assumption and the manning distribution tables, since the manning distribution is subject to great uncertainties due to Valemon not being operated yet, the numbers are just mere assignments of probabilities by assessors and analysts based on their background knowledge and experience., it might be a good point to assume day and night shift manning activities as well for more realistic distributions.

The information source has been stated as Statoil manning input but it is sort of not clear which manning input and which specific source is being considered.

As Valemon is going to be built and developed new and more valid data on manning distribution will be available and that should be included to these current tables. The activity levels might also require modification, which also determine the alterations to input manning distributions.

The criticality of this assumption could be seen in the table 5.35 in the relevant tab of: “relevant RA sections”= ALL !!

As a final comment we would like to say, this assumption could be challenging, just like any other challenging events when it comes to human behavior, since the human behavior and reactions to the world could sometime be quite unpredictable and since saving the lives of these unpredictable creatures is of high priority especially in accordance with offshore safety regulation, enough care should be taken to be able to come up the best and more accurate results.

The approach towards this issue is usually the cautionary one. Generally, in case of great uncertainties, like the case here that the platform has not been built yet, the assumptions should be tending toward being conservative to predict the almost worst possible consequences.

A Comparison of manning level between Valemon and Kalundborg QRA

Since this assumption is considered to be very critical and both degrees of uncertainty and sensitivity for this assumption has been ranked as high, we have made a comparison between the manning distribution in Valemon and Kalundborg refinery as well.

The results of risk picture differ greatly mainly because of:

- The different nature of Valemon (offshore) and Kalundborg (Onshore)
- Time of operation (Valemon has not been built yet and therefore manning assumptions have great uncertainty, Kalundborg on the other hand, has been in operation for some years now)

Finally, If we compare the results of the FAR values with the FAR value results for activity 5 in Valemon (table 5.33) we see the results in table 5.20.

Table 5.39. Comparison of FAR between Kalundborg and Valemon

	Calculated FAR	RAC FAR
Valemon(activity level 5)	6.73	10
Kalundborg	9.1	5

We see that the FAR value is quite smaller for the offshore facility Valemon. Normally, for offshore installations average FAR value tends to be considerably lower due to personnel being located 2/3 of time in the living quarter. [31] We should also note that although the accident scenarios for offshore installations are quite wide in range, the manning level for Valemon is considerably lower in general than that of for Kalundborg refinery. And the fact that Kalundborg is a refinery and mainly deals with process accidents results in the general more potential fatalities.

However, as a result of manning distribution assumption, we can generally reach to this conclusion:

The main point here is eventually the assigned manning distributions are just knowledge-based and are set upon the background knowledge of the assessor and therefore there are a great deal of uncertainties with them as well as with the corresponding consequences and the number of fatalities they potentially cause.

For a more through comparison of manning level between Kalundborg and Valemon see Appendix H.

In the next chapter we will have a general overview of the examples mentioned in chapters 3 and 5 and will compare an example between two QRAs. The main focus is on how the assumption has been presented and documented and how it will affect the risk level of the analysis if not being valid or is subject to great uncertainties.

Chapter 6

6. General Discussions of the mentioned examples

As we can infer from the previous chapters of this work, one of the important aspects in a QRA is to ensure a comprehensive documentation of assumptions and premises for the analysis. Assumptions and premises need to be documented where they belong in relation to calculations. In addition, there should be a summary of all assumptions and premises as a reference source. [4]

In this work, so far we have discussed the role of uncertainty associated with assumptions in a QRA, and then we have chosen several examples of assumption documentation in different QRA studies. In chapter 3 we reviewed some scattered examples of assumptions for three not quite developed and up-to-dated QRAs and then we reviewed some assumption presentations for Kalundborg QRA, which is considered quite recent and up-to-date compared to those three ones. A brief commenting has been done.

Finally, in chapter 4, we introduced Valemon TRA, which according to the discussed measures, has been shown to be the most effective and relative QRA study with respect to our purpose of the work. Therefore, we chose to discuss 5 examples from the Valemon TRA assumption section in detail in chapter 5. Compared to the other four studies, Valemon TRA seems very recent and complies with an acceptable extent with the Statoil required guideline (GL0282) for documentation of assumptions.

The individual and detailed discussion and comments after each assumption example has been made in the previous chapter. In this chapter we will have a general discussion and evaluation about general pros and cons of different examples of assumptions and finally we will make a comparison between them defining the more important assumptions for this work.

6.1 Final discussions for all examples of assumptions

By now we are expected to be able to reason why it is very important to document and present the assumptions in a QRA; moreover, the validity of them is of greater importance with respect to the results. In order for the assumptions to be reliable and consistent with the risk results, basis for calculations has to be documented.

When it comes to decision support, limiting interpretations only to mere results and presented numbers could be very misleading sometimes without understanding the basis for them. The emphasis has been on the combination of assumptions and premises that are critical and interact with one another. In this section we will point to some general comments about the examples.

- **Basis for establishing assumptions**

In the previous section we have compared one example of assumptions between two different QRA reports. (Manning level, see appendix. D) The comparison is possible between similar examples in different reports if the relevant data is available. There are always differences in how assumptions are established and presented in a report and the fact that the nature of the facilities might differ from one another adds up to these discrepancies. The focus here is not these differences. We are interested to know as a whole, which way of presenting and establishing assumptions is more useful for interpreting the risk results. Therefore while we are discussing a possible advantages and disadvantages of an example of assumptions we should try to relate to the fundamentals of assumption requirements that we have discussed. We should always challenge the assumption by asking questions like: What source is it based upon? How reliable is it? Who has assumed this? Why has he/she assumed this? And what are the risk results if it id not valid? In other words, WHAT IF the assumption is not valid?(a kind of sensitivity analysis) Given the above discussion, it is of value to acknowledge the fundamentals for both establishing and presenting the assumptions.

- **Gradual Improvement of Assumptions documentation in QRAs**

According to chapter 3 to the end of chapter 5 examples, one could conclude that the role of assumptions have been more appreciated in time. There have been guidelines and frameworks providing information about presenting and classifying assumptions. And as we could see in the last QRA report, Valemon, assumptions are comparatively well established and documented. There still have been some assumptions (mostly analytical for simplification of calculations) which were not listed yet indirectly implied in the report and used as a basis for further calculations. That shortcoming is recommended to be considered in further work. The important thing is that the justifications on documenting assumptions be clear and robust enough that no participants in the whole risk assessment process would question and challenge the requirement for the more detailed assumption documentation. As part of this work also, an effort has been made to emphasize on the importance of assumption documentation by clarifying the role they play in a QRA.

- **Interdependencies of Assumptions in a QRA**

Another point we would like to comment on is the effect of interdependencies of assumptions with each other in a QRA report. Although it has been stated several times that assumptions should be documented separately and in different categories, it is still wise to try to look beyond just separate categories. Assumptions are interrelated and invalidity or change in one assumption will require modifications in others as well. As an example we could refer to the dependencies of the first two examples mentioned in chapter 5. The assumed number of vessel visits could be an underlying assumption for the expected number of lifts on the platform, which will eventually influence the risk for dropped objects. If the assumption is based on one visit of vessel per week, then the lift numbers are also

established on that number of visits; consequently, if the assumption is changed to 2 vessel visits a week the number of lifts and therefore the frequency for dropped objects would also change.
In order to be able to track the interrelated assumption effects on each other, it is wise to mention the relevant areas of influence for each assumption and always emphasize on the underlying assumptions as well. The relation between assumptions impacts should be easy to track and trace.

- **Independent versus General evaluation of Assumptions**

Generally, whenever one would like to investigate and assess a system it would be very useful to look at the system at two different levels; one by decomposition the system and breaking it down to separate individual components and observe and evaluate the details; and also on a different level with a general overview of the whole system and its inputs, process and purpose and outputs.
The relation between these two levels might not always lead to the expected results and could be challenging. But we, as humans can develop an understanding on different levels based on our experiences and then use our power of reasoning and evaluation to get to the desired point. When the purpose is to understand a QRA system and the produced results, the same argument applies. And in this work, by investigating the assumptions, we are basically, looking through one detailed part of a QRA. And eventually we shall relate the role of assumptions to the purpose of the whole QRA system in a greater scale.

- **Impacts of an assumption on other parts of a QRA (Traceability)**

The improvement in assumptions in QRAs were observed and discussed but the main focus of this work from the beginning has been investigating the effects of assumptions on other parts of the risk analysis especially the total risk picture that serves a good basis for decision making. The desired achievement is that presented results of a QRA could be counted as being reliable in order not to be misleading for decision support. And In order to get there, one might challenge the underlying assumptions in each and every assumptions presented and more importantly the background knowledge, K, for the assumption. The thing to be considered during the analysis of the assumptions is that the statements about the assumptions, the estimated values, assigned probabilities etc., are all based on some background knowledge and historical data. Since there will always be uncertainties about the background knowledge, we would never be certain of the validity of the stated assumptions. The assumptions are merely based on different assessor's background knowledge and hence constitute epistemic-based uncertainties. One suggested approach is that to hold uncertainty (according to Aven[s1]) as an inevitable component of risk and always be aware of its presence and then treat assumptions as some available and initial inputs to the system and the outputs would then be the current result of the analysis. In this work, we have qualitatively discussed the effects of assumptions being varied or totally being invalid. (a coarse sensitivity analysis) We have then in each example outlined the highly affected areas by the assumptions. Here is when traceability of sources of assumptions would be very important.

- **Assumptions validity and presentation**

In summary, when presenting assumptions in a QRA report, we are mainly concerned with two aspects. First is the quality and criticality of the assumptions that is how reliable basically the assumptions are. This is acquired by stating the basis and the background knowledge the assumption have been established upon. The Second important thing to mention is the way of presenting the assumptions. Assumptions should be presented along with the risk results and are therefore important in communicating the building blocks of the work. They might be very reasonable and wisely established assumptions due to detailed and carefully selected background knowledge but poorly presented or not been presented at all. Referring to our discussion and examples presented in chapter 3, we could claim that organized and clear presenting of assumptions are very essential since if the assumptions are not easy to be acknowledged, the value of the whole risk analysis work could be influenced. One thing is what the message is, and another thing is how to communicate it through. According to Kimberly M. Thompson[], better characterization of uncertainty in the risk assessment lead to better risk communication. We will not go further in this aspect. However, having this fact in mind, we would like to comment on the way assumptions were presented in Valemon report in the next point.

- **Assumptions Presentation for Valemon**

Looking at the special tables the Valemon assumptions are presented in, one might find the tables seeming very informative and detailed compared with other examples. We have discussed this matter separately for each example, but the general comment here, is that although the boxes and tabs in the presenting of assumption look informative enough. In most of the cases they have been left empty. (According to Appendix K of the report, assumptions for Valemon[19]). Or it is filled out very coarsely. If we take a look at another example just with focus on the format of the table below:

Table 6.1. An example of a presented assumption in Valemon TRA[19]

1.13 Supply vessel arrival speed	
Description	Supply vessels may arrive the safety zone with a speed from 0-16 knots (typical transit speed) as follows: 0-5 knots – 20% 5-10 knots – 50% 10-16 knots – 30%
Influence on risk level	Higher speed gives increased impact energy given a collision, and thereby increased risk.
Relevant RA sections	Appendix C; Ship collision risk
Lifetime variation	No
Simplification? If yes; influence on risk level	
Information source	Statoil
Comment	
Status	

It would be very idealistic to have all the fields filled but as far as they are included, it is a wise choice to make the best estimates about them. Since the choice of the titles of fields seem informative enough and help the reader easily understand the basis for the assumption as well as its validity time and more importantly the impacts and influences on the total risk level and other parts of QRA. As for the example in this table the information source is just stated as to be Statoil but according to Espen Fyhn Nilsen, risk analysis specialist, Statoil ASA, it is not clear enough which kind of source at Statoil is meant; it could be a person or a guideline or a conversation over email etc.! It is also not so much clear what is meant by the ´status´ field. As for ´simplifications´, it might have been a good choice to state the simplifications made to establish this assumption since these simplifications could in themselves be counted as new sources of uncertainty.

In the end we would like to mention that the assumptions are considered an essential part of a QRA. Conclusively they should be as reliable as possible and presented as informatively as possible. In addition if assumptions are presented in detail along with subsequent hidden factors such as degrees of sensitivity and uncertainty associated with them, they would add up to the value of the risk results. Moreover, they will provide a clearer picture for interpretation of results for decision support purposes. For example, if the budgets for a project were limited, the priorities would be to apply risk reducing measures and improve assumptions with higher importance i.e. higher degrees of uncertainty and sensitivity.

Given the argument above, as a final part to this chapter, we would like to present the 5 assumptions discussed in chapter 5 in the following table. We have ranked the assumptions according to their assigned and assumed (based on our background knowledge and degree of belief) importance ranking:

Table 6.2 Assumptions ranking

Number	Assumption	Degree of uncertainty	Degree of Sensitivity	Degree of Importance
1	Manning Distribution (Operational)	High	High	High
2	Collision Resistance of Jack-up (Design)	High	High	High
3	Supply Vessel Visits (Operational)	High	Medium	High-Medium
4	Lifting Activities (Operational)	Medium	High	Medium-High
5	Equipment Count	Low	Medium	Low-Medium

The reasons and background information for assigning the rankings in the table above have been mentioned under discussion part of each assumption in chapter 5. In this part we would just limit our conclusion to the results presented in the table. One can see from the table that attention should be given to improve manning level and the design assumption in this report since they have been considered to be of higher criticality should a prioritization be made.

Note that in ranking place of 3 and 4, we have placed a higher emphasis in uncertainty rather than sensitivity for ranking assumptions as being important. It should be noted that there is a difference in presenting the importance of assumption as M-H or H-M. And in our opinion uncertainties are more challenging to deal with when dealing with an assumption compared with a sensitivity degree for this report, since Valemon platform has not been built yet, one should at this stage focus on the degree of uncertainties. However, it is always the combination of these two factors which defines the importance of an assumption.

For example, a high degree of uncertainty combined with high sensitivity could lead to the conclusion that the uncertainty factor has a significant effect on risk. However, if the degree of uncertainty is high but the risk and/or vulnerability indices are relatively insensitive to changes in the uncertain quantities, then the effect on risk could be minor or moderate. [s1]

And finally the equipment count assumption has been documented to have the lowest rank in importance analysis of the assumptions. Consecutively, if the assigned budget for this project is limited, this assumption would be set aside for a while since it is not affecting the risk picture considerable compared to other assumptions selected.

One should note that all discussions about ranking of assumptions are highly relative and based on the assessor`s background knowledge and subjective opinions.

Another important thing to consider regarding the discussions of assumptions, is that almost all assumptions mentioned for Valemon QRA are based on very background knowledge of the 6 assumed activity levels defined for Valemon and mentioned several times in this work. This underlying assumption could be ranked as “high” in both uncertainty and sensitivity basis. This is mainly die to Valemon platform not being built and operated yet.

However, we have not included this underlying assumption of different activity levels in the table above since according to [s1] the highlighted uncertainty factors (presented in Table 6.10) are related to potentially observable quantities and events.

Finally, a semi-quantitative approach offers practicality and the suggested method may serve as a screening of uncertainty factors. If an uncertainty factor is found to have a significant effect on risk and/or vulnerability, it could be selected for a more thorough treatment in the analysis. This may not always be possible though. In practice, a QRA will always have to be based on a certain background knowledge (including a number of assumptions and suppositions). The probabilistic analysis will not be able to reflect all uncertainties.[s1]

Chapter 7

7.Conclusions and Recommendations

In the beginning of this thesis work, we outlined some objectives. In the end, we would like to take a look at the work and see if we have answered all the questions proposed in the beginning of the work.

The main challenging purpose has been to define the role of assumptions in QRAs and also determining how important an assumption is relative to other assumptions mentioned in the QRA. This objective has been achieved by a thorough investigation of impact assessment of the assumptions with respect to other parts of the QRA and especially the risk results. We applied the suggested approach and checklists suggested by Aven [s1] in order to define an \`importance\` factor to the examples of assumptions.

Since future events are the main concern of any QRA, some uncertainties are always inherent about these future events and the world in general. One inevitable part of a QRA is called assumptions. Assumptions serve as uncertainty factors in a QRA since they are based on some uncertain background knowledge and will further build up new background knowledge for future assessments. In this work, we have focused on the role of assumptions in a QRA, their way of documentation and presentation and more importantly their importance relative to the overall risk description presented as results of a QRA.

Throughout this work, emphasis was made on how uncertainties will play a great role in any risk analysis. Uncertainty is seen as a main component of risk and the risk description. The reason is that probability is only a tool for expressing uncertainty. Surprises relative to the assigned probabilities could occur if the background knowledge on which the probabilities are conditioned turns out to be wrong.[s1] That is why we have been focusing on uncertainty factors and sources while discussing the examples of assumptions.

<u>Uncertainty factors description by investigating assumptions</u>

By choosing to go through the details of some assumptions and trying to define uncertainty and sensitivity levels for them, one might argue that we are just creating more and more uncertainties and uncertainty sources by extensive discussions around them and hence confusing the results. Well, if we look superficially enough, that might be correct but we always have to look beyond this. This is a misconception, according to Aven[3] that there are large inherent uncertainties in risk analysis when the purpose of the risk analysis is to describe the uncertainties and not accurately measuring them.

By breaking down and going through the details of one part of a QRA (assumptions), we are clarifying and explaining about the possible sources of uncertainty. We are not adding to uncertainties about the world, we are just acknowledging them so that we would be prepared for potential future events to some extent.

Importance of documenting assumptions

An important aspect in a QRA is to ensure a comprehensive documentation of assumptions and premises for the analysis. Assumptions and premises need to be documented where they belong in relation to calculations. In addition, there should be a summary of all assumptions and premises as a reference source.[4] There have been several standards and guidelines published with this respect.

As a result, initially, a detailed discussion has been made to justify the importance and the requirement for presenting and documenting assumptions. This has been done by emphasizing on the role of assumptions in QRA. And also we stated that there is a great deal of uncertainty both in developing these assumptions and by further using these assumptions for basis of future work. This was mainly due to diverse and different background knowledge the assumptions are based upon. See chapter 2.

Improvement of Assumptions

In chapters 3 and 4 and 5 which serve as the empirical part of this work, we introduced how these unknowns (uncertainties) are presented and dealt with in a typical risk analyses. There has been a great improvement over the years in presenting and documenting the assumptions in QRAs. And as years went by the importance and value of this quote " risk analysis is simply the consequence analysis of the assumptions" [20] seemed to be more and more captured by the risk analysts and parties involved in any parts of risk analyses. This has gone to the extent that some operator companies like Statoil published guidelines emphasizing on the importance of assumption section and categorization and description of the assumptions for their review and approval. Assumptions should be documented together with the influenced parts of the QRA by them so that assumption importance analysis could be carried out more practically and the impacts of assumption would be more noticeable (traceability of the assumption).

Approach for evaluating and raking assumptions

The main focus throughout this work has been to state there are always uncertainties hidden in the background knowledge of any assessor performing a risk analysis. This is mainly due to the unknown nature of future events to human beings. This uncertainty is mainly associated with assumptions made in a QRA. And since assumptions play a great role in a QRA, we have tried to define and address uncertainty sources with assumptions in a

QRA. We have discussed this matter about 5 main assumptions examples chosen from a recent QRA, Valemon report for Statoil.

According to Aven [], we have pointed to a stronger emphasis on uncertainties. It has been stated that the main calculation schemes and solid analytical results used today (in presenting the risk results) can be kept. What is new is a more comprehensive uncertainty assessment to better reflect possible surprises hidden in the background knowledge that the probability assignments are based on. A scheme for how to judge the importance of these uncertainty factors have been applied in this work according to Aven [s2,3], but further research and development is required to find practical procedures for treatment of uncertainty and assumptions specifically in QRAs related to oil and gas industry.

Difference in Background knowledge for establishing assumptions

In this work, it has been chosen that there are uncertainties about the future phenomena and the purpose of a risk assessment is to describe and reveal these uncertainties. But we should also pay attention to the fact that a risk analysis is being made by human being(s). And each person's background knowledge and degree of belief differs from those of another one. Uncertainties are out there in the world. However, the way we observe and describe them in the world could be different in many ways.

This difference between human beings ways of perception has to be accepted. (See section 2.3.3). Therefore if an assumption has to be justified by all participants in a QRA, the background knowledge of the analysts along with every sources of uncertainty detected should be mentioned and presented as well.

Generally, while we are dealing with a system, there are always uncertainties about the inputs, the operation of the system and the possible future outputs. The more complex the system is the more complicated it will be to observe and understand the uncertainty sources (factors) in a system.

While we are talking about QRAs for oil and gas which are normally very extensive and detailed assessment of facilities, it could be very challenging to mention and observe all sources of uncertainties. Additionally, one should acknowledge the role of human beings in the system as well. In addition to uncertain nature of future events in a QRA, having different human beings as part of the system all with their own specific and "unique" background knowledge and free will would complicate the system even more and introduces more sources of uncertainty to the system.

The requirement to look beyond the calculated risk results

In order to assess risk, we need solid calculations and results. Therefore we make some assumptions and base the rest of calculations in light of the assumptions. And further we should present the results along with their foundation; assumptions and presuppositions.
In this work, we have emphasized on the improvement of presenting assumptions along with their role of corresponding uncertainty and sensitivity in determining their criticality in a QRA report.

Solid results of a risk analysis without referring to assumptions are not useful especially on the long run. It is the presentation of the assumptions which makes a QRA a living study one could also use later on in the future.[4]

Therefore, we should not look at any system superficially and as a very certain and deterministic system. We should not let the fancy results of risk analysis deceive or mislead us by making us simply ignore the foundation behind them.
It is wise not depend only one possible state the system might work in. We would like to know and be prepared for the several other potential states of the system. And for that we need to know the different inputs to the system. The inputs in our work have been considered assumptions. In this work, we have in fact performed a consequence analysis of assumptions. We should be aware of uncertainties throughout the work and look beyond the expected values and probabilities. That is why we have presented assumptions together with their degree of importance according to their degree of uncertainty and sensitivity.
We have several times mentioned that we need to look beyond the expected values and calculated probabilities. In this work an effort has been made on where to look beyond these numbers. The missing piece has been the degree of uncertainties.

According to Aven [6], we have proposed a simple, practical method to classify uncertainty factors and thus characterize uncertainties that are not properly captured by probabilities and probabilistic risk indices. If left untreated these uncertainties could be lost and reduce the confidence in the analysis. The approach is based on a thinking where a broad risk description is reported, covering the probabilistic analysis, sensitivity analysis and the result of the uncertainty factor assessment, and this informs the decision maker—not prescribing what decision to be made.[]Presented with a risk description covering the components (P,S,U), the decision-maker must make an overall review and judgment.[6]

However, some might argue that the applied approach is somewhat simple and coarse since the scoring criteria for the approach are mostly case and knowledge-based. Nevertheless, this somewhat simple approach helps develop a clearer picture for interpretation of risk results for managerial review and judgment. And nevertheless, developing and improving new criteria for ranking uncertainty factors is recommended in further studies.

Chapter 8

8.Recommendations and further studies

What we have done in this work besides justifying the requirements for assumptions and the presentation and classification of them in a QRA, has been to point out the importance of assumptions in a QRA. We have done this by assessing the impacts of assumptions semi-quantitatively as suggested by Aven[s1,2]. We have stated that it is more practical to present the degree of combination of uncertainty and sensitivity (importance) along with the calculated and estimated risk results. By fulfilling this, we are practically encouraging the reader to look beyond just mere numbers or calculations of expected values, probabilities and distributions and detect the uncertainty role in the results. However, we have not seen this classified and extended approach for documentation of uncertainty factors in the reviewed examples of QRAs in this work. Therefore one recommendation for further work could be to focus on presenting the importance analysis for assumptions along with their uncertainty and importance ranking degree. Checklist and criteria for ranking assumptions as important could also be further investigated and improved.

Moreover, it is recommended for further developing a clear picture of the role of assumptions in a QRA, that a more detailed (perhaps more quantitative) sensitivity analysis for assumptions ranking is done. There are normally a great number of assumptions made in a QRA, hence, it might be challenging and time consuming to provide sensitivity analysis for all of them. Therefore we recommend that by investigating and comparing the results of somewhat simplified impacts assessments of assumptions on total risk level and the importance ranking introduced[6,7], only more critical assumptions be chosen for this purpose. A more thorough and detailed sensitivity analysis for improvement of those assumptions is then recommended. As a very common example of `important` assumptions in most QRA reports, manning level can be mentioned. It is considered one of the most challenging assumptions when it comes to uncertainty and sensitivity analysis.

9.Final Word

The presentation and documentation of assumptions made in a QRA, besides all the advantages that will create including introducing the uncertainty sources and background knowledge defining the foundation for the risk calculations and thus making the participants see beyond the results, is just another ways of communication of risk results.

The analyst is basically trying to inform others involved in the analysis about his ideas, degree of belief and background knowledge of certain phenomena. So assumptions help create an easier way for the message to be passed along.

Generally, risk communication is another topic in risk management and is considered an important task. Discussions on risk communication, however, are beyond the scope of this work. But since we have emphasized so many times that the purpose of risk analysis is to support decision making and communication is considered to have a great influence in this aspect, we would like to refer to an example about different ways of presenting risk.

According to Kahneman[51]:

> Low probability events are much more heavily weighted when described in terms of relative frequencies (how many) than when stated in more abstract terms of “chances”, “risk” and “probability”(how likely).
>
> In one experiment, professionals evaluated whether it was safe to discharge from the psychiatric hospital a patient with a history of violence, Mr.Jones.
>
> The information they received included an expert`s assessment of the risk. The same statistics were described in two ways.
>
> - Patients similar to Mr. Jones are estimated to have a 10% probability of committing an act of violence against others during the first several months after discharge.
>
> - Of every 100 patients similar to Mr. Jones , 10 are estimated to commit an act of violence against others during the first several months after discharge.
>
> The professionals who saw the frequency format were almost twice as likely to deny the discharge (41% compared to 21% in the probability format).
>
> Therefore, the effect of frequency format is larger and consecutively, the more vivid description produces a higher decision weight for the same probability.

Vivid Probabilities From the Thinking, Fast and Slow book by Daniel Kahneman[51]

As a final word, assumptions are important in a QRA based on their degree of uncertainty and sensitivity, which is gained through impact (consequence) analysis of them with respect to other parts of a QRA. In addition to degree of validity and reliability to assumptions, the way they are presented is also of great importance

As a result, one should be aware of the way of presentation of results and assumptions. This is important especially when it comes to communication of risk and managerial review and judgment for decision support. Poor presentation of assumptions could lead to bad communication of results and poor judgments eventually.

The main message is we shouldn't be deceived by the fancy results of a risk analysis and no matter in what way assumptions, uncertainties or results are presented, an interpreter of the results should be wise enough to look and know beyond the solid results. And that is achieved by the power of reasoning and thinking that we humans are blessed with. It is in light of our experiences and reason that we gain knowledge. *And knowledge is the key factor to victory*.[38]

However, we should accept that our knowledge is not as extensive as to foresee future events and therefore we just accept some uncertainties exist with any future activity and there is always a possibility of a surprise no matter how deterministic a system is.

We should therefore try to understand the sources of uncertainty and try to take preventive measures for undesired consequences; in other words, we should be prepared for these surprises to the possible extent. The risk analysis is just widening this extent. It does not increase, uncertainties. It increases our knowledge about uncertainties. Therefore we will know more that we don't know!!'

If we know that we still do not know much, we will try to know more and so in we learn.

To end this work here, we would like to refer to a famous saying about different approaches for knowledge. The original quote is in Persian; a translation has been provided:

> *The person who knows and knows that he knows, glides his horse of honor over the blue revolving skies.*
>
> *The person who knows but doesn't know that he knows, awaken him or else he shall remain forever unaware that he knows.*
>
> *The person who doesn't know and knows that he doesn't know, will struggle, but he will get somewhere somehow.*
>
> *The person who doesn't know and doesn't know that he doesn't know, is condemned to everlasting darkness of ignorance.*
>
> *(Attributed to Nasir al-Din al-Tusi, Persian mathematician and philosopher, (1201-1274))*

REFERENCES

[1] Aven, T., (2008), *Risk Analysis: Assessing uncertainties beyond expected values and probabilities,* University of Stavanger, Norway, ISBN: 9780470517369, Published by John Wiley and Sons, Ltd

[2] Aven, T., (2011), *Quantitative Risk Analysis :the scientific platform*, ISBN: 9780521760577, Published by Cambridge University Press, UK

[3] Aven, T., (2010), *Misconceptions of Risk*, ISBN: 9780470683880, Published by John Wiley and Sons Ltd,UK

[4] Vinnem, J.E., (2007), *Offshore Risk Assessmet:Principles, Modelling and applications of QRA studies, 2nd edition*, ISBN: 9781846287169, Published by Springer-Verlag London Limited,UK

[5] Aven, T. and Vinnem,J.E., (2007), *Risk Management with applications from the offshore petroleum industry*, ISBN: 978184626520, Published by Springer -Verlag London Limited, UK

[6] Aven, T. and Flage, R., (2009), *Expressing and communicating uncertainty in relation to quantitative risk analysis*, University of Stavanger, Norway

[7] Aven, T and Selvik,J.T., (2010*), A framework for reliability and risk-centered maintenance*, University of Stavanger and IRIS , Norway

[8] Aven, T. and Milazzo, M.F. (2011), *An extended risk assessment approach for chemical plants applied to a study related to pipe ruptures*, University of Stavanger, Norway, University of Messina, Italy

[9] Randi, V., (2011), *Master Thesis: A further development of the Extended Risk Based Inspection methodology – guidelines and performance*, University of Stavanger, Norway

[10] NORSOK Standard Z-013, edition 3, (2010), *Risk and emergency preparedness assessment*

[11] Statoil Guideline GL0282, (2010), *Guidelines for risk and emergency preparedness analysis*

[12] Facts 2012, Norwegian Petroleum sector available at :
http://npd.no/en/Publications/Facts/Facts-2012/ accessed May 2012

[13] Azeri, Chirang & Gunashli, (2004), *full filed development Phase 3,Environmental and soci-economic impact assessment*

[14] Safety and Oil Spill Prevention Audit, DCOR Platform Eva DCOR LLC, Oil Company, *Mineral*

Resources Management Division, Safety Audit 2010, California State Lands Commission

[15] Ferdous R.,Khan F., Sadiq R., et al, (2011) Journal: *Analyzing system safety and risks under uncertainty using a bow-tie diagram: An innovative approach,* Canada

[16] Giuseppe Curcurùa, Giacomo Maria Galantea, **Epistemic uncertainty in Fault Tree Analysis approached by the Evidence Theory** , Palermo, Italy

[17] *Valemon TRA main report* (2012), Lilleaker Consulting AS, Gjettum, Norway

[18] *TRA of Valemon; Appendix K; Assumptions*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[19] *TRA of Valemon; Data dossier – Attachment A7 Vessel Collisions*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[20] *TRA of Valemon, Appendix C; Vessel collision risk*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[21] *TRA of Valemon, Appendix I; Input to DAL*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[22] *TRA of Valemon, Appendix J; Other accidents*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[23] *TRA of Valemon, Appendix F; Process Accidents*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[24] *TRA of Valemon: Appendix F- Attachment F1, Equipment Count*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[25] *TRA of Valemon, Appendix G; Dropped objects*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[26] *Appendix A - Attachment A6, Dropped Objects*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[27] *TRA of Valemon, Appendix A; Data dossier*, (2012), Lilleaker Consulting AS, Gjettum, Norway

[28] *Energy Report, Leismer CPF Facility QRA*, (2008), Det Norske Veritas, Canada

[29] *Aker Spitsbergen - Risk Assessment of Riser Operations*, (2009), Scandpower, China

[30] *Design Accident Loads and Concept Risk Assessment for the Statoil Bressay Concept Study Project*, (2010), Risktec Solutions Limited, UK

[31] *QRA Kalundborg Main Report*, (2010), Scandpower As, Trondheim, Norway

[32] *QRA Kalundborg, Technical Note 1: RAC and System Description,* (2010), Scandpower As, Trondheim, Norway

[33] *QRA Kalundborg, Technical Note 2: Assumptions,* (2010), Scandpower As, Trondheim, Norway

[34] *QRA Kalundborg, Technical Note 3: Process Leak analysis*, (2010), Scandpower As, Trondheim, Norway

[35] Emails From Nilsen, E.F. (2012), Assumptions, Risk Analysis, etc.

[36] Vinnem, J.E, (2011), *Compendium: Applied Risk analysis*, University of Stavanger, Norway

[37] Gudmestad, O.T, (2010), Compendium: *Marine Technology and Design*, University of Stavanger, Norway

[38] Nilsen, E.F., (2001), *Doctoral Thesis: Economic Accidental Risk Analysis,* Norwegian University of Science and Technology, Trondheim, Norway

[39] Thompson, K.M., (2002), *Variability and Uncertainty Meet Risk Management and Risk Communication*, Society for Risk Analysis

[40] Epistemology and approaches towards Knowledge fundamentals available at :

http://www.importanceofphilosophy.com/Epistemology_Fundamentals.html

accessed: February 2012

[41] Philosophers, Ideas and Propositions available at:

http://www.philosophypages.com/hy/5g.htm accessed February 2012

[42] Standford Encyclopedia of Philosophy,

http://plato.stanford.edu/entries/kant-judgment/ accessed march 2012

[43] Synthetic a priori proposition by Kant :

http://www.britannica.com/EBchecked/topic/578646/synthetic-a-priori-proposition

accessed may 2012

[44] Aven, T., (2012), *On the meaning of a black swan in a risk context*, University of Stavanger, Norway

[45] Intro to Philosophers and philosophy available at:
http://www.spaceandmotion.com/Philosophy.htm Accessed: May 2012

[46] Rationalism versus Empiricism
http://www.newworldencyclopedia.org/entry/Rationalism Accessed : February 2012

[47] Kant: The "Copernican Revolution" in Philosophy available at:

http://instruct.westvalley.edu/lafave/KANT.HTM
Accessed: March 2012

[48] Philosophers and theories available at:
http://www.netplaces.com/philosophy-book/the-three-sages-socrates-plato-and-aristotle/plato.htm Accessed: March 2012

[49] Kant`s propositions available at :
http://www.sparknotes.com/philosophy/kant/themes.html/
Accessed at June2012

[50] Bakke, J.R., (2011), Compendium: *Technical Safety*, University of Stavanger, Norway

[51] Kahneman, D. (2011), *Thinking, fast and slow*, ISBN: 9780141033570, Published by the Pinguin Group, England

Appendices
Appendix A
Appendix B
Appendix C
Appendix D
Appendix E
Appendix F
Appendix G
Appendix H

APPENDIX A: Philosophers and Epistemology

Aristotle (Greek, Empiricist) (384-322 BCE)

Theory of forms cannot be proved since it cannot be experienced or sensed

Essence of things, not separately in "the other world" but exists as an integral >> universals
Theory of Potentiality:
Within everything, people included exists a natural evolution towards fulfilling its own potential, in essence, becoming its own form!
Both inductive and Deductive

Spinoza (Dutch, rationalist, monist) (1632-1677)

Metaphysical monist (one entity: God, Nature)

Believes in one substance; other things are attributes, modes or modifications of that only substance through operation of necessity

Truth and Falsity

Adequate and Inadequate ideas

Three kinds of knowledge:

- From random experience and imagination
- From common notions
- From Intuition

Hume (Scottish, empiricist and skeptic) (1711-1776)
Certainty is a vague concept
You cannot learn something until you experience it
Subjective views based on subjective experiences
That sets different reference points in the eyes of the assessor, based on different backgrounds and experiences

The only certainty is that nothing is certain!

Plato (Greek, rationalist) (429-347 BCE)
There exists a "real", "perfect" world beyond our perception

Ideas (opinions) vs True knowledge (facts, science, forms)

Senses are good to get in touch with reality but REASONING needed to approach the forms

Descartes (French, Rationalist) (1596-1650)

Deep insight into his own nature by thought alone; mind is simple, math is the solution

People are misled by putting too much faith into their senses only.

Cartesian doubt; being skeptical of one`s beliefs

Everything could be questioned but self-awareness; I think, therefore I am!

Kant (German, Both Rationalist and Empiricist) (1724-1804)

Aimed to unite reason with experience

Hoped to end an age of Speculation

Opposing: Plato, Descartes, Hume

Copernican Revolution: objects must conform to our cognition

Epistemology:[40][41][42][46]

History and Philosophy **Empricist vs Rationalisim viewpoint:**

Summary of Rationalism

The paradigm rationalist philosophers are Plato (ancient); Descartes, Spinoza, Leibniz (modern).

1. Don't trust senses, since they sometimes deceive; and since the "knowledge" they provide is inferior (because it changes).

2. Reason alone can provide knowledge. Math is the paradigm of real knowledge.

3. There are innate ideas, e.g., Plato's Forms, or Descartes' concepts of self, substance, and identity.

4. The self is real and discernable through immediate intellectual intuition (*cogito ergo sum*).

5. Moral notions are comfortably grounded in an objective standard external to self — in God, or Forms.

Kant says rationalists are sort of right about (3) and (4) above; wrong about (1) and (2). Kant would like (5) to be true.

Summary of Empiricism

The paradigm empiricist philosophers are Aristotle (ancient); Locke, Berkeley, Hume (modern).

1. Senses are the primary, or only, source of knowledge of world. Psychological atomism.

2. Mathematics deals only with relations of ideas (tautologies); gives no knowledge of world.

3. No innate ideas (though Berkeley accepts Cartesian self). General or complex ideas are derived by abstraction from simple ones (conceptualism).

4. Hume — there's no immediate intellectual intuition of self. The concept of "Self" is not supported by sensations either.

5. Hume — no sensations support the notion of necessary connections between causes and effects, or the notion that the future will resemble the past.

6. Hume — "is" does not imply "ought". Source of morality is feeling.

Kant thinks empiricism is on the right track re (1), sort of right re (2), wrong re (3), (4), (5), and (6).

Plato

Plato`s belief is anything you think you see is only the idea of what you think it is!

Plato believes that we're living in the world of images and shadows and that the "real" world exists elsewhere.

Knowledge is fourfold, according to Plato.

- The knowledge from imagination, dreams, and what was later called the unconscious
- Our perceptions of the outside world
- Mathematical knowledge
- Philosophical knowledge, which was Big Picture knowledge, an awareness of absolutes, universal truths in the form of those elusive Forms

Plato called the first two mere opinions, because while perception may be reality, things are perceived differently by different people. The second two were True Knowledge, because Plato believed that two plus two would never equal five, and Forms are immutable, eternal truths not to be messed with.

“In the visible realm things are always changing and nothing is absolute where as intellectual truths will always be true throughout time.”

Plato believed that there was another world beyond this changeable and destructible one in which we live, one consisting of unchanging eternal Forms. He asserted that what we see and touch are only very distantly related to the ultimate realities that exist.[40][41]

Descartes

The French philosopher René Descartes, whose *Meditations on First Philosophy* defined the course of much philosophy from then up till the present day, stood near the beginning of the Western European Enlightenment. Impressed by the power of mathematics and the development of the new science, Descartes was confronted with two questions: How was it that people were coming to attain such deep knowledge of the workings of the universe, and how was it that they had spent so long not doing so?

Regarding the latter question, Descartes concluded that people had been mislead by putting too much faith in the testimony of their senses. In particular, he thought such a mistake was behind the then-dominant physics of Aristotle. Aristotle and the later Scholastics, in Descartes' mind, had used their reasoning abilities well enough on the basis of what their senses told them. The problem was that they had chosen the wrong starting point for their inquiries.

By contrast, the advancements in the new science (some of which Descartes could claim for himself) were based in a very different starting point: The "pure light of reason." In Descartes' view, God had equipped humans with a faculty that was able to understand the fundamental essence of the two types of substance that made up the world: Intellectual substance (of which minds are instances) and physical substance (matter). Not only did God give people such a faculty, Descartes claimed, but he made them such that, when using the faculty, they are unable to question its deliverances. Not only that, but God left humanity the means to conclude that the faculty was a gift from a non-deceptive omnipotent creator.[42][43]

Hume

Hume's Philosophical Contribution:

Hume's contribution to the development of philosophy spans across all the discipline. His skeptical doubts concerning the relationship between cause and effect as well as the existence of substances (including the first person) are to date the starting points for research on those topics: they pose some of the deepest challenged to the possibility of any metaphysical inquiry, as already Kant realized. But, Hume has given substantial contributions also to the ethical theory, in which he defended a version of sentimentalism, a popular view at the time in England already defended among others by Adam Smith. Hume's account of religion, fully spelled out in the posthumously published Dialogues Concerning Natural Religion (1779), also constitutes a key stone in the history of theological thinking, mining all attempts to construe theological knowledge on rational grounds. In general, Hume systematically criticized all those philosophical ideas, theories, and methodologies relying on rationalistic grounds; because of this, he is regarded as probably the main champion of empiricism in the history of Western thought.

Spinoza:

Spinoza was a metaphysical monist. This means that he defended the view that there is only one entity. According to him, that entity is God. Everything that exists is in God, is a way in which God is. More technically speaking, Spinoza called the ways in which God may be attributes or modifications of God. Let’s see more closely what they are.

> These are the fundamental concepts with which Spinoza sets forth a vision of Being, illuminated by his awareness of God. They may seem strange at first sight. To the question "What is?" he replies: "Substance, its attributes, and modes". ”

— Karl Jaspers [46][41]

Aristotle

For Aristotle, "form" still refers to the unconditional basis of phenomena but is "instantiated" in a particular substance (see Universals and particulars, below). In a certain sense, Aristotle's method is both inductive and deductive, while Plato's is essentially deductive from a priori principles.[18]

In Aristotle's terminology, "natural philosophy" is a branch of philosophy examining the phenomena of the natural world, and includes fields that would be regarded today as physics, biology and other natural sciences. In modern times, the scope of philosophy has become limited to more generic or abstract inquiries, such as ethics and metaphysics, in which logic plays a major role. Today's philosophy tends to exclude empirical study of the natural world by means of the scientific method. In contrast, Aristotle's philosophical endeavors encompassed virtually all facets of intellectual inquiry.[48][42]

Kant:[49][47]

"Kant(1724-1804) named his branch of epistemology Transcendental Idealism, and he first laid out these views in his famous work The Critique of Pure Reason. In it he argued that there were fundamental problems with both rationalist and empiricist dogma. To the rationalists he argued, broadly, that pure reason is flawed when it goes beyond its limits and claims to know those things that are necessarily beyond the realm of all possible experience: the existence of God and free will. Kant referred to these objects as "The Thing in Itself" and goes on to argue that their status as objects beyond all possible experience by definition means we cannot know them.

To the empiricist he argued that while it is correct that experience is fundamentally necessary for human knowledge, reason is necessary for processing that experience into coherent thought. He therefore concludes that both reason and experience are necessary for human knowledge.

The philosophy of Immanuel Kant is sometimes called the "Copernican revolution of philosophy" to emphasize its novelty and huge importance. Kant synthesized (brought together) rationalism and empiricism. After Kant, the old debate between rationalists and empiricists ended, and epistemology went in a new direction. After Kant, no discussion of reality or knowledge could take place without awareness of the role of the human mind in constructing reality and knowledge.

The following important theory developed in that period is the Kantian synthesis *of rationalism and empiricism. According to Kant, knowledge results from the organization of perceptual data on the basis of inborn cognitive structures, which he calls "categories". Categories include space, time, objects and causality. This epistemology does accept the subjectivity of basic concepts, like space and time, and the impossibility to reach purely objective representations of things-in-themselves. Yet the a priori categories are still static or given."*

APPENDIX B : Kant`s Propositions and Assumptions in QRAs

Kant`s synthetic a priori:[43][49]

> As Kant's ingenious solution is that synthetic a priori knowledge is possible because our mental faculties organize experience according to certain categories so that these categories become necessary and universal features of our experience. For instance, we do not find causation in nature so much as we cannot not find causation in nature. It is a feature of the way our minds make sense of reality that we perceive causes and effects everywhere at work. For Kant, then, the category of the synthetic a priori is the key to explaining how we gain substantive knowledge about the world.

Great emphasize has to be made on distinguishing between describing facts or what has been accepted as facts and system description in a QRA and what cannot be accepted as facts since they are not universally true and they have some references to experience, those that are in turn called assumptions or premises in a QRA which have references directly based experience.

Definition of assumptions can in a way be justified with Kant`s proposed term of synthetic a priori as a term versus analytic a priori which, on the other hand, could represent what is considered to be `facts` in a QRA.

Analytic a priori is defined by Kant as something (some statement) that the conclusion is contained in the definition with no reference to experience; it is basically the way it is. These analytic a priories according to Kant are therefore non-informative. Synthetic a priori is however when some new information that has its source on experience has been added to the definition of a fact; therefore adding new information to those already accepted facts. The definition of a priori versus a posteriori is as follows:

A priori knowledge or justification is independent of experience (for example "All bachelors are unmarried"); a posteriori knowledge or justification is dependent on experience or empirical evidence (for example "Some bachelors are very happy"). A posteriori justification makes reference to experience; but the issue concerns how one knows the proposition or claim in question—what justifies or grounds one's belief in it.

In the writer`s opinion, when referring to facts, one actually talks about analytic a priories and when talking about an assumptions, however, one uses a synthetic a posteriori by adding some new information on the basis of observations (experiences) to an already accepted a priori (a fact).
So synthetic truths are true in virtue of the kind of experience we have and we treat assumptions in this work as such statements.(Once again relate a symbiosis that Kant made between rationalists and empiricists.)

After a QRA has been done and assumptions have been documented, it is possible that during or at the end of the lifetime of a facility for example Valemon here, these synthetic a priories will change to a posteriories since they will be known by experience. A synthetic a priori therefore, adds to our knowledge and is gained through knowledge.

In general the truth or falsity of synthetic statements is proved only by whether or not they conform to the way the world is (experiences) and not by virtue of the meaning of the words they contain. Note that the role of deduction and reasoning has not been denied here; it has been applied in evaluating the added information to the accepted fact.

It is worth mentioning that our knowledge would be limited to the phenomena and we may be totally unaware of the noumena in itself. According to Kant, it is vital always to distinguish between the distinct realms of phenomena and noumena. Phenomena are the appearances, which constitute our experience; noumena are the (presumed) things themselves, which constitute reality. All of our synthetic a priori judgments apply only to the phenomenal realm, not the noumenal one. (It is only at this level, with respect to what we can experience, that we are justified in imposing the structure of our concepts onto the objects of our knowledge.) Since the thing in itself (Ding an sich) would by definition be entirely independent of our experience of it, we are utterly ignorant of the noumenal realm.

Thus, on Kant's view, the most fundamental laws of nature, like the truths of mathematics, are knowable precisely because they make no effort to describe the world as it really is but rather prescribe the structure of the world as we experience it. By applying the pure forms of sensible intuition and the pure concepts of the understanding, we achieve a systematic view of the phenomenal realm but learn nothing of the noumenal realm. Math and science are certainly true of the phenomena; only metaphysics claims to instruct us about the noumena. [46][47][49]

APPENDIX C: Decision Making Under Uncertainty; cautionary and precautionary approach

Main challenges with Risk Management, Assessment and Analysis(chapter 2)

The main challenge present yet most of the time hiding in all different steps of risk assessment, management and analysis is the issue of *uncertainty.*

Uncertainty is an inseparable part of risk yet it is hidden at a superficial evaluation of any risk assessment. The impacts of uncertainty, however, are revealed if one takes a more close attention.

As an example, the main challenge of risk management is **Decision-making under uncertainty.**

Risk management often involves decision-making in situations characterized by high risk and large uncertainties, and such decision-making presents a challenge in that it is difficult to predict the consequences (outcomes) of the decisions.

In high-risk situations, various decision-making strategies can form the basis for the decision. By "decision-making strategy" we mean the underlying thinking and the principles that are to be followed when making the decision,

A decision-making strategy takes into consideration the effect on risk (as it appears in the risk analysis) and the uncertainty dimensions that cannot be captured by the analysis. The result is thus decisions founded both in calculated risk and applications of the cautionary principle and precautionary principle. The cautionary principle means that caution, for example by not starting an activity or by implementing measures to reduce risks and uncertainties, shall be the overriding principle when there is uncertainty linked to the consequences, i.e. when risk is present (HSE 2001, Aven and Vinnem 2007). The level of caution adopted will, of course, have to be balanced against other concerns, such as costs. However, all industries would introduce some minimum requirements to protect people and the environment, and these requirements can be considered justified by reference to the cautionary principle. In the face of uncertainties related to the possible occurrences of hazardous situations and accidents, we are cautious and adopt principles of safety management, such as:

Thus the precautionary principle may be considered a special case of the cautionary principle, as it is applicable in cases of scientific uncertainties (Sandin 1999, Löfstedt 2003, Aven 2006). There are, however, many definitions of the precautionary principle:

The precautionary principle is the ethical principle that if the consequences of an action, especially the use of technology, are subject to scientific uncertainty, then it is better not to carry out the action rather than risk the uncertain, but possibly very negative, consequences.

Challenges of current risk assessment: [2]

Many researchers and analysts have questioned the scientific quality of risk assessments (Aven, 2010a,h,i). For example, O'Brien (2000) argues that risk assessments generally serve the interests of business (i), as well as government agencies (ii) and many risk analysts (iii). She writes:

> (i) The risk assessment gives the industry the aura of being scientific. The risk assessments show that the activities are safe, and most of us would agree that it is rational to base our decision-making on science. **The complexity of a risk assessment makes it difficult to understand its**

premises and assumptions if you are not an expert in the field. In a risk assessment there is plenty of room for adjustments of the assumptions and methods to meet the risk acceptance criteria. In the case of large uncertainties in the phenomena and processes studied, the industry takes advantage of the fact that in our society safety and environment-affecting activities and substances are considered innocent until "proven guilty". It takes several years to test for example whether a certain chemical causes cancer, and the uncertainties and choice of appropriate risk assessment premises and assumptions allow interminable haggling.

(ii) Risk assessment processes allow governments to hide behind "rationality" and "objectivity" as they permit and allow hazardous activities that may harm people and the environment (O'Brien, 2000, p. 106). The focus of the agencies is then more on whether a risk assessment has been carried out according to the rules, than on whether it provides meaningful decision support.

(iii) Risk analysts know that the assessments are often based **on selective information, arbitrary assumptions and enormous uncertainties**. Nonetheless they accept that the assessments are used to conclude on risk acceptability.

This critique of risk assessment is supported by many other researchers. Reid (1992) argues **that the claims of objectivity in risk assessments are simplistic and unrealistic. Risk estimates are subjective, and there is a common tendency of underestimation of the uncertainties**. The disguised subjectivity of risk assessments is potentially dangerous and open to abuse if it is not recognized. According to Stirling (2007), **using risk assessment when strong knowledge about the probabilities and outcomes does not exist is irrational, unscientific and potentially misleading**. Renn (1998) summarizes the critique drawn from the social sciences over many years and concludes that technical risk analyses represent a narrow framework that should not be the single criterion for risk identification, evaluation and management. Tickner and Kriebel (2006) particularly stress the tendency of decision-makers and agencies not to talk about uncertainties underlying the risk numbers. Acknowledging uncertainty can weaken the authority of the decision maker and agency, by creating an image of being unknowledgeable. **Precise numbers are used as a facade to cover up what are often political decisions.**

The answer to this critique is, according to O'Brien (2000), to look for an alternative to risk assessments. But in our view there is no alternative to risk assessments: to support the decision-making we need to assess risk. **The right way forward is not to reject risk assessment, but to improve the tool and its use.** The challenge is how decision-making on risk can be informed by the best available technical and scientific knowledge. We need to strengthen the quality of the risk assessments and the associated risk assessment process, to meet the above critique. However, to be able to do this we need to be precise on the fundamentals of the risk assessments and we need to establish a suitable framework for being able to make judgments about the scientific quality of the risk assessments. Addressing the basic building blocks of the risk assessments, for example related to how to understand and describe risk and uncertainties, we can contribute to this end and are then able to study the two fundamental scientific requirements: reliability and validity of the risk assessments. The reliability requirement is concerned with the consistency of the "measuring instrument" (analysts, methods, procedures), whereas validity is concerned with the assessment's success at "measuring" what one set out to "measure". This analysis also provides insights on how to manage risk and in particular how to define and use managerial review and judgment in a practical decision-making context.

We may all acknowledge that safety-related decision-making should be risk-informed, but practice shows that it is common to apply risk-based approaches. This may be a result of a more or less conscious management strategy but as we will see from the analysis in the coming chapters, it is strongly influenced by the adopted scientific approach to risk. [2]

APPENDIX D: Bayesian Approach and Risk [2][4][13][14]

Bayesian approach:

The subjectivist interpretation of probability is often called the Bayesian standpoint, after Thomas Bayes (1702-1761) who proved a special case of what is now called Bayes theorem.

Introducing two approaches towards events in universe
A word on probability approaches

Probability

1) Classical

The probability is an "objective" entity and is equal to the long-term (relative) frequency of an event.

The probability of an event may be estimated on the basis of experience data, or based on symmetry arguments (e.g., for a dice)

2) Bayesian

The probability is a "subjective" measure of my belief about

a situation, about the occurrence of an event, or about the truth of a statement.

"What is the probability that San Fransisco is north of Madrid?" (This statement has no meaning for a classical statistician).

Traditional statistical inference

Traditional statistical inference is based on the following thinking: obser- vations are sampled from a large population of units. Variations within the population and sample are described using a stochastic model; and combining the data and the model, conclusions are made on performance measures related to the whole population, or specific units of the population.

Bayesian theory

Traditional Bayesian theory is based on the use of subjective probabilities to express uncertainties about unknown quantities, both observable quantities of the world and parameters of models of the world. Probability theory is used to manipulate the probabilities. The probabilities are updated when new information becomes available in a coherent way using Bayes' formula.

Bayesian decision analysis includes, in addition to this, specification of utilities for possible outcomes of decision alternatives, and the use of the maximum expected utility as a decision criterion.

According to Vinnem[4]

Risk quantification is often characterized by a mixture of the classical statistical approach and the Bayesian (subjective) approach. Most professionals are trained in the former approach. Where the probability of end events is considered to be independent of the analyst, and as a quantity

characterizing the object being studied. The classical concept of probability implies that the results of risk analyses are calculations (estimations) of these "true probabilities`.
The latter is the Bayesian approach- which is the basis of this thesis work-where the concept of probability is used to express the analyst`s measure of uncertainty or degree of belief.
The classical approach assumes that there is a true value of risk and that uncertainties may be expressed by distributions around the expected values, which then should be determined.

The Bayesian approach is based on the premise that the risk expressions are the characteristics of uncertainty about what will be the future experience with respect to accidents and fatalities.

APPENDIX E: Vessel Collision Risk Calculations (Chapter 5, Example 1)[19][20]

Vessel Collision Risk; The main consequence corresponding to the assumption of number of vessel visits:

Since the importance of the collision risk is considered significant, a through and total Vessel Collision Risk for the Valemon platform and the jack up rigs have been carried out based on the historical data provided in data dossier and the results have been attached and document to the main TRA report. Collision frequencies, hit velocity distributions and weight distributions are applied here based on that.
The relevant vessel types for the Valemon field are passing vessels, fishing vessels and supply vessels serving Valemon. But since our assumption here mainly concerns the supply visits, we will limit our discussion only to supply vessels.
Collisions onto the jack-up rig, which can affect Valemon main structure, are also considered

Supply Vessel collision Risk

Supply vessel collisions can occur as the supply vessel is approaching the unit, or during maneuvering or loading operations in the vicinity of an offshore installation. Most supply vessel impacts are low energy impacts while performing operations close to an installation.

Some of the immediate effects caused by any potential collision of the vessel and platform were mentioned above. For example a collision can lead to loss of a main safety function, such as the control room, the evacuation/escape route or the structural load bearing capacity for the design basis[13,14]
Additionally, some collisions might have very severe consequences; therefore, we will discuss the risk of collisions, to some extent in order to emphasize on the potential consequences.

One of the very important aspects about collision study is the calculation of the Impact energy the collision will cause. As a result the calculated (estimated) value would set the grounds for design basis of different parts of the structure. We will not go through the detailed method of calculation of these impact energies in this thesis work.

But it is worth mentioning that the number of supply vessel visits (our underlying assumption for ship collisions) do not serve as contributors to impact energy, they only affect the collision frequency. Other factors such the size and displacement and added mass of a vessel as well as the velocity at impact are main contributors to impact energy estimation. Supply vessel collisions can occur as the supply vessel is approaching the unit, or during maneuvering or loading operations in the vicinity of an offshore installation. Most supply vessel impacts are low energy impacts while performing operations close to an installation because of the low speed rate which is one of the contributors to impact energy calculations. Although the speed of the visiting or attending vessel is not of great value, due to considerable visiting frequency (fair number of supply vessel visits to the platform) the risk, associated with them is not only negligible but also considerable according to the FAR distribution diagram of different accident categories (fig 4.5)

Based on the argument above and also since the assumption is directly related to collision frequency calculation, we will briefly introduce the model that has been used in this report for visiting vessel collision frequency estimation [19]. Some new assumptions have been used when out of necessity.

Introducing the model (method) for calculating the impaiemnet frequencies

- **First Step** : Historical collision frequencies have been documented. Supply vessel and other vessel collisions can occur as the vessels are approaching the installation, or during maneuvering or loading operations in the vicinity of an offshore installation.

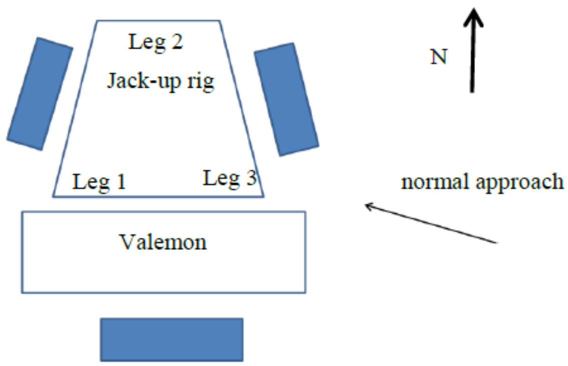
There are some assumptions listed in this section that need to be considered:

- *The collision frequency for attending vessels is lower for fixed installations than for mobile installations*
- *Further, it is assumed that on average, the NCS installations have 150 vessel visits per year (based on Statoil reference)*
- *Activity levels 1,4 and 5 are treated equally, since number of visits are equal. The same is done for activity level 2 and 3.*

- **Second step: Conditional probabilities given a collision**

When approaching Valemon or jack-up rig from onshore, the normal approach will be from east-southeast. Valemon with jack-up as one "unit" has a somewhat larger footprint than Valemon standing alone, but this is not judged to significantly increase the collision frequency for approaching supply vessels. It is assumed that 50% of the collisions will hit the jack-up, and that the remaining 50% will hit the Valemon jacket. (Assumptions, knowledge-based probabilities)

When operating near the platforms, supply vessels have two loading positions at jack-up rig and one loading position near Valemon, as illustrated in Figure 4.9. It is assumed that the conditional probabilities for hitting Valemon and jack-up rig are 40% and 60%, respectively.



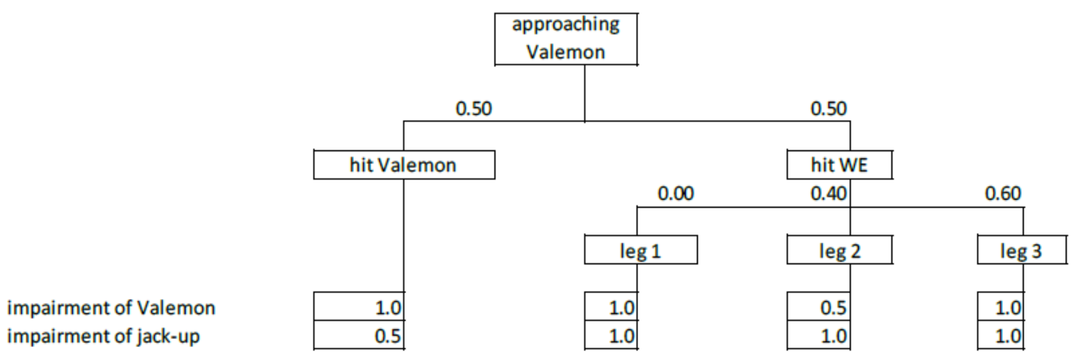
Appendix E fig.1 Loading positions for supply vessels (blue boxes)

There are some assumptions applied for this section as well:
Assuming loading in lee position, supply vessels are 60% in west position and 40% in east position, given the wind data for the field, ref. /6/.(Assumption based on historical knowledge)

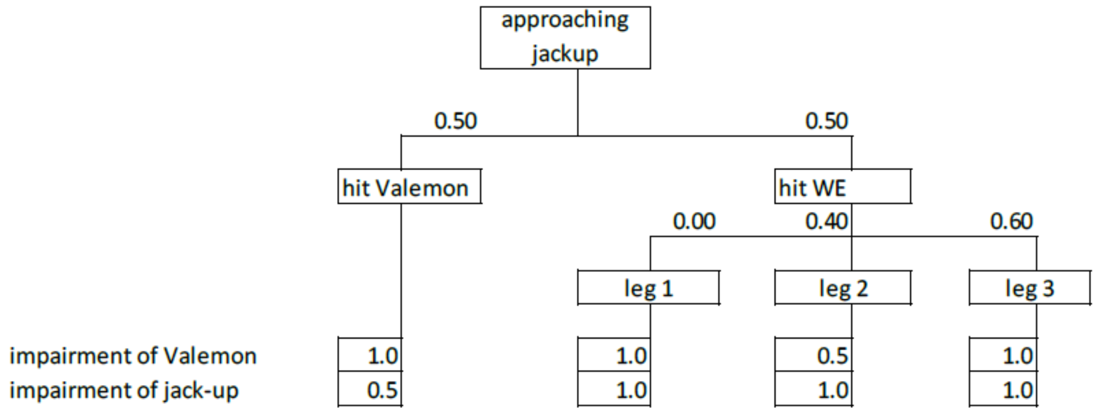
When loading to/from the jack-up rig on one side, it is assumed that each of the two nearest jack-up legs have probability of 50% of being hit. The conditional probabilities of hitting each leg become:
Leg 1 (southwest): $0.6 \cdot 0.5 = 0.3$
Leg 2 (north): $0.6 \cdot 0.5 + 0.4 \cdot 0.5 = 0.5$
Leg 3 (southeast): $0.4 \cdot 0.5 = 0.2$

Further, *it is assumed* that if the northern leg of the jack-up (furthest away from Valemon) is hit, there is 50% probability that it will impair Valemon. If one of the other two legs is hit, impairment probability of Valemon is assumed 100%. If Valemon is hit, the probability of impairing the jack-up rig is assumed 50%.

Based on the assumption above, some probability distributions have been formed (totally knowledge/experience-based). One example of the event tree for supply vessels approaching jack-up and Valemon becomes:



Appendix E, Figure 2Event tree for supply vessels approaching Valemon



Apendix E, fig 3,Event tree for supply vessels approaching jack-up[20]

Another assumption to be noted in here is that a collapse of one of the installations may impair the other installation. Valemon may be impaired due to collision on jack-up rig, and vice versa. According to this assumption, the hit and impairment probabilities are not assumed independently and the effect on one another has also been considered.

- **Third Step : Applied collision frequencies**

Combining the historical collision frequencies with number of visits and conditional probabilities of hitting Valemon and jack-up rig, the resulting frequencies become:

Appendix E, Table 1,Collision impairment frequencies for Valemon and jack-up rig, activity level 1,4 and 5[20]

Type of collision	Collision frequency [per year]	
Visits to Valemon	Valemon	Jack-up rig
Approaching supply vessel resulting in high energy impacts	$9.06 \cdot 10^{-5}$	$9.06 \cdot 10^{-5}$
Attending supply vessels resulting in high energy impacts	$2.59 \cdot 10^{-4}$	-
Attending supply vessels resulting in low energy impacts	$5.93 \cdot 10^{-3}$	-
Other attending vessels resulting in low energy impacts	$7.74 \cdot 10^{-4}$	-
Visits to jack-up rig	Valemon	Jack-up rig
Approaching supply vessel resulting in high energy impacts	$2.09 \cdot 10^{-4}$	$2.09 \cdot 10^{-4}$
Attending supply vessels resulting in high energy impacts	$2.39 \cdot 10^{-4}$	$3.59 \cdot 10^{-4}$
Attending supply vessels resulting in low energy impacts	$5.47 \cdot 10^{-3}$	$8.21 \cdot 10^{-3}$
Other attending vessels resulting in low energy impacts	$7.14 \cdot 10^{-4}$	$1.07 \cdot 10^{-3}$

In activity level 6, with Valemon stand-alone and normally not manned, the number of visits to Valemon is even lower. The frequency for collision impairment of Valemon upon approaching/attending Valemon becomes:

Appendix E, table 2, Collision impairment frequencies for Valemon and jack-up rig, activity level 6[20]

Visits to Valemon	Collision frequency [per year] Valemon
Approaching supply vessel resulting in high energy impacts	$4.18 \cdot 10^{-5}$
Attending supply vessels resulting in high energy impacts	$1.20 \cdot 10^{-4}$
Attending supply vessels resulting in low energy impacts	$2.74 \cdot 10^{-3}$
Other attending vessels resulting in	$3.57 \cdot 10^{-4}$

Once again, one should note that the values presented in the tables are based on historical data and some other underlying assumptions applied. The noticeable point is they might look quite accurate in a value, but there is high probability they are not correct. The values are accurate in terms of mathematical calculation not in terms of uncertainty description.

It might be useful to refer to this statement:

Probabilities are expressions of uncertainty based on particular background knowledge. There is a great deal of uncertainty in terms of interpretation of this background knowledge and relating it to future events between different individuals.

However, for a given background knowledge the probabilities are not uncertain. [6]

There have been some important assumptions in this modeling which have not been mentioned anywhere else in the report and yet count as a baseline for such calculations seen above.

APPENDIX F : Design and Limit States [37]

(Related to Chapter 5, Example 3)

In general the problem with dimensioning is given on the following form: $R > S$ where R = capacity, and S = load-action

Limit states

The function $g = R - S$ (10.1)

is called a limit state function. Depending on the value of this function we have the following states:

$g = 0$ $g > 0$ $g < 0$

The limit state Allowed state Not allowed state

In the example of chapter 10.1 we have already looked at three limit states:

Yield Collapse Deflection

The Oil Directorate defines the following limit states in which a construction shall be controlled:

Serviceability Limit State (SLS) is given by criteria of functional ability, i.e. non-acceptable displacements, deflections and vibrations.

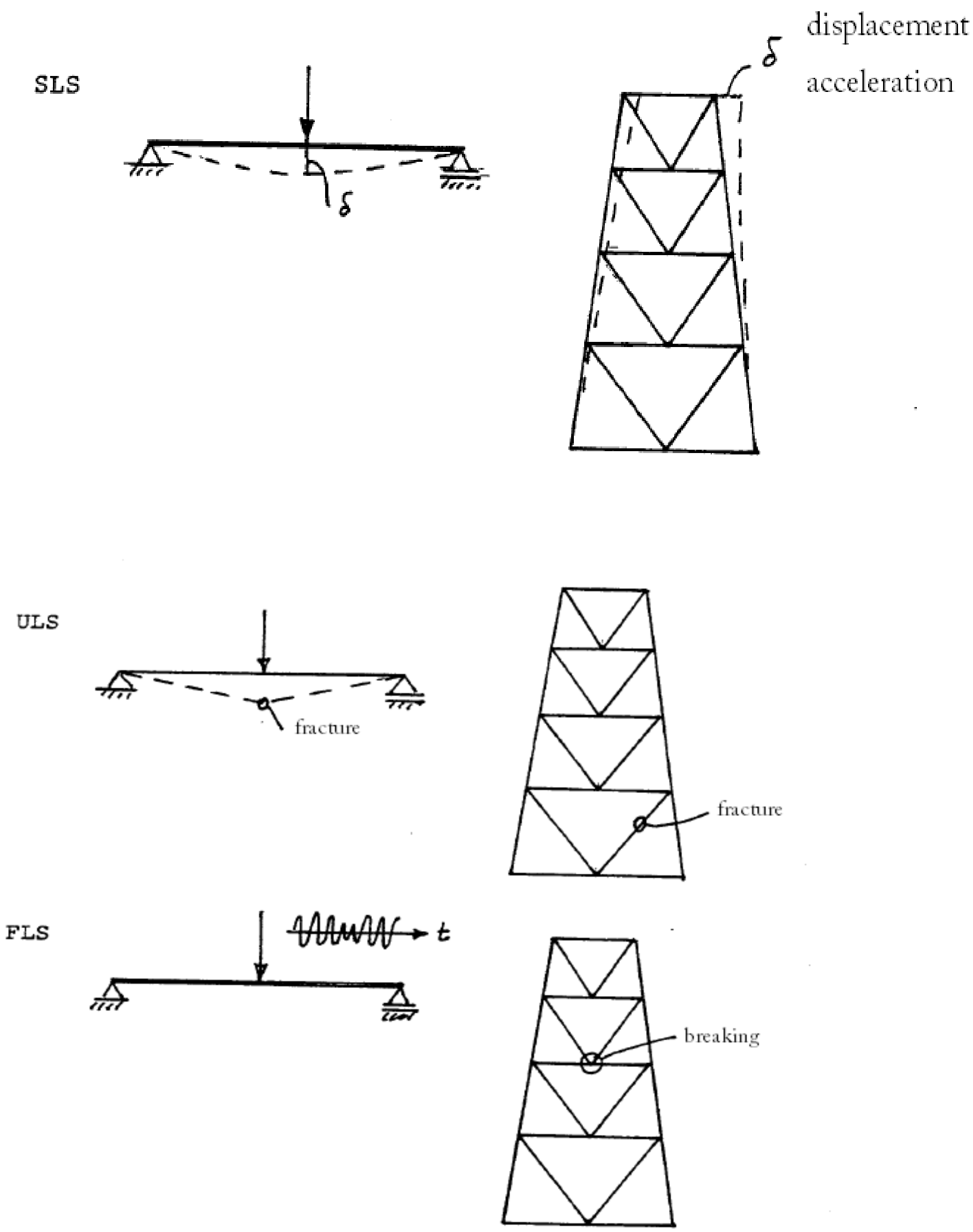
Ultimate Limit State (ULS) is given by the risk of fraction, large inelastic displacements or strains which can be compared to a fraction.

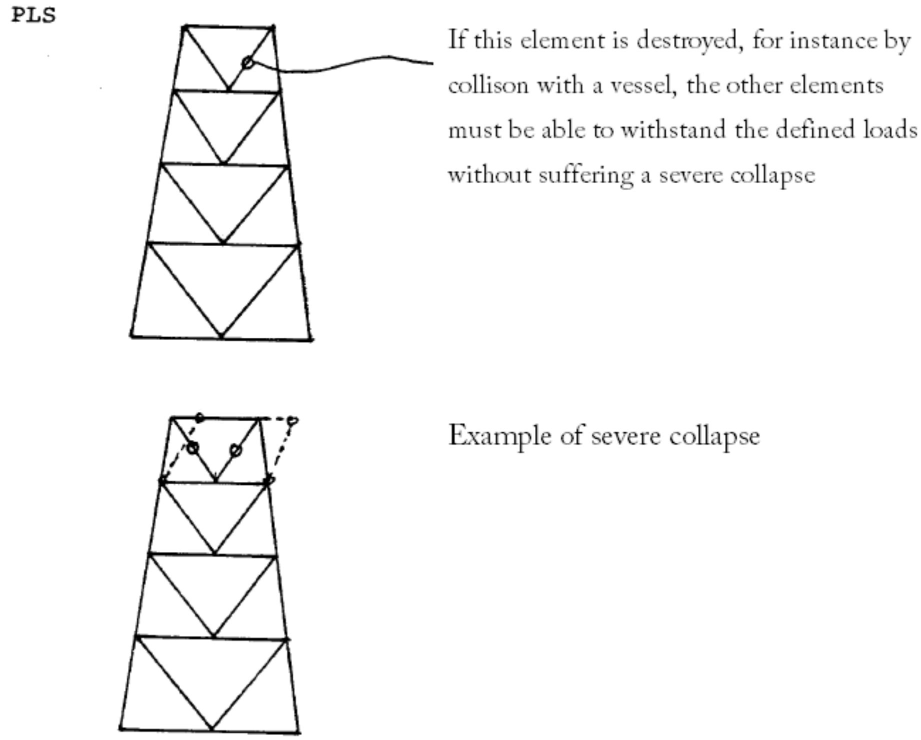
Fatigue Limit State (FLS) is the defined life length given by the risk of fraction due to the effect of a repeated load (fatigue)

Progressive collapse Limit State (PLS) is give by the risk of a severe collapse after an abnormal or “freak” event such as explosion, fire, collision, earthquake or other accident which leads to fracture of an element.

In Norwegian standard NS 3479 the last limit state, PLS, is called Accidental Limit State (ALS)

Examples:


SLS
δ
displacement
acceleration
δ
ULS
fracture
fracture
FLS
t
breaking



Appendix F, fig1. Limit State Design

The control of the PLS is performed in two stages

1. It must be proven that the construction only suffers local damage when exposed to an abnormal action.

2. The construction shall, in its damaged condition, still be able to withstand the defined loads

APPENDIX G : EQUIPMENT COUNT and P&IDs

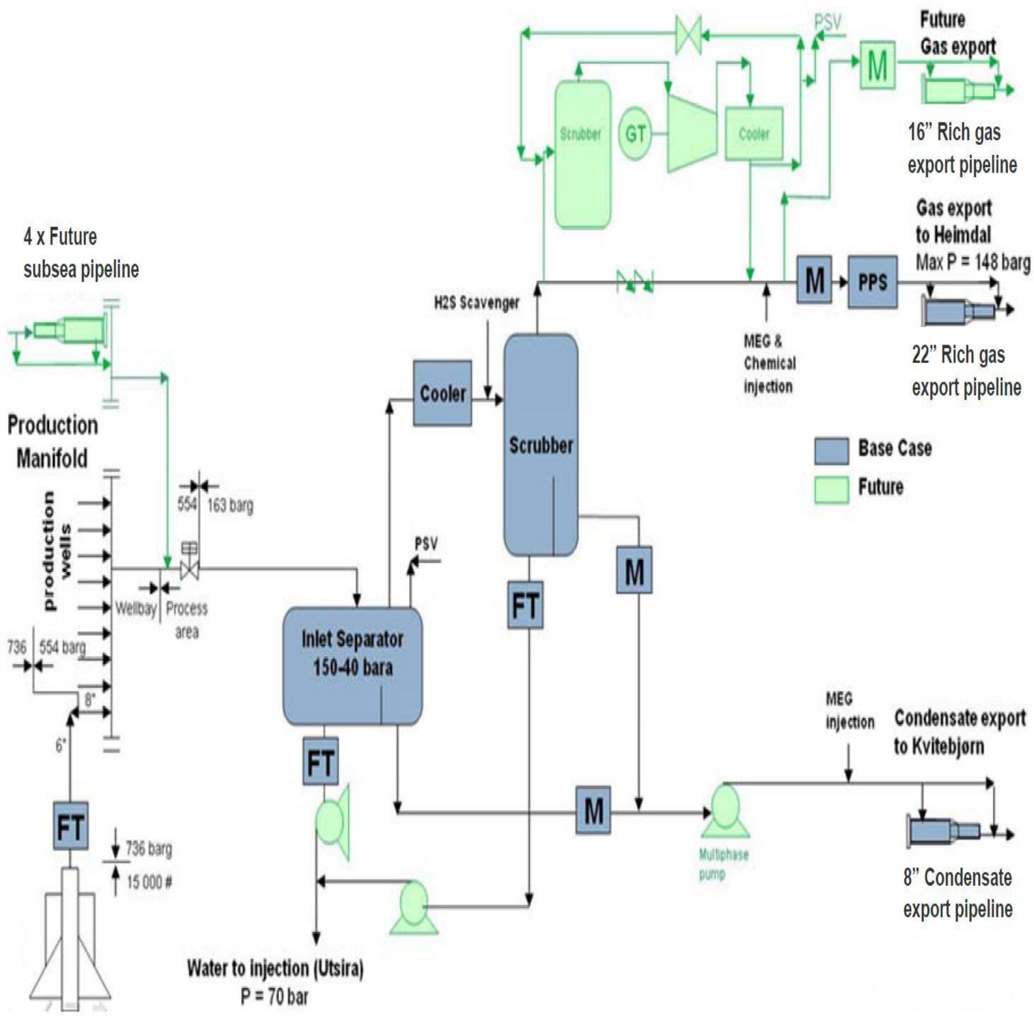
(relevant for Chapter 5,Example 4)

Process and Instrument Drawings [13][14]

A P&ID is a complex representation of the various units found in a plant. It is used by people in a variety of crafts. The primary users of the document after plant startup are process technicians and instrument and electrical, mechanical, safety, and engineering personnel.
In order to read a P&ID, the technician needs an understanding of the equipment, instrumentation, and technology. The next step in using a P&ID is to memorize your plant's process symbol list. This information can be found on the process legend. Process and instrument drawings have a variety of elements, including flow diagrams, equipment locations, elevation plans, electrical layouts, loop diagrams, title blocks and legends, and foun-dation drawings. The entire P&ID provides a three-dimensional look at the various operating units in a plant.

Valemon Process System [23][17]

A schematic of the process system is shown in Figure below. The wells are classified HPHT.



Appendix G, fig1. The process on Valemon platform

Well-stream fluids (from wells which are HPHT wells) are choked and delivered through a manifold to an inlet separator. The gas from the top of the separator is sent to a gas cooler and further into a Wet Gas Scrubber. The gas from the scrubber goes through gas metering before bypassing a pig launcher for export to a Huldra/ Heimdal.

The condensate from the inlet separator combines with the condensate from the wet gas scrubber and is piped to the Export Condensate Meter Skid. The metered condensate bypasses a pig launcher and is delivered to the condensate export line to Kvitebjørn Platform.

Produced water from the inlet separator combines with the water from the scrubber and is piped to water injection well in the Utsira formation.

The operating pressure in the two export pipelines is 130 barg. [17]

Valemon Process Risk [23]

The process including future gas compression and risers consists of 18 different isolatable segments. Additionally, there are up to 17 X-mas trees and wellheads. In this process risk analysis, all X-mas trees are considered one isolatable segment and similar for the wellheads. Therefore, a total of 20 isolatable process segments are analyzed separately.

A process segment is usually isolated by quite a few ES/XS valves and blown down by one or two blowdown valves. Failure of one valve could have much more impact on the leak duration than failure of another valve. With several valves dedicated to a segment, there will be variety of failure scenarios and number of fire scenarios could then be overwhelming.

It is also worth considering the following table with the different segments being categorized in order for easier failure location detection, traceability and more efficient containment .(segmentation is very practicable in determining the leak location)

Appendix G,Table1. Example of Equipment count in segments [24]

#	Segment name	Comment
1	Production manifold	There will be an increase in segment volume and segment leak frequencies when future subsea wells are tied in.
2	X-mas trees	There are maximum 17 wells producing simultaneously. Each of the 17 X-mas trees is a separate isolatable segment.
3	Wellheads	There are maximum 17 wells producing simultaneously. Each of the 17 wellheads is a separate isolatable segment.
4	Future import pipe section	This is the small pipe segment between the future import riser ESV and the downstream XSV. There could be up to 4 such segments.
5	Separation without future compression	Includes gas export metering and pig launcher
6	Condensate	There will be an increase in segment volume and segment leak frequencies when condensate export pumps are introduced
7	Future fuel gas	
8	Future fuel gas pumps	
9	Future compression	
10	Future scrubber pumps	
11	Gas export pipe section	This is the small pipe segment between the gas export riser ESV and the downstream XSV.
12	Future gas export pipe section	This is the small pipe segment between the future gas export riser ESV and the downstream XSV.
13	Condensate export pipe section	This is the small pipe segment between the condensate export riser ESV and the downstream XSV.
14	Flare system	
15	Gas export riser	Analysed in appendix D
16	Future gas export riser	Analysed in appendix D
17	Condensate export riser	Analysed in appendix D
18	Future import riser	Analysed in appendix D
19	Separation with future compression	Same as segment 5, but without gas export metering and pig launcher
20	Gas export metering with future compression	

Now that we have reviewed the relevant drawings and segmentation, we could refer to a detailed analysis and tables related to equipment count[24]

Equipment count in Valemon

The number of possible leak sources per process unit need to be identified in order to calculate the annual leak frequencies. These leak sources include flanges, valves, instruments, pumps and other process equipment like pressure vessels and heat exchangers.

The identification of these sources is mainly done by using the P&IDs.
Piping is also a possible source of leak and the piping lengths determine the leak frequency from these. Main process piping lengths have been estimated by IET and used as basis for the piping leak frequency calculations.
The equipment count procedure used is summarized below.

Wellheads

The Joint between XMAS TREE/BOP stack and the well itself.

X-mas trees

Entire unit including valves, flanges, rams etc. down to the wellhead connection and up to the first flange, but excluding all piping, valves and fittings beyond the first flange (e.g. flowline or choke/kill connection) and excluding the flange itself.

Flanges

Flanged joints comprise 2 flanges normally; spectacle blinds and orifice plates count as 3. Screwed joints count as 2 flanges. Clamp (Grayloc) and Hammer union (Chicksan) joints also count as 2 flanges. Flanges shall be counted as flanged joints.
Experience tells that number of flanges is higher than what is counted on P&IDs. Since piping isometrics and 3D plots have not been available, number of flanges has been multiplied with 1.5.

Instruments

One Instrument could comprise the instrument itself, plus up to 2 valves, up to 4 flanges, 1 fitting, and associated small bore piping (1"or less). However, instruments are counted as an instrument unit.

Valves

A valve includes two leak points in addition to the valve itself, namely the connections to the pipe in both ends. These connections are assumed to have the same annual leak frequency as the flanges. That is, for a normally open valve, two flanges are counted in addition to the valve, whereas for a normally closed valve, only one flange is counted.

Piping

Piping is measured in length (meters) per size category for material types (steel or flexible) excluding valves, flanges, and instrument fittings. Note the different size categories between piping and pipelines/risers. Redundant piping are not included if completely separated and isolated.

Small bore piping has been estimated as 2 meter per connection. Small bore piping is usually all except for main process piping. So, for each connection (a flanged connection or valve welded to a pipe) two meters of pipe with diameter corresponding to the flange/valve diameter have been counted.

Major equipment items

These include compressors, heat exchangers, pig launchers, pig receivers, pressure vessels, pumps, storage tanks, and turbines.
Each item comprises the item of equipment itself, but excluding all valves, piping, flanges, instruments and fittings beyond the first flange and excluding the first flange itself.
In the pages that follow, equipment count sheets are provided for each process unit.

The “Factor”-column indicates how many distinct units of the same type that is analyzed. For instance, if there are 2 identical pumps a factor 2 is applied instead of doing two identical equipment counts. Note that when a factor of 1.5 is used for flanges, this is due to uncertainty in number of flanges as described above.

In the above example of assumptions, we are mainly involved with flanges, valves and piping when dealing with equipment count as it was stated earlier in the description of the assumption.

Below we will present an example of how equipment count tables are usually illustrated in a report. We will provide the table related to the segment which was introduced in the previous section. For all lists of segments and tables, refer to Appendix.3.

Equipment count sheets (Example)

Segment 1 – Production manifold

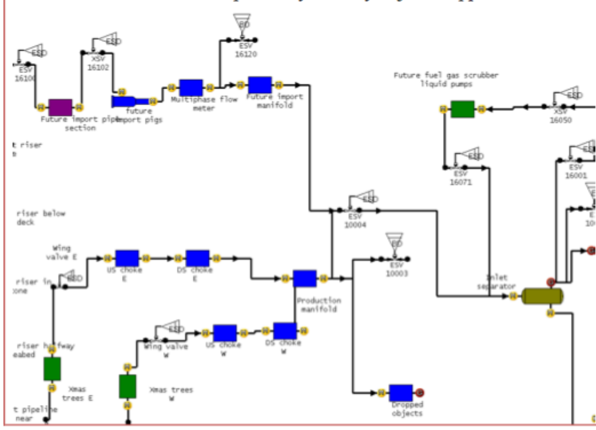
Appendix G, Table 2. Equipment count for segment 1

Unit	Equipment	Dimension	Count	Factor
US choke E				
	Flanged connections	1	1	12
	Flanged connections	6	5	12
	Instruments:	Pressure	7	8
	Piping (in m):	1	2	8
	Piping (in m):	6	30	8
	Manual, choke valve	6	1	4
DS choke E				
	Flanged connections	8	5	12
	Instruments:	Pressure	5	8
	Piping (in m):	8	10	8
	Manual, block valve	8	1	8
	Manual, check valve	8	1	8
	Manual, choke valve	8	1	8
Production manifold				
	Flanged connections	1	3	1.5
	Flanged connections	2	3	1.5
	Flanged connections	4	1	1.5
	Flanged connections	8	20	1.5
	Flanged connections	16	4	1.5
	Flanged connections	>16	2	1.5
	Instruments:	Pressure	2	
	Piping (in m):	1	6	
	Piping (in m):	2	6	
	Piping (in m):	4	2	
	Piping (in m):	16	30	
	Piping (in m):	>16	15	
	Actuated, blowdown valve	4	1	
	Actuated, ESDV valve	>16	1	
	Manual, block valve	1	3	
	Manual, block valve	2	3	
	Manual, block valve	8	1	
	Manual, check valve	1	1	
	Manual, check valve	8	1	
Future import manifold				
	Flanged connections	12	3	1.5

We have selected the first segment, production manifold description and its own specific assumptions here and the data sheet provide in table above is the equipment count for that segment. It is easier to do equipment count based on segmentations.

Appendix G,Table 3. Production Manifold Segment with respect to Equipment Count

Isolatable segment: 1 – Production manifold
Description: The segment consists of all flowlines downstream the X-mas tree wing valves including the production manifold. Number of flowlines in operation will vary with time and equals number of producing wells. Maximum number of producing wells is 17. Each flowline is split in two units; upstream and downstream the chokes since the pressure drops significantly through the choke. The flowlines are routed at east and west side of the wellhead area and 50% of them are therefore located on either side in the model. Future subsea tie-ins (up to 4 risers) will be directed into a future import manifold which will be part of this segment 1. The “dropped object” unit is representing a leak case where the well intervention deck is impaired by a heavy object dropped above.



There have been other assumptions within this segment as we can see in the description.

APPENDIX H : Comparison between Valemon and Kalumdborg Manning Level Assumption [31] [32]

Comparison between Kalundborg and Valemon : Manning Distribution (relevant for end of chapter 5)

Having section 5.7 in mind as a background for comparison, we will introduce the manning distribution assumptions for Kalundborg.

Here will be the manning level distribution of the Kalundborg refinery and we will compare the results of the risk picture (in terms of FAR and PLL) with those presented in section 5.7.2 for Valemon.

Appendix H, table 1. Manning distributions for Kalundborg [31]

Area	Area Dwg.	Day or Shift	↓ Number → d/s	Distribution per group and area (%)									
				Admin + TNE Incl. visitors Area B based 20/1	Admin + TNE Incl. visitors Area D Based 280	Admin Incl. visitors Area C based 12	Process tech. On-site 20/10	Process control Tech. & eng. + Off-site tech. 64/10	Pier persons 3	Contractors + Mechanical Maintenance 108	Contractors + EIAA Maintenance 37	MOD Modification Dept. 52	3. party 5/27
New Admin. building	D	Day		1 %	73 %								
		Shift											
Lab. + Port + Firest. + Cant.	B	Day		93 %	1 %	5 %							
		Shift		100 %									
Safety Building	C	Day				95 %							
		Shift											
Block 1		Day		1 %	5 %		44 %			15 %	7 %	15 %	
		Shift					22 %						
Block 2		Day		1 %	5 %		11 %			15 %	7 %	15 %	
		Shift					5 %						
Block 3		Day		1 %	2 %		11 %			6 %	4 %	12 %	
		Shift					5 %						
Block 4		Day		1 %	2 %		11 %			6 %	4 %	12 %	
		Shift					5 %						
Block 5		Day		1 %	2 %		11 %			6 %	4 %	6 %	
		Shift					5 %						
NCC	G	Day			1 %		2 %	30 %			5 %		
		Shift					2 %	95 %					
OCR 1	I	Day					5 %						
		Shift					28%						
OCR 2	J	Day					5 %						
		Shift					28 %						
CCR	H	Day									2 %		
Warehouse + Mec. Workshop	A	Day			2 %					25%		5%	
		Shift											
AEIA workshop + Changing room	F	Day			2 %						45 %	5%	
		Shift											
Contractor area	E	Day			2%			60%		15%	10%	10 %	
		Shift											
Off-site tank area		Day		1 %	2 %			10 %		10 %	10 %	20 %	
		Shift						5 %					
Pier		Day			1 %				30 %	2 %	2 %		
		Shift							20 %				
PCC		Day							70 %				
		Shift							80%				
Melbyvej	L	Day											
		Shift											
Melbygården	K	Day											
		Shift											
Total		Day		100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
		Shift		100 %			100 %	100 %	100 %				100 %

Here the format for the table presented is nearly the same as Valemon (tables divided by areas and groups) but the main difference here is that there has been a distinction between day and shift positions. It should be noted that Kalundborg refinery is an onshore facility therefore; it is not like that people would also stay there after work for all time. Nevertheless, for some more sensitive posts, there has to be 100% shift present. We can see that this is the case for process units at least. Another thing to be noted in this table is the process and maintenance crew; they seem to be the most distributed parties all over the blocks, which is not the case in offshore facilities. On offshore platforms the process module corresponding crew for example would spend about 20% of their offshore stay in process or other related and usually high risk areas and spend the rest 80% in LQ. (The probabilities are merely knowledge-based information of the writer.)

As we can see from the table the areas defined in Kalundborg and the group personnel differ completely from those of Valemon. We should bear in mind that the nature of these two facilities also differs. There are different ways of operating these two facilities, especially with the manning level and distribution that is so different off and onshore. For instance, we see that they are taking shifts in onshore facility Kalundborg, daytime and shift, which mean a position being shared between a certain number of people.

Another different aspect on and offshore especially on night shifts is that for onshore facilities in case of night shift work, the personnel usually go to the facility to do some required work and then get back home; there is not a living quarter as in offshore facilities onboard. However, nightshifts in offshore means that doing the necessary job in the related area of the platform and then go directly to living quarters and spend the rest of night. The point is the personnel on night shift at offshore facilities do not necessarily spend their whole time on process, wellhead or other areas with great potential of risk or as it was stated in Kalundborg report in high risk areas.

According to Kalundborg report, people working night shifts at Kalundborg, are usually considered to working high risk areas.

That being said is of course the general assumption but that assumption is subject to uncertainty and is not always the case for offshore facilities due to the nature of the work that needs to be done. For instance, at offshore, if there is some immediate work required in high risk areas such as process areas or well intervention deck then the crew has to spend some time in those areas of course there would be a greater risk to Personnel but that is not always the case.

Another great difference between Kalundborg and Valemon except for their nature of work and the geographical location is that Valemon has not been built yet and so the manning values are just mere assumptions and improvement will be done to the manning level and the calculations would then be more realistic.

Kalundborg, on the other hand has been in operation for quite some time now; as a result the manning distributions are almost the case as in reality.

Finally, the mentioned differences in pattern and structure of both facilities require different patterns of manning distributions which will eventually result in different total risk picture of the two facilities especially in calculations of FAR and PLL values.

Risk Picture

According to Kalundborg risk picture results:

The average FAR value (day and shift) is estimated to 9.1 (exclusive work accidents).

The value is higher at night due to considerably fewer people working in low risk areas, i.e. personnel at night works mainly in the process areas.

The criterion for Kalundborg according to the framework has been set to FAR value of 5. (table 5) The average personnel risk is above the criterion with about a factor of two. The main contributor is fires in areas where auto ignition is very likely to occur.

For offshore installations average FAR value tend to be considerably lower due to personnel being located 2/3 of time in the living quarter (FAR values are in most cases about 1 for living quarters).

As we can recall from the Valemon risk picture the RAC for FAR value was set to be 10.

This is another source of difference between Kalundborg and Valemon.

Appendix H, Table 2. average FAR values for all workers at Kalundborg

	Average FAR
Day	8.8
Shift	16.5
Total	9.1
Criterion	< 5

Some reasons to justify the higher FAR values (and not the criteria) at onshore refineries such as Kalundborg could be due to some main risk driving factors:[31]

- Large inventories that produce leaks with long durations, combined with many ignition sources that cause a high frequency for delayed ignitions, and consequently events that generates high explosion loads

- The high ignition probability (self-ignition in particular) that cause a high frequency for fires, combined with equipment being vulnerable to fire exposure, cause a high frequency for large massive escalated fires (i.e. high economic risk)

- Manned buildings and 3rd parties within area of exposure of significant explosion loads

- Manned buildings and 3rd parties located within area that may be exposed to combustible gas due to leaks from storage tanks

- Manned buildings and 3rd parties located within area that may be exposed to toxic gas

Here the direct effect of manning levels on high risk to personnel and high FAR values can be observed.

If we compare the results of the FAR values with the FAR value results for activity 5 in Valemon, we see the results in table 6.

Appendix H, Table 3. comparison of FAR between Kalundborg and Valemon

	Calculated FAR	RAC FAR
Valemon(activity level 5)	6.73	10
Kalundborg	9.1	5

We see that the FAR value is quite smaller for the offshore facility Valemon. We should also note that although the accident scenarios for offshore installations are quite wide in range, the manning level for Valemon is considerably lower in general than that of for Kalundborg refinery. And the fact that Kalundborg is a refinery and mainly deal with process accidents results in the general more potential fatalities.

According to Espen Fyhn Nilsen,risk analysis specialist at Statoil ASA:

PLL is mainly an indicator and there are different ways of calculating it and the methodology for calculating it is the same but the technique for modeling and calculation of PLL values varies a lot depending on the companies performing the risk analysis. Normally each company uses their own special resource to present PLL values.

There is usually a general and total PLL presented in the result and then the contributors to the PLL usually depending on accident scenarios are also being presented. The same thing applies for FAR values as well. Defining FAR and PLL value contributors per accident category or per area, gives a reader a good insight through the results.

The main thing that we should always bear in mind is that in calculation of PLL values there are a lot of assumptions since the basis is usually building some scenarios with fault and event trees and assign a probability to the occurrence of that scenario (frequency) and then relate to the number of fatalities each scenario might end up with and then do the necessary calculations and several of these scenarios are considered before they are summed up and make the total PLL value.

The main point here is eventually the assigned probabilities are just knowledge-based and are set upon the background knowledge of the assessor and therefore there are a great deal of uncertainties with them as well as with the corresponding consequences and the number of fatalities they are assumed to cause not to mention the feasibility of scenarios themselves.

Comments:

Eventually it might not be the good comparison between the Kalundborg and Valemon manning distribution due to the reasons mentioned above that we would summarize here as well:

- Different nature of work
- Different location (on and offshore)
- Time of actual operation