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Communication of uncertainties and robustness in quantitative risk assessment

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SUMMARY

The use of quantitative risk assessment, in all phases of an offshore oil and gas project in Norway, has clear requirements in NORSOK Z-013. The purpose of QRA is to describe the risk picture and give decision support through all project phases. These decisions are not only related to choosing between two or more alternative designs in concept selection phase and detail engineering. Important decisions with regards to safe design, barrier management, safe operations and organization, use information from the QRA.

In an early concept selection phase of a project, very limited site specific data is available and calculations must be done based on a set of assumptions and generalizations. Expert knowledge, historical and generic data is used.

Some generic data can be solid in an early phase project, such as meteorological data, ship traffic and information about earthquake rates, while other generic data like gas and oil spill rates may not even be representable for the new installation. Generic data reflects a wide variation in types, sizes and age of installations. The data also represents a wide geographical area, something that can have a significant impact as oil production is moved closer to the Arctic environment. The development and use of more and more subsea production facilities creates a larger difference between new and old installations.

Creating a risk picture based on generic data can have epistemic uncertainties that can be reduced. A QRA should focus on describing these uncertainties and the evolving process should focus on uncertainty reduction. Reducing epistemic uncertainties means increasing the strength of knowledge.

Classifying uncertainties by their strength of knowledge and the degree of sensitivity will give the risk assessor a tool to manage the risk better through the project phases. It will be clearer to the assessor and risk manager which knowledge that needs strengthening to reduce uncertainties according to the wanted effect, and help make better decisions to reduce risk. Assessing the strength of knowledge and sensitivity will identify the robustness of the QRA and can introduce a more effective way of reviewing and updating the risk picture as more knowledge is available.

In this thesis we perform a review of the available literature on such a new risk perspective, focusing on uncertainties and how it will apply to performing a QRA. The thesis will also show how this affects the complete project process from concept selection to operation and how a new risk perspective applies to the purpose and requirements stated in NORSOK Z013 for QRA. Through a case study where the new risk perspective is applied, we will show how the new risk perspective give the assessors the tools to better manage risk through all phases of a project from concept selection to operations and adds to the life cycle value of a project.

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1 Introduction

1.1 Background

QRA is an abbreviation for quantitative risk assessment. Sometimes the abbreviation is used for quantitative risk analysis. The difference between analysis and assessment is that an assessment includes an analysis as well as an evaluation of the result. (Vinnem, 2014)

PSA (Petroleum Safety Authority) states that "*The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations*." (PSA, 2010, p. 5) By this we must also acknowledge that a QRA (Quantitative Risk Assessment), as depicted in NORSOK Z013, is not only to comply with the requirements of having done one and confirming that we are under the acceptable risk limits.

Risk managers are required to do something to reduce the risk to ALARP (As Low As Reasonable Practicable) and no operating oil company in Norway will accept just monitoring the activity and be happy the expected results of the QRA were below acceptance limits if a person dies. Actually most, if not all, oil and gas operating companies, and by extensions their contractors, in Norway have a vision of zero injuries and harm to personnel, facilities and environment. As examples AS Norske Shell calls it "Goal Zero" (Shell Global, 2015), ConocoPhillips Norway calls it the "Zero Philosophy" (ConocoPhillips Norway, 2015).

By introducing the "zero" philosophy the operators aspire to a vision to always try and reduce risk to the lowest possible extend.

1.2 Goal

The goal of the thesis is to show how a new risk perspective, focusing on and communicating uncertainties, will be better suited for input to managing risk through all phases of oil- and gas project on NCS (Norwegian Continental Shelf).

1.3 Limitations

This thesis will look at the theories behind the new risk perspective focusing on uncertainties. These theories can be applied to all risk assessments but in this thesis we will look at it in an offshore risk assessment process on NCS where QRA is used to describe the risk picture.

A QRA offers quantitative results for many different scenarios but this thesis will use process leaks as scenario. The theory can be applied to all forms of scenarios, irrespective if the assessment results are quantitative or qualitative, as the uncertainties can be handled and communicated separately.

The thesis focuses on the regulations for QRA on NCS as described by NORSOK Z013. The international standards for offshore facilities and national standards for onshore facilities are not included.

Risk treatment is not a part of NORSOK Z013 and there are many factors, outside the scope of this thesis, that comes into account for the decision maker in risk treatment and those will not be covered here.

We will not cover the emergency preparedness assessment in NORSOK Z013, but as the standard acknowledges (PSA, 2010), the input and results of one process can be used as input to the other.

1.4 Content

The content of this thesis is divided into chapters covering the theory, regulations and a case study, followed by discussion and conclusions.

Chapter 2 will review some of the available theory on uncertainties that is applicable to a QRA. The goal is to inform the reader of the difference between traditional probability view of risk and a new risk perspective where the uncertainty is the focus**.** (Flage & Aven, 2009) Different aspects of uncertainties are presented to make the reader understand what we are uncertain about.

Chapter 3 reviews the context where a QRA is used and how the regulations from PSA through NORSOK Z013 reflects this context. This context is necessary to understand, in order to understand how the new risk perspective, focusing on uncertainties rather than focusing on probabilities, is a better tool.

Chapter 4 will provide a practical example of how the new risk perspective with the theoretical details, as explained in chapter two, can improve the QRA process and better fulfill the intentions and requirements as described in chapter 3.

1.5 Abbreviations

AIR	Average Individual Risk
ALARP	As Low as Reasonable Practicable
ESD	Emergency Shut-Down
FAR	Fatal Accident Rate
FPPY	fatalities per platform year
LNG	Liquefied Natural Gas

LQ	Living Quarter
MOB	Man over board
NCS	Norwegian Continental Shelf
PFD	Probability of Failure on Demand
PLL	Potential Loss of Lives
PS	Performance Standard
QRA	Quantitative Risk Assessment
RAC	Risk Acceptance Criteria
RIF	Risk Influencing Factor
RM	risk metrics
RNNP	Risk level in the petroleum activity
SCE	Safety Critical Element
SoK	Strength of Knowledge

2 Risk description and a new risk perspective

2.1 A new risk perspective

Traditionally risk has been defined, as it still does by NORSOK Z013, as the "combination of the probability of occurrence of harm and the severity of that harm". (PSA, 2010, p. 13) This definition we can denote:

$$R = (C, P)$$

Where R is risk, C is the consequence and P is the probability of that happening.

Most people can relate to this and has at some point encountered this definition. This definition is very practical when working with numbers. As an example an investment analyst can calculate the probability of a value X going up or down in a certain time, based on this he can calculate predictions of potential winnings or loss and do an informed decision, backed by his calculations, about doing an investment or not, and if he does the investment, he can use these predictions to calculate how much he is going to invest, again based on his calculations and risk appetite. Of course, the better knowledge, the investment analyst has about the phenomena that affect the value X, the better, or in other words, the more precise his calculated estimates can be.

Risk defined by frequency probability, is a good tool for the investment analyst because to him the values, such as interest rates and stock value is viewed as stochastic variables. In investments, this risk is defined as volatility, and estimating the volatility is based on historical data. He can observe a quantity of them in order to analyze them and he has little influence on them, he can just make predictions and decisions. It would be very fortunate for him, and very unfortunate for everyone else if he could influence the values, hence we have laws to prevent such things. When a decision is made, he can, only monitor the actual values to make a new prediction and/or decision to sell or invest more. A very good investment analyst also makes mistakes and unforeseen events can render his predictions false and he does bad investments from time to time. What separates a good investment analyst from a bad one is the relation between number of good and bad investments and their accumulated values. This way his success is based on similar operations that is repeated many times and this is in conformance with the frequentist view of risk. An investor can make hundreds or maybe thousands of such investments per year. The newest computerized investment robots makes millions of such micro investments and is solely based on predefined logic and the historical data as input, and they make lots of money even if some of those investments represents losses. It is the share volume that makes the difference.

In an offshore project, frequentist view of risk is used through models to predict the probability for an event to occur and their consequences. An offshore risk analyst can subjectively or by frequency make a probability of an event A, say a gas leak occurs, based on historical data for similar operations. Then, based on his knowledge K, calculate the consequence C. Based on this information the risk manager can measure if the calculated risk is within his RAC (Risk Acceptance Criteria). This can again help him to decide whether to go ahead with the operation or not or compare two different operations. But here is where the benefit of this as a tool stops for the offshore risk analyst and the offshore risk manager, because the offshore risk analyst and manager are required to identify the RIFs (Risk Influencing Factor) and reduce them to ALARP. Therefore it is necessary for the offshore risk analyst and manager to view risk in a different perspective that gives more sense when trying to do something about the value. PSA acknowledges this and states that (PSA, 2015a)"…*this approach to defining risk is too narrow and limiting for the ability to understand, administer and manage activities and enterprises*."

A new risk perspective, as presented by Terje Aven (Aven, A unified framework for risk and vulnerability analysis covering both safety and security, 2007), offers such a tool for offshore risk assessments and focuses on uncertainties rather than probability as the definition of risk. Aven's definition of risk can be shown as;

$$R = (A, C, U)$$

Where A is an event or condition, C is consequence and U is uncertainties. The events A is a part of the consequences C, and then we can simplify and denote risk as

$$R = (C, U)$$

Where R is still risk, C is consequences including A, and U is the associated uncertainties. In a QRA the events A studied are unwanted events.

PSA have updated their definition of risk to "*the consequences of the activities, with associated uncertainty*". (PSA, 2015b) The term consequences are used as a collected term for all types of consequences the activities can produce, not limited to potential harm to people, environment or assets, but also includes the unwanted events A, and conditions that can potentially lead to such. Taking this into account, that events A is part of consequences C, we see that PSA new definition of risk is according to (Aven, A unified framework for risk and vulnerability analysis covering both safety and security, 2007) where risk is denoted as $R = (C, U)$.

PSA also defines the associated uncertainties as the uncertainties regarding what the consequences will be. This is related to both uncertainties about which events can occur and what can be their potential consequences. In notation we see that we have uncertainties

$$U(A) \text{ and } U(C)$$

Probability is just one tool to measure such uncertainties and this can serve as a way to weigh one solution against another. Other tools to measure uncertainties are also available.

2.2 Risk description

A risk perspective is a wholesome view of the entire concept and describes how we choose to view risk. The risk definition is a representation of what are the main components of that view. The corresponding risk description as presented by (Aven, The risk concept-historical and recent development trends, 2012) can be denoted:

$$(A', C', Q, K)$$

Where A' is the specified events, C' is the specified consequences, Q is a measure of the uncertainties, as mentioned probability P is just one tool, and K is the background knowledge that A', C' and Q is based on. If we regard A as part of C as in $R = (C, U)$, the corresponding risk description will be;

$$(C', Q, K)$$

PSA defines the risk as related to the activities (PSA, 2015b), these include all the processes regarding technical, operational or organizational changes and that this includes the background knowledge of such processes. This confirms that PSA is in accord with the risk description as denoted by (C', Q, K). The uncertainties can then be written;

$$U(A|K)$$

Where we mean the uncertainties concerning the events that can occur, given our background knowledge K, and;

$$U(C|K)$$

Which are the uncertainties about the potential consequences of those events, given our background knowledge K. This way we see that the uncertainties depend on how strong or weak the knowledge is.

2.3 Risk presentation

In a QRA the results are calculated and represented quantitatively in the form of RM (risk metrics) such as presented by Vinnem (Vinnem, 2014).

- PLL (Potential Loss of Lives), also called fatalities per platform year, FPPY, and may be considered as the fatality risk of the entire platform.
- FAR (Fatal Accident Rate) value implies the number of fatalities in 100 million man hours.
- AIR (Average Individual Risk) value is the average number of fatalities per exposed individual.

There is a mathematical connection between these values, for further description, see (Vinnem, 2014)**.**

These RM are then used to compare two different solutions or to decide if the RM is below the RAC.

$$RM < RAC$$

But only presenting these metrics does not present the whole risk picture and the RM presents different information about the risk picture. The risk picture should also include K according to the new risk perspective.

If we go back to the investor and say that he has still not adopted the new risk perspective. He has clients that want to invest their savings and he presents the prospect of X based on his calculations. All calculations support a positive return on the investments and the clients agrees based on the information they are receiving. However, since he is not including his background knowledge about the investment, underlying uncertainties stays hidden. By adopting the new risk perspective he would have to present his knowledge about X so that the clients can make a better informed decision.

2.4 Aleatory and Epistemic uncertainties

We have seen that we are not uncertain about our predictions given our background knowledge K, but the factors that are used to arrive to the actual result. So to define the uncertainties and assess them we need to understand what these uncertainties are.

This thesis will focus on two types of uncertainties, aleatory and epistemic. Epistemic uncertainties relate to the knowledge about the factor and can be reduced. (Helton & Burmaster, 1996) As referred to in (Flage & Aven, 2009). The aleatory uncertainties are also called random or stochastic and thus have the attribute that they are random, we cannot control them just observe them. So for an investor who decides to make an investment based on his calculated predictions and can only monitor the factors to make a new decision, for him the factors are aleatory. If he could control them it would most likely be illegal. But maybe he sees a new turn of events and gain new knowledge about the factors he monitors so he can make a better calculation in his model, then he has strengthen his knowledge K and thus reduced the epistemic uncertainties.

We mentioned the zero vision, were the oil and gas operators in Norway acknowledges that all risk can be reduced. So to reduce risk, and if risk is viewed through the new risk perspective where $R = (C, U)$, we must reduce the consequence and the uncertainties, where U is the epistemic uncertainties as the aleatory uncertainties cannot be reduced. We can in many ways reduce C, but that is very different from reducing U because C will always be in the theoretical future and contain randomness that cannot necessarily be reduced. For example we cannot predict the actual number of personnel in a certain area when a fire or explosion occurs because we cannot say exactly when, if it happens.

As risk is not the mathematical product of C and U, reducing U does not necessarily means reducing the actual risk. But, as we will see in this thesis, in order to efficiently reduce risk, the epistemic uncertainties must be reduced first. Reducing uncertainty U means strengthening our knowledge K about the factors that influence the risk.

2.5 Subjective and frequentist probability

Probability can be expressed as a subjective probability P with references to a standard (Aven, Misconceptions of risk, 2010) or as a frequentist probability P_f.

A subjective probability expresses that the degree of belief for a positive return is equal to pulling a red ball out of an urn where there are red and white balls. In probability the opposite of subjective is not objective, but frequentist.

A frequentist probability P_f means the fraction of times an event will occur, given the situation is repeated a theoretical infinite number of times under equal conditions. This includes that a hypothetical large population must be introduced to make an estimate P_f^*.

Let's say that we are interested in throwing a six in a game with a die, knowing there are six mutual exclusive possibilities of the die, from 1 to 6 the probability of getting a six is

$$P_f(6) = {}^{1}/_{6}$$

if we assume the die to be fair. It is true that this probability is objective, but its estimate P_f^* is not. Say that we throw the die 60 times, then we expect to get a six, ten times, but the actual result can be zero or 60. This is due to natural variation and not uncertainties.

If we have the recorded data of, say 600 die throws, and count the actual number of times the six appeared, we can make an estimate P_f^*. If we count the number of times the six appeared to be 80, then

$$P_f(6) \neq P_f^*(6) \text{ Because } P_f(6) = {}^{1}/_{6} \text{ and } P_f^*(6) = {}^{80}/_{600} = {}^{2}/_{15}$$

A frequency interpreted estimate P_f^* does not express uncertainties but natural variation. For P_f^* to come close to or equal of P_f, we would need to theoretically repeat the throw of the dice an infinite number of times.

Let's say that a leak scenario is assessed as the event A'. To produce a probability of the event to occur, we base our estimate P_f^* on number of recorded leaks that have occurred in the past. For this estimate to hold "true" or as they in many cases are presented as objective, we have to make the assumptions that all recorded leaks have happened under the same conditions as our scenario. This implies that the reasons for the leaks are arbitrary in the same manner as throwing a die. If this is the case, then the risk managers would just have to accept this risk and nothing could be done to reduce it. Thus the past would be representative for the future given a large enough sample. With leaks, this is not the case, and great efforts are put into reducing the possibilities of a leak to zero as in the companies zero philosophies. There will always be risk of a leak, but reducing it to ALARP is always a goal.

However such an estimate P_f^* can serve as decision support when comparing two mutual excluding scenarios to decide which is the safest, then their estimated outcome will be based on the same assumptions. Of course there would be more criteria that affect the decision of the decision maker, such as cost, schedule and risk to other than people, but we will not cover that further in this thesis.

We can easily say that in real life, a hydrocarbon leak cannot be reproduced under the exact same conditions an infinite number of times, thus there exist no true objective P_f, and therefore the opposite of subjective is not objective but frequentist in statistics.

2.6 Model uncertainty

A system is what we are doing a risk assessment of, for example a process system, a social system, a road system or an activity can also be regarded as system with risk influencing factors. We cannot calculate a system, but we can create a model $G(X)$ of the system in interest to find out something about a true value Z that will be realized in the future. (Aven & Zio, 2013) Model uncertainty is our knowledge, or lack of, how well the model reflects the "real world".

Aven and Zio (Aven & Zio, 2013) defines the difference between the model output $G(X)$ and the true value Z as the model error $DG(X)$.

$$DG(X) = G(X) - Z$$

Model output uncertainty is our lack of knowledge, the epistemic uncertainty, about this error. There are two origins to model output uncertainty, that is the model input uncertainty and the structural model uncertainty. For practical reasons when performing uncertainty assessment in QRA, this thesis will differ between the two.

2.6.1 Structural model uncertainty

The structural model uncertainty is our lack of knowledge on the model output due to the structure of the model, how it's built, simplifications, assumptions and such. It implies regarding the model input X as the true value, i.e. we can ignore the model input uncertainty. Model structure uncertainty is the epistemic uncertainty about $DG(X_{true})$.

In QRA, the values of interest will be realized in the future and experimental data to accurately estimate its "true" value will not be available. We define the model structure uncertainty as;

$$U(DG(X_{true})|K)$$

In practical cases, it might not be a goal to have no model error, simplifications and assumptions may be introduced and agreed upon, having consensus between experts, to adapt the complexity and recourses to achieve the objective. When this is done knowingly, we can still have very small model uncertainty with an accepted level of model error.

2.6.2 Model input uncertainty

The model input uncertainty is our uncertainty about the input values used. The inputs to a model are variables and parameters.

A variable is defined by Oxford dictionary as "Not consistent or having a fixed pattern, liable to change". (Oxford Dictionaries, 2015a) A variable is a factor we expect to change and use as input to our calculations where we can give the variable an upper and lower limit as the output will depend on the input, with a variable input we expect a variable output. The uncertainties with regards to the variables are regarding our knowledge about what will be the correct value.

There is another type of variable, but one that we cannot control, that also affects the outcome, that is a parameter. A parameter can have variation or be a constant, but since we cannot control it, we want to separate it from the other variables. A parameter is defined by Oxford dictionary as "A Numerical or other measurable factor forming a set that defines a system or sets the conditions of its operation." (Oxford Dictionaries, 2015b)

The difference between a variable and a parameter is that we can exercise control on our variables, according to the change in parameters. Since the parameters can also have variation, some might say they are two of the same, but the practical distinction comes clear if you use energy or recourses to hold a (controllable) variable constant while waiting for the correct (uncontrollable) parameter to set, instead of controlling your variable to the actual parameter.

In our model we define an input variable X, we will extend the input to include an input parameter λ. Our uncertainties regarding these is we can denote

$$U(DG(X)|K) \text{ and } U(DG(\lambda)|K)$$

If a parameter is a constant, say the gravity, we cannot control it and it will not change. This way we have no parameter uncertainty about it, as long as we actually know the value and have not made an assumption about what we think it is. We can also know, about a variable X, say that it will be between X_{min} and X_{max}, this knowledge might be strong but still we will not know exactly which value that will be true in the real life. For modelling, assumptions must be made about the variable.

For example in a leak scenario, the leak size and consequence is determined by a set of variables and parameters. The leak rate, not meaning how often a leak occurs but how many kilograms per second that is released, determines the cloud size will change over time until it stops, it's a variable. We can exercise control on this leak rate by safeguarding the system with a pressure release system, flaring or segmentation of pipes, reducing the supplied volume to the leak. What we cannot control is the hole size where the leak occurs, or the weather conditions when it occurs. These inputs must be set as parameters to the modelling scenario. Both the weather conditions and the hole size can also vary, but stays constant through the hole model iteration and doesn't change over time. For modeling with different hole sizes or weather condition, more iterations have to be performed with new values as parameters.

2.7 Assumptions, presumptions and presuppositions

Assumptions, presumptions and presuppositions made about variables, parameters and models, represents the uncertainty U because the assumptions and presuppositions are there to replace a factual knowledge. If we know something exactly, like the gravity constant, we don't have to make assumptions and presuppositions. We can choose to simplify our model by saying the gravity is $9.8\ Newton$ instead of $9.82\ Newton$. We then assume this to be good enough, but our knowledge can still be strong and by doing this knowingly, we don't necessarily introduce more uncertainty even though we will have a difference in model input and real life, thus introducing a model error.

An assumption is defined by Oxford dictionary as something that is stated as true or certain without evidence. (Oxford Dictionaries, 2015c) Therefore with more knowledge, or evidence, it becomes less of an assumption and less uncertain.

A presumption is the same as an assumption but is taken for true on the basis of probability. A presupposition is different from an assumption in the way that is represents a condition without being stated. To presuppose something is to define a precondition of possibility.

For practical reasons they should be treated the same when assessing uncertainties in a QRA. In many cases these terms are used for the same thing although they have different definitions. Since a presupposition is not necessarily stated, more experience may be necessary to deduct this information from a QRA.

As an example, in a QRA, the event gas leak is investigated. A presumption is made about the deterioration of the pipelines based on historical data of similar equipment as the cause for leaks. This is a presumption as it is regarded as true on the basis on frequency probability. The frequency probability is assumed to be representative. At the same time, without stating it, the QRA also makes the presupposition that the equipment will be operated correctly at all times, since it is not taking into account operational failures, but this is not necessarily stated in the text.

2.8 Uncertainty Assessment

When we have chosen to regard uncertainties and not probabilities as the main component of risk, we will need to assess the uncertainties so that we can convey this information in a structured and transparent manner. To present the results in a transparent manner does not mean that the results become objective, but that the assessor(s) should convey the information about their limitations, or strength of knowledge, in the assessment in such a way that the decision takers can take this information into account. To make it clear for the recipient of the QRA what we are uncertain about and how things can be improved, we need to classify our uncertainties.

2.8.1 Classifying uncertainties

We have already classified some of uncertainties with regards to what we are uncertain about. We have uncertainties about the identified events;

$$U(A|K)$$

We have uncertainties about the consequences;

$$U(C|K)$$

In the risk perspective $R = (C, U)$, we have defined that A is a part of C, so our top uncertainty will be $U(C|K)$.

When using a model to calculate the risk, we defined the uncertainty about the output due to model structure;

$$U(G|K)$$

Uncertainty about the inputs to the model due to the variables;

$$U(X|K)$$

Uncertainty about the inputs to the model due to the parameters;

$$U(\lambda|K)$$

The model will be a representation of the unwanted event, such as a gas leak, and show what consequences this can have.

Such an event is not random as a probability would maybe suggest, but happens due to technical, operational and organizational factors that occur during operations. In a QRA we are also interested in these factors that can prevent the event for happening and those that can mitigate the potential outcome. As this is a natural part of risk assessment, and we are going to regard the uncertainties as the main component of risk, we should also have uncertainties for these factors as they are different than model inputs, model and outputs.

To do this we will take basis in an event causal chain that is used in barrier management. These are often represented by a bow-tie, as shown in Figure 1, to show how the barriers work to prevent threats to become an unwanted event. These are often called preventive or causation barriers (Vinnem, 2014). It also shows how the potential outcomes are affected by the consequence reducing or mitigating barriers.

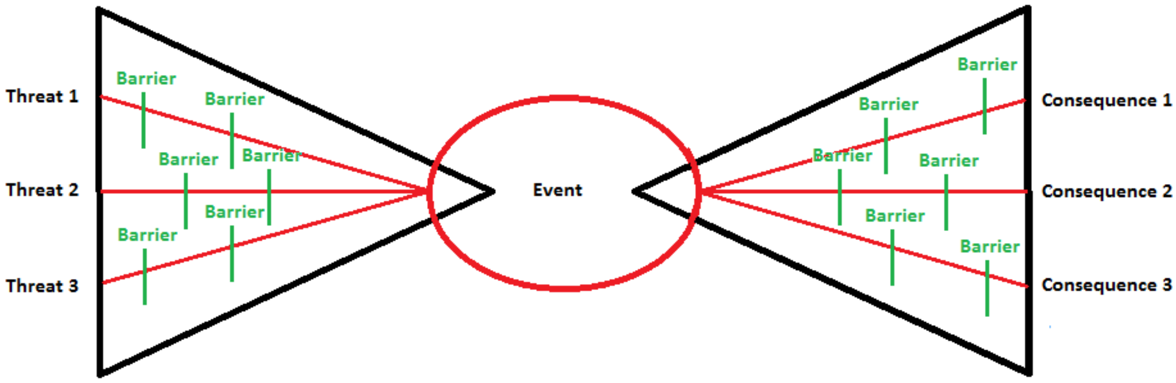

Figure 1: Bow Tie diagram

Our knowledge about the hazards, causation barriers, the initiating event, mitigating barriers and consequences should be separated when communicating uncertainties. The hazards and initiating event is what we know about the event A and the consequences is part of our knowledge regarding C.

As we have chosen to define A as a part of C, the threats, events and consequence are all included in

$$U(C|K)$$

Our model with variables and parameters represent the scenario when a threat has caused an initiating event I and gives us the consequence C as output. In this modeling we have to make assumptions about the state of the barriers, as well as the assumptions made about the model, variables and parameters, to be able to say something about the probability of an event to occur $P(A|K)$ and the outcome as part of the risk picture. For this risk picture to be "true", the assumed state of the barriers must also be true therefore we need to define and assess the uncertainties with regards to these. For causation barriers and mitigating barriers we write;

$$U(Bc|K) \text{ and } U(Bm|K)$$

Flage and Aven (Flage & Aven, 2009) covers this to show how the risk description in QRA can be done. We will also use the notation of uncertainties regarding the outcomes as (Flage & Aven, 2009) shows, where Z is physical quantities such as a fire, heat load and gas dispersion, and L is the losses in terms of lives, environmental impact or assets. The uncertainties regarding these outcomes we write respectively;

$$U(Z|K) \text{ and } U(L|K)$$

The information contained in a QRA is closely related to the later process of barrier management and barrier management is the process that actively reduces risk to ALARP.

The next figure, Figure 2**,** shows the relationship between the different uncertainties that we have classified. The reason we do this is because these uncertainties have different effect on the risk and that information should be presented to the other processes that will use this information.

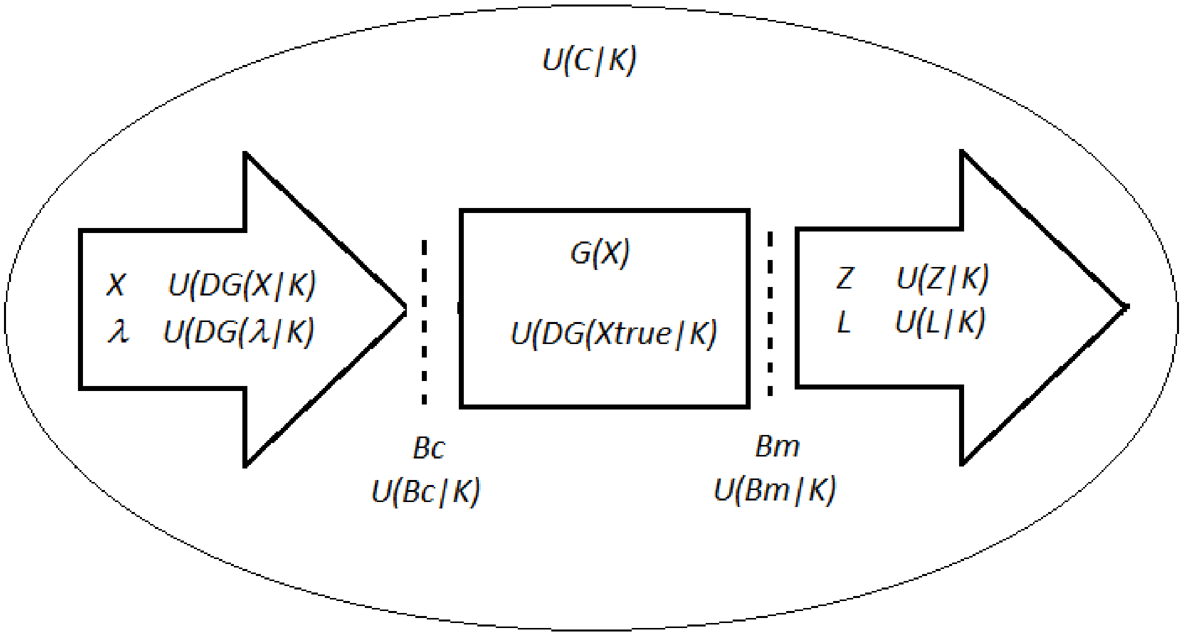

Figure 2: Relationship between uncertainties

As an example we see that for risk reducing measures, we must do something about the barriers, changing our model does not reduce risk. To obtain a more precise result, we cannot change the barriers but we must do something about our model.

2.8.2 Strength of Knowledge

We have defined the different uncertainties and see that they all are depending on our background knowledge K. The knowledge is then the main dimension to consider first when assessing the uncertainties in a QRA. By the definition of epistemic uncertainties, the stronger the knowledge is, the smaller the uncertainty. To assess the SoK (strength of the knowledge), we are going to concentrate on a crude grading as presented by (Flage & Aven, 2009) and (Aven, Practical implications of the new risk perspectives, 2013) .

To make a crude grading SoK we will evaluate the following conditions:

The knowledge is weak if one or more of these conditions are true:

- The assumption(s) made represents strong simplification
- Data are not available, or are unreliable
- There is lack of agreement/consensus among experts

- The phenomena involved are not well understood; models are non-existent or known/believed to give poor predictions.

However, if all of the following conditions are true, the knowledge is considered strong:

- The assumption(s) made are seen as very reasonable
- Much reliable data are available
- There is broad agreement/consensus among experts
- The phenomena involved are well understood; the models used are known to give predictions of the required accuracy.

Cases in between are classified as having a medium strength of knowledge.

Let's say that a new oil reservoir is found profitable on the NCS and decision to move forward with concept selection for a production platform is taken. The risk assessment team is put together to do a QRA in the concept selection phase. Meteorological data is gathered and used as the background knowledge K. Each parameter and variable can individually have significance on the risk picture. It is therefore necessary to regard each of them as an assumption itself and assess the strength of knowledge for each one.

We are going to look at the wind direction in this example. The expected wind direction is shown in a wind rose. The assumption is defined as: "The expected wind direction at any random time is given by the direction distribution presented by the wind rose".

The phenomena, or event, this is going to be studied for in this case is the platform layout. The wind direction is important for the overall design of the platform with regards to where the LQ (Living Quarter) should be, and where the process and drilling area should be. This is because in a case of a hydrocarbon leak in the process and/or drilling area, it is safer to have the LQ upwind so that the hydrocarbon leak is not transmitted to where most people will be. This is the reason why all platforms on NCS have the LQ in the south/west-west direction and the process flare, which is a potential ignition source, in the opposite direction.

To assess the SoK we use the criteria presented by Flage and Aven (Flage & Aven, 2009).

- The wind rose is a reasonable representation of the expected wind direction over the lifetime of the platform.
- Much reliable data is available. Meteorological data has been systematically collected over a period of many years and purchased from a reliable source.
- There is a broad consensus among experts.
- The phenomena are well understood and the wind rose is considered to be a prediction with the required accuracy with regards to the platform layout.

All the following conditions in (Aven, Practical implications of the new risk perspectives, 2013) are true and we have a strong knowledge about wind direction and how it affects the layout of the platform.

2.8.3 Sensitivity

We can have uncertainty about a risk influencing factor such as a variable or a parameter. But having uncertainty doesn't necessarily mean that it affects the risk. As mentioned before, reducing uncertainty doesn't necessarily mean to reduce risk. This is due to sensitivity. If a system in our model is not sensitive to changes in a variable, we can still have little uncertainty in the result. We grade the sensitivity as presented by (Flage & Aven, 2009)**.**

- Minor sensitivity – Unrealistically large changes in base case values needed to bring about altered conditions.
- Moderate sensitivity – Relatively large changes in base case values needed to bring about altered conditions.
- Significant sensitivity – Relatively small changes in base case values results in altered conditions.

If the wind direction is regarded as a part of the overall weather conditions, then the sensitivity analysis would be of the weather as a whole, the importance of one parameter can be hidden and be a critical uncertainty. In this case we are not uncertain about the possible directions, or their average frequencies, but the uncertainty is that we cannot know exactly what wind direction that will be at the moment a leak occurs because we cannot control weather and thus the direction will be random.

The use of wind direction when assessing SoK was in the example in 2.8.2, for deciding the direction of the platform. The wind physics can change, but as an average it will not change quickly but rather gradually with small increments over a long time period as climate changes. Since the platform is going to be situated on the location for, say 40 years, the 30 year average is a good representation of what directions to be expected and unrealistically large changes is needed to bring about altered conditions, thus the sensitivity is minor.

The average wind direction gives you an average result over a long time period, however if the wind direction is at the least favorable direction at a leak time, the resulting potential harm to people can vary drastically from the most favorable direction.

To know how sensitive the risk is to the least favorable wind direction, another analyses using the least favorable direction as an input parameter could be necessary. Without this extra analysis, i.e. obtaining a stronger knowledge, we should not conclude that the sensitivity is low as we do not know exactly. We can also say that it can be difficult to decide the sensitivity with a weak knowledge, and SoK should have priority over sensitivity when assessing the uncertainty. If a parameter is used for different scenarios, i.e. different model, the sensitivity must be determined in each case.

In cases we have weak knowledge about, say a phenomena represented by a model $G(X)$, we have a weak knowledge about how the factor propagates through real world compared to the model. It will be difficult to decide what a small or large change is in base case value that will bring about altered conditions. As our knowledge is stronger about the model and how it represents the real world, we will be able to predict more accurately what is a small and large change and what will result in an altered condition or not.

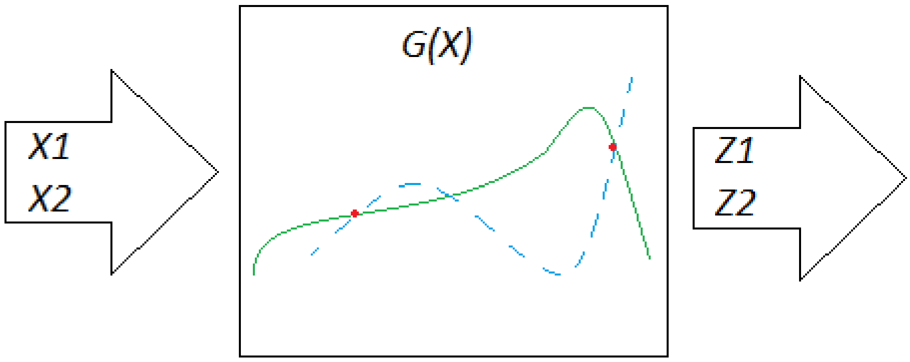

Figure 3: Sensitivity and model uncertainty

As illustrated in Figure 3, the two sample inputs of $X1$ and $X2$ on the model gives two sample outputs $Z1$ and $Z2$. The red dots illustrate a weak knowledge of the model compared to the phenomena, where we only know the place of the two dots. The blue dotted line shows us we have a moderate knowledge about how X behaves in G and can make a more precise decision. The green line shows we have strong knowledge and we see that with weak knowledge the results can be the same with a theoretical infinite number of possible functions. How strong knowledge is required will depend upon the phenomena the model represents.

2.8.4 Belief in Deviation

It requires us to have good knowledge about the model to say something about the sensitivity. In that sense we then assume to know what the input will be. That might not always be the case as we might have a deviation from what we expect. How much we believe, based on our subjective knowledge, the value will deviate from its base case, we define as belief in deviation as described in (Berner & Flage, 2014).

As an example if we have a variable input X to a model $G(X)$. To get a result out, we have to assign a value x_0 to X. This assigned value can be based on an assumption about X. Our belief in deviation expresses how much we think the actual value X_{true} will deviate from the base case model input x_0 to which the model output is based on. In a leak scenario such a variable can be the gas pressure inside the pipe set to x_0. If a process is very stable and has no known causes for upset for example downstream a compressor running at fixed speed, then our belief in deviation is very low. However if the gas pressure is due to other variable processes known to fluctuate, we will have a medium or high belief in deviation. Again we see that belief, that suggests a subjective knowledge, requires us to know something about the variable in question to make a qualified assumption about its value. Otherwise, this will be based on other assumptions that again can be a root for more uncertainty. As mentioned previously, every variable and parameter must be regarded as separate assumptions.

2.8.5 Three dimensions

We have presented the strength of knowledge, sensitivity and belief in deviation. Together these three form a three dimensional characterization of uncertainty as presented by (Berner & Flage, 2014) where they are grouped in different settings according to **Table 1**

Table 1: Settings faced when making assumptions in a risk assessment.

Belief in deviation from assumption	Sensitivity of risk index wrt to assumption	Strength of Knowledge	
		Strong	Moderate / Weak
Low	Low	Setting 1	Setting 2
	Moderate / High	Setting 3	Setting 4
Moderate / High	Low	Setting 3	Setting 4
	Moderate / High	Setting 5	Setting 6

Based on the resulted settings, Berner and Flage (Berner & Flage, 2014) suggest different treatment responses by quantitative or semi-quantitative methods. The semi quantitative ways described by (Aven, Practical implications of the new risk perspectives, 2013) is basically covered by the means to find a setting according to (Berner & Flage, 2014). This include crude strength of knowledge and sensitivity categorization according to (Flage & Aven, 2009)

Aven (Aven, 2013) also introduces the assumption deviation risk as a semi-quantitative way where the following are considered:

- Magnitude of the deviation
- Probability of this magnitude to occur
- The effect of the change on the consequences.

If we regard the probability of the magnitude to occur as a subjective, knowledge based, probability, then these three considerations also covers the three dimensions in (Berner & Flage, 2014), strength of knowledge, belief in deviation and the sensitivity. The assumption deviation risk is another way of describing the uncertainty and involves a more calculated approach of representation. This can be more useful in some cases rather than just classifying the uncertainty in a different setting.

2.9 Robustness

How robust the results in a QRA are, depends on how sensitive the results are to changes in the base case. If large changes in base case are required to change the risk picture, the results in a QRA can be regarded as robust. If however, small changes in base case values will result in a change of risk picture, the results of the QRA are not robust. We see that this coheres with the sensitivity definition described by (Flage & Aven, 2009). We have also seen that the sensitivity also depends on the knowledge, and the same does the belief in deviation. If each the uncertainties in a QRA are given a setting 1 to 6 according to (Berner & Flage, 2014)**,** it will cover the three dimensions of uncertainties. Counting the number of uncertain assumptions for each setting it would be possible to quantify the robustness of a QRA.

Say a QRA is performed in an early phase of a project and then updated during the middle and late phases as more knowledge is available. In this case we counted the total number of uncertainties to 1000. Out of those 1000 the following distribution between settings are found for each phase as shown in Table 2.

Table 2: Total count of uncertainties in QRA distributed by assessed setting

Setting	Early Ph.	Mid Ph.	Late Ph.
1	100	125	225
2	100	200	250
3	200	250	250
4	250	250	225
5	250	125	50
6	100	50	0

It is natural that in an early phase there are more uncertainties of a high setting. As the project evolves with more information, the knowledge becomes stronger and the uncertainties should ideally be reduced. Another thing to notice is that the most important uncertainties, that should be given priority, are the ones with the highest settings.

If we look at these distributions in a line chart, as shown in Figure 4, the picture will become clearer and show that a progress is made in the robustness.

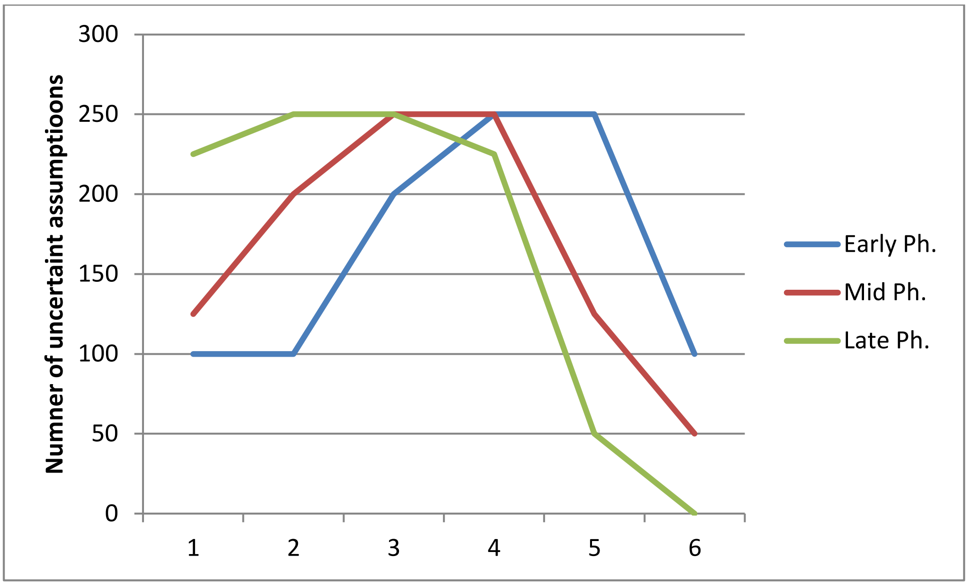

Figure 4: Total count of uncertainties in QRA distributed by assessed setting

This quantification of robustness does not only show the status of the QRA, but it also shows where the organization can prioritize their resources in order to increase the robustness. In the example we see that not much changes in the count of assumptions with setting 1 from early to middle phase of a project. On the other hand, we see that the assumptions with setting 6 are reduced to zero from early phase to late phase, as it ideally would be.

3 The use of QRA in offshore projects

3.1 The purpose of QRA

It is not the purpose of a QRA to reduce risk. The purpose is to assess the risk. The risk reduction is part of the risk treatment done by the risk managers. The NORSOK Z013 standard defines the role a risk assessment in general shall have in an offshore project according to ISO/IEC 31000. (PSA, 2010) The defined elements of a risk assessment are

- risk identification
- risk analysis
- risk evaluation

ISO/IEC 31000 and NORSOK Z013 standard also emphasize the importance of communication, consultation, monitoring and reviewing the risk through the whole process. As shown in Figure 5, communication and consultation is a dynamic process through all stages of a risk assessment, and all stages of a risk assessment are done through all stages of a project. This statement strengthens the need for the risk analyst to convey the information in a way that is suited for their intended purpose.

The NORSOK Z013 standard does not cover risk treatment. However the risk assessment process can be used to identify potential risk reducing measures and the evaluation of these.

The direct purpose of a QRA is stated by PSA as "to establish requirements for effective planning and execution of risk and/or emergency preparedness assessment". (PSA, 2010, p. 5) But all NORSOK standards as a whole, including Z013, have the goal of adding value, reducing cost and increase safety. Having these goals in mind, the risk analyst must consider what the information in the QRA is going to be used for. The standard also emphasizes that the requirements in NORSOK Z013 standard are related to ensuring that such an assessment/analysis are suited for their intended purposes rather than specific requirements on how such is performed.

NORSOK Z013 standard does not reflect the PSA new risk perspective as described in chapter two. The definition of risk in Z013 is "combination of the probability of occurrence of harm and the severity of that harm." (PSA, 2010, p. 13) But since the new risk perspective does not exclude probability, but rather takes a more wholesome view of risk, many of the clauses and sub-clauses still support viewing risk as a combination of consequences and the related uncertainties.

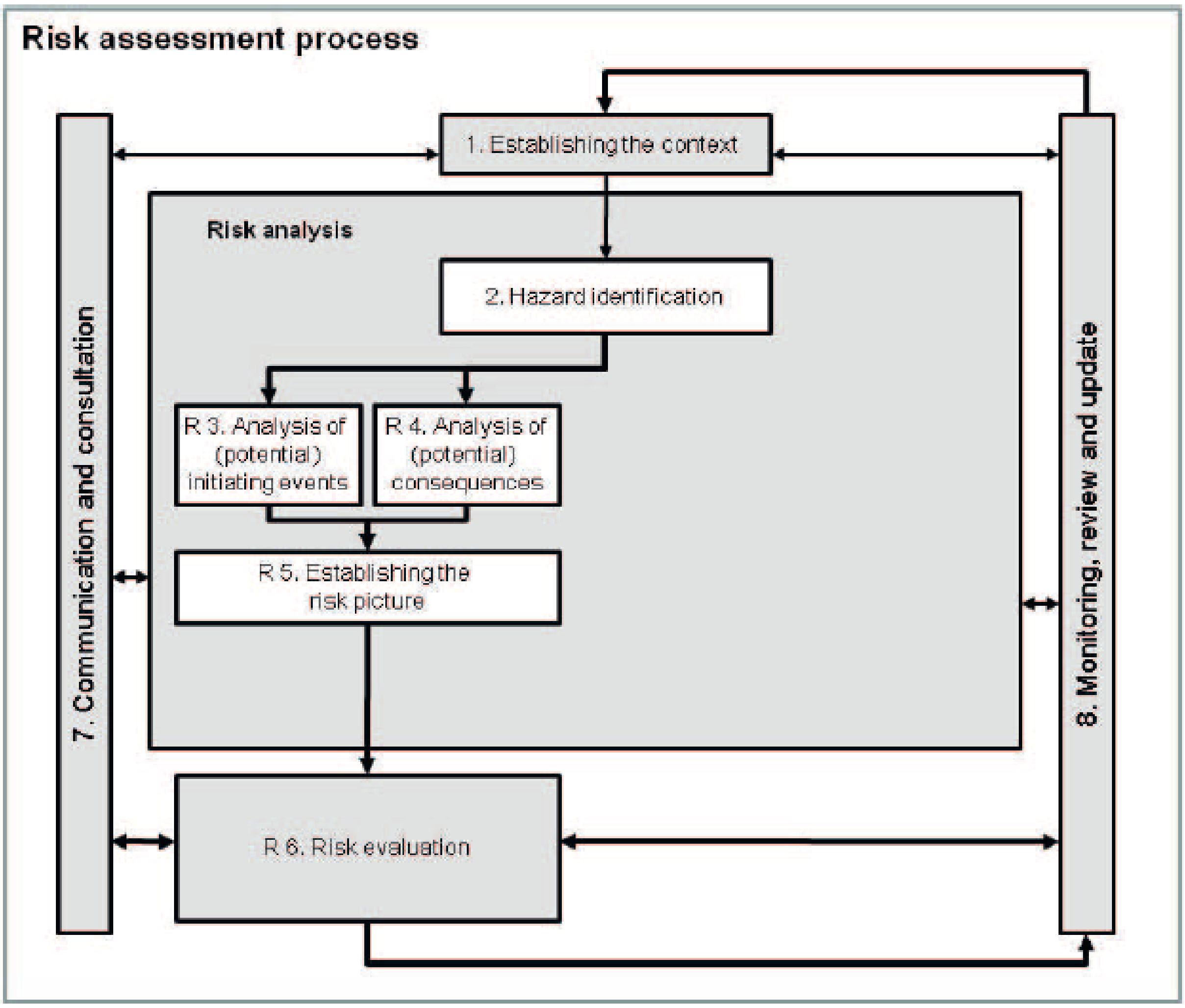

Figure 5: Risk assessment process (Source: NORSOK Z013 Edition 3 2010)

3.2 Project phases and QRA

NORSOK Z013 standard divides the requirements for a risk assessment in to general requirements (Clause 5) that is applicable throughout the project, and more specific, additional, requirements according to which phase the project is in. NORSOK divides the additional requirements into the following phases (PSA, 2010, p. 5)

- Concept selection (Clause 6)
- Concept definition and optimization (Clause 7)
- Detail engineering (Clause 7)
- Operating (Clause 8) phases.

The two first phases is part of project planning and detail engineering is part of project execution as shown in Figure 6.

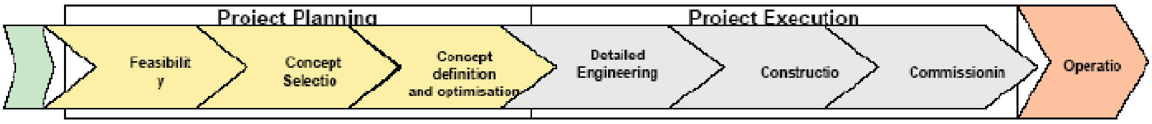

Figure 6: Project phases as defined by NORSOK (Source: NORSOK Z013 Edition 3 2010)

Normally, each of these phases transition from one to the next with decision milestones, also often referred to as decision gates. When a decision is made and the plan for execution for the next phase has started, it can be extremely costly to go back and redo the work due to wrong decisions. To make the optimal decisions, the information and the communication of it, has to be optimal.

In an early phase, such as in concept selection, the engineering and the QRA is based on limited data and many assumptions to compensate for the lack of information. This is a natural and necessary part of this phase and should be treated as such. NORSOK Z013 standard (PSA, 2010) acknowledges this and states in clause 5.2 that when establishing the context of a risk assessment process, the objective shall be tailored to the required and available level of detail. Furthermore, it can be difficult to define the system boundaries when the boundaries itself must be based on a set of assumptions as the detail design knowledge is not available.

As the project move into detail engineering, the concept is decided and the detail knowledge about the actual design is produced. The knowledge is getting stronger, and the uncertainties in a QRA should be reduced accordingly. The system subjected to the assessment shall be suited for its purpose, particularly with respect to decision input at the right time. When more detailed decisions are being made, more detailed (stronger) knowledge is required.

When defining the methods, models and tools to be used, the availability of relevant and/or required data and models shall be considered. To use the new risk perspective focusing on communicating uncertainties as a tool can serve the purpose better, especially in an early phase of a project when uncertainties are higher and detail knowledge is not yet available. The tool can then focus on reducing the right uncertainties, and only when new data or knowledge is available, find the need to update the frequency calculations as necessary. It will also be more transparent when documenting uncertainties as stated in NORSOK Z013 standard (PSA, 2010) when alternative approaches are used to compensate for lack of relevant data and models and the limitations in the validity.

When entering and being in an operational phase, uncertainties should ideally be reduced to zero as we have actual operating conditions to record and thus the knowledge should be strong.

By communicating uncertainties rather than probability, we now have a tool to follow this natural progress more continuously and resources can be more efficiently used.

3.3 General requirements to risk assessment

The main general requirements for a risk assessment process in clause 5.1 (PSA, 2010, p. 18) states that it shall always:

3.3.1 "Identify hazardous situations and the potential accidental events"

There can be cases that does not get identified and not subjected to the rest of the process. In other cases there will not be possibility to perform a QRA covering the complete array of possibilities and a qualitative selection has to be made about which scenarios that will represent the risk pictures. This is done on the basis of the knowledge of experts.

NORSOK Z013 standard states in clause 5.3 (PSA, 2010) that one of the objectives in hazard identification is identification of possible risk reducing measures. With weak knowledge, this can be very hard, especially when deciding on which risk reducing measures to choose from a variety. With weak knowledge the effect can be difficult to decide and then it is difficult to efficiently use the recourses available. Maybe lots of recourses are put into a few measures, chosen from best available knowledge, but as detail design goes on, maybe a less expensive and less resource demanding measure would be found.

Say the team has the possible risk reducing measures 1, 2 and 3 to choose from. With weak knowledge they might not know which one will give the best result. This can lead to the following scenarios;

- All are implemented to be as safe as possible with the cost and resources that requires.
- One or two of them are seemed best, based on weak knowledge, and due to limitations in recourses the 3rd one is left out. This can prove to be wrong when more knowledge is available.

In both cases recourses are stretched and cannot efficiently focus on the best possible measure with regards to both safety and resources. Reducing uncertainties does not necessarily mean reducing risk but before risk reducing measures can be done efficiently, the uncertainties must be reduced first.

3.3.2 "Identify initiating events and describe their potential causes"

The initiating events and causes are the hazards that make up the left side inputs of the bow tie diagram. There can be many causes that lead to the same initiating event I. Failure to identify a cause or an event leads to the event not being subjected to the rest of the QRA process. The more detailed requirements for analyzing the initiating events and their causes is more detailed in NORSOK Z013 standard clause 5.4 (PSA, 2010) for general requirements. Additional requirements in concept selection phase are found in clause 6.4 (PSA, 2010, p. 31) where it's stated that "*extra focus shall be on unconventional concepts*" With unconventional concepts it can be more difficult to do an analysis as less operational data is available. In other words the knowledge is weaker and the need to focus and communicate uncertainties rather than probabilities can be stronger.

In concept definition and detail engineering, NORSOK Z013 standard (PSA, 2010, p. 34) says that the data shall also be based on "*best available site specific information*". This underlines the need to update the QRA with available information and update the knowledge of the assumptions made in previous phase.

In operational phase, clause 8.4 (PSA, 2010) have additional requirement to update the QRA with data that are considered statistically significant. If uncertainties are put into a setting in previous project phases, it will be more transparent which data that are more important and updating the data will be easier and maybe less recourse demanding in later phases. Clause 8.4 also focuses on updating the QRA with regards to barrier data.

3.3.3 "Analyze accidental sequences and their possible consequences"

Accidental sequences are what can happen after the initial event and is represented by the right side of the bow-tie. The accidental sequence leads to the defined consequences C'. The more detailed requirements for this analysis found in clause 7.5 (PSA, 2010). The sub clauses are detailed to specific scenarios and we will not cover all of them in detail here. However it is worth to notice that the level of detail that is required reflects the level of details that should be covered by a proper analysis of the uncertainties in previous phases of a project

In the operational phase, NORSOK Z013 standard (PSA, 2010) says that the analysis shall reflect the need for information by personnel involved in the operations. If uncertainties are properly classified with regards to the end user, this information will be easier to identify and convey to the end users.

3.3.4 "Identify and assess risk reducing measures"

To reduce risk, the measures are often introduced in the forms of barriers. Risk reducing measures can also be in the form of more robust design and gives requirements to the design process. Uncertainties about design details and barriers must be communicated to the right users. This is not necessarily only the decision makers. By communicating these details better to the users, the users are also better enabled to give feedback to the assessors about necessary changes to base case that can occur during the project.

3.3.5 "Provide a nuanced and overall picture of the risk, presented in a way suitable for the various target groups/users and their specific need and use"

Since NORSOK Z013 standard was last revised, PSA have acknowledged that focusing on probabilities is a limiting way of viewing risk (PSA, 2015a). To provide a nuanced risk picture, the new risk perspective focusing on uncertainties should be used. This sub clause also underlines the requirement to communicate the uncertainties based on who is going to use the information and who needs to be informed about the uncertainties. This relates not only to decision makers but uncertainties related to risk reducing measures must be communicated to barrier management, designers and operators.

NORSOK Z013 standard focuses on clear communication and consulting through all clauses of its requirements. The objective of communication is also defined as a continuous process throughout the risk assessment, not only limited to establishing the finished risk picture. Clause 5.6 states that the intention of establishing the risk picture is to provide information, not only to the relevant decision makers, but also the users. The information shall be clear and balanced and contain the main risk contributing factors and also include a discussion about uncertainty. Limitations and the difference opinions based on expert knowledge should be highlighted in such a way that the risk picture is suitable for decision making and understandable to all relevant personnel.

Another clear requirement for the risk picture is that all assumptions and presuppositions shall be clearly and explicitly documented and categorized as analytical, technical or organizational/operational. The analytical part represents the methods used in the QRA and the knowledge is based on. The technical part we can relate to the previous mentioned barrier management and design. The organizational/operational part relates to the organizing of activities and the operational phase. The details of these assumptions and presuppositions shall be described in a manner that is understandable to the end user of the information.

The presentation of the risk picture shall include a ranking of risk contributors as well as the identification of risk reducing measures and present important operational assumptions in order to control risk.

In chapter two we focused on the sensitivity of assumptions, this is also very well covered in clause 5.6 and states that a sensitivity analysis shall be carried out to include identification of the most important assumptions/parameters in the analysis. This is in line with the theory about sensitivity presented in chapter two. Another important aspect of the sensitivity analysis requirements is to evaluate the effects of changes in the assumptions/parameters. This represents the belief in deviation dimension as covered in chapter two.

3.4 Risk analysis/assessment and risk management

Risk analysis is a part of risk management, and knowing and considering what the information is going to be used for in a later stage is imperative for the effectiveness or robustness of the risk assessment. Not just in a safety setting, but also in cost effectiveness and value setting. Therefore the uncertainties must be communicated in such a way that the next link in the project chain can concentrate on the important information and reduce the efforts on finding it as well as reducing the reducing the recourses on not so important information. This way the risk assessors should not expect the decision makers to find or automatically focus on the important, but see it as their task to communicate it.

Consider that the risk analyst does the QRA, the risk manager and/or the project manager makes the decisions based on the information they receive. These decisions again affect the design that the engineer makes and again this affects how the operator is able to operate the design. The risk analyst is in this case the provider or producer of information, the managers the receivers and the engineer and/or the operator is the end users. This chain cannot be completely regarded as separate links and exclusive processes where everyone is operating individually, they have some overlapping interests.

For example if the risk analyst makes an assumption, in a concept selection phase of a project, about a parameter λ in his model, the output will only be valid as long as the assumption is valid. The concept is selected based on the model output by the managers. How true this assumption is in the future, can be affected by how the engineer makes the design in the detail design phase or how the operator uses the design in the operating phase. If a wrong assumption is made in the beginning of a project, the mistake will propagate through the project phases if not uncovered. The biggest problems with detecting and correcting a mistake in later phases is that

- The mistake becomes more difficult to detect in later phases, because the amount of information generated grows rapidly
- The later a mistake is corrected the more costly it will be to correct

To have wrong assumptions propagating through the project phases not only adds to the cost but decreases the safety if not corrected.

In Figure 7 we show that the decision makers does not need to know all the details of the QRA, but there are certain details that they really need to focus on and that is the job of the assessors, as information provider, to highlight and communicate. Otherwise the decision makers would need the same competence, as the assessors, to efficiently deduct this information. As mentioned the decision makers also have other information they must consider. This important information is highlighted with a green overlap between the QRA and management.

The same is for the design engineers that get their guidelines from the decision makers. The better the designers are able to make their design according to the framework, and make their decisions on the lowest level possible where the competence is better, the more value they can add to the project. Therefore it is also important that the design engineers have a good knowledge about the reasons the framework is as it is, and not just knowing the frames. The framework has some of its base in the QRA and the important information contained is shown as green. This information is due to many technical assumptions made in the QRA. There are also many operational and organizational assumptions made in a QRA, not always stated thus becoming a presupposition. These also affects the operators in an operating phase and the focus area is shown as green between QRA and operators.

We have added barrier management to this illustration. This is because PSA ask for better barrier management in offshore oil and gas projects. (PSA, 2015c) Barrier management affects the design, operations and organization and the decisions made through the project. There can be many assumptions made, technical, organizational and operational, in a QRA and barrier management involves all. Effective and good barrier management is based on good information and knowledge, of which a QRA should be a provider for.

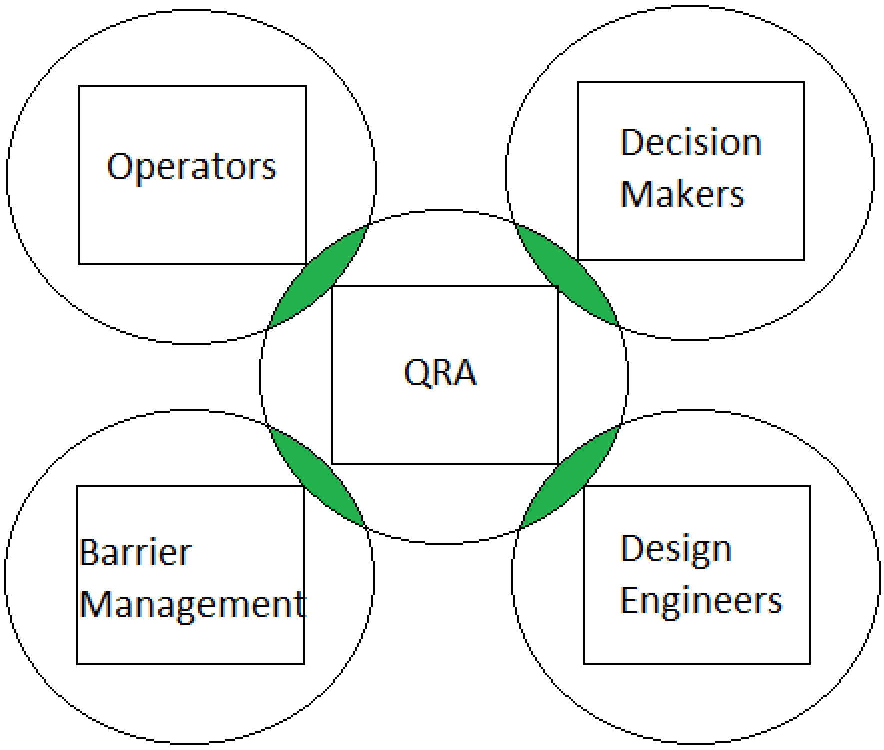

Figure 7: QRA interface with other processes in offshore project

As mentioned, barriers are put in place to reduce the probability of an unwanted event, causation barriers Bc or to reduce the consequences, mitigating barriers Bm. Uncertainties, $U(Bc|K)$ and $U(Bm|K)$, about these barriers in the QRA must be highlighted. These are often very sensitive to the result otherwise the barriers would not be needed. PSA separates between technical, operational and organizational barriers. (PSA, 2015d) The difference between them can be illustrated by the following example.

Imagine an unwanted event occurs and a stop button must be pushed in order to stop the process. In this case the stop button is a technical barrier element, the person pushing the stop button is an organizational barrier element and the task of pushing it is an operational barrier element. The task of pushing it will be defined in a specified procedure to handle the unwanted event, so that the procedure with its specified content will be the barrier element in itself. Failure in one of these elements prevents the barrier function of stopping the process. The quality of the barrier elements also affects the performance of the barrier function. The technical quality of the stop button, the quality (competence) of the operator and the quality of the procedure (how well does the task reflect the purpose).

A QRA does not necessarily makes statements about such factors, thus instead of being an assumption, they are presuppositions or presumptions. Not being stated does not remove the fact that they are equally important, and with sensitivity of barriers, they can be even more important than some of the assumptions made.

A technical barrier element is often referred to as a SCE (Safety Critical Element). If it fails, the system will fail and we can have an unwanted event. SCEs are designed to a minimum PS (Performance Standard) that states how the element should perform in order to perform its barrier function. A PS also defines how the verification of such performance should be done to make sure that it is according to requirements. Verifications are often done at many stages such as design, procurement, installation and commissioning. The information has its base in the QRA and such information must be communicated in a way that it is transparent and easy to find and focus on. This information is often found in the technical assumptions made in a QRA.

Organizational and operational barrier elements are not under the same strict supervision as technical barrier elements. But with 40% to 50% of the leaks on NCS in the years 2001 to 2004 and between 55% and 83% in the years 2005 to 2011 according to PSA (PSA, 2014) and RNNP (Risk level in the petroleum activity) being due to operational and/or organizational factors and not technical, the real improvement for achieving the zero philosophy should be focusing on organizational and operating barriers in the same way as technical. This thesis will not cover more about how this can be done through such things as competence requirements or procedure development, but the start of such a process will be that the QRA communicates the uncertainties about such barriers as equally important as technical barriers as input to the organizational decisions and the operating personnel.

4 Using the new risk perspective in QRA

4.1 Introduction

The latest revision of NORSOK Z013 standard came in 2010. Due to that and the relatively long process of going from concept selection to operating oil production, it is very difficult to use an example that is actually made according to these requirements. The platforms that have a QRA according to newest revision are still in planning or in detail engineering/construction. Another problem of using such a QRA from the offshore is that the level of detail in them can be spread over hundreds of pages and it would be too extensive to analyze it all. This problem is not only valid for performing this thesis, but also for the end users within the organization or project and highlights the need to focus the information communicated to relevant parties.

To address the theories and requirements, a smaller project was necessary to show the essence of this thesis. The points made can however be scaled up to larger QRA in efforts to focus the information and communicate uncertainties.

Another point to note is that this case study is not based on a QRA performed to the requirements in NORSOK Z013 standard. There are different requirements to onshore based installations but this thesis will not cover these requirements. This case is however relevant to the theory of communicating uncertainties as the onshore plants deals with hydrocarbons and the assumptions made can be easily transferred to an offshore facility.

The case is based around an onshore LNG (Liquefied Natural Gas) plant situated near a residential area. There is a rather large main QRA produced for the facility, but this case will concentrate on a QRA performed for a single operation of bunkering a ship that uses the LNG for propulsion fuel.

The objective of the performed QRA was to calculate the risk, taking into consideration the fueling operation. The risk calculated was in the form of individual risk and individual specific risk to onsite manning, 1st and 2nd party, and for off-site population, 3rd party.

This thesis will not cover all assumptions and points made in the QRA, only those necessary to make the point and reflect on the information provided. It is not the intention of this case study to make a risk assessment or evaluate the performed assessment, but to evaluate how the information in the QRA is communicated to the relevant parties.

4.2 The case

To bunker a ship with LNG from the plant, two trucks was planned to drive to the ship and use the truck onboard pumps to bunker the ship through flexible hoses. This is a temporary solution while building a permanent solution where pipes would go directly from the plant to the ship. This operation can potentially add to the overall risk as it adds complexity to the already situated plant.

The risk to on- and offsite personnel is due to potential leaks and ignition of LNG. In other words the initiating event I studied is a LNG leak. The causes to such a leak will be a rupture in the technical containment barriers such as the hoses. The probability of a leak is based on the historical leak frequency of such hoses and the severity of the leak is determined by the leak size and time. Leak size is determined by the leak frequency of small, medium and full rupture and the historical data that supports such. The three evaluated leak sizes are input parameters to the model. They do not vary and these are not possible to control as they are represent a potential future event and the uncertainty to which size an actual leak will have is represented by using the three different sizes.

The leak frequency is also an input parameter to the model and the uncertainty about this parameter is represented by their frequency probability and is well documented by a qualitative assessment in the QRA and a good description of why it is chosen as representative.

The leak time is determined by an industry standard and QRA had recommended a leak time of 90 seconds where 60 seconds are detection and initiation time and 30 seconds is reaction time. This leak time has been chosen to represent the risk picture and is dependent on many controllable factors in such a way that the leak time should be regarded as a input variable to the model.

This case study will focus on the model input variable leak time. As a variable is controllable, its information and uncertainties represents the identification of risk reducing measures in the form of mitigating barriers. To reduce the possibility of a leak to occur, something would have to be done with the input parameter leak frequency. If that was to be done, if the frequency was not acceptable, the hose design would have to be changed to a more robust design.

Since the assumptions and uncertainties are well documented, it is possible to deduct these and use the information, but if this was a larger installation such as an offshore oil producing platform the total amount of information can make it more likely to not be picked up by the relevant party.

The QRA contains an assumption register and they are well documented. The assumption made for detection and isolation time of 90 seconds, contain many underlying assumptions. The main assumption of 90 seconds is also evaluated with regards to sensitivity. The problem however is that the underlying assumptions that lead to the assumption of 90 seconds are not separately evaluated with regards to sensitivity and their potential impact on the result stays somewhat hidden.

In this case study we will look at these underlying assumptions and evaluate them according to strength of knowledge, belief in deviation and sensitivity.

4.3 Assumptions

The main assumption of 90 seconds is based on an industry standard for similar systems. This tells us that for this to hold true, the systems technical, operational and organizational factors should be a minimum of average quality as represented by the industry standard. It would be very difficult to verify this unless there is sufficient data from an operational period that verify that practice is according to standard.

As mentioned, the main assumption is based on a series of underlying assumptions that are written in text. We will focus on two of them as the rest of the text can been seen in coherence with these two.

1) Procedures have been made and relevant training to handle leakages has been carried out
2) Gas detection on the trucks will shut down bunkering during a leak

In this case, we evaluate the dimensions of uncertainties as if we evaluated them when performing the QRA in an early phase or concept selection, as NORSOK Z013 standard would refer to it for an offshore facility. As this QRA was created before the later project phases, we have no updates in detail engineering or operation to evaluate, but we will make an example when evaluating the robustness.

4.3.1 Assumption 1 – Procedures and training

This could easily been seen as two different assumptions one about procedures and one about training. There is a third sentence in the QRA that also relates to this that assumes the manual ESD (Emergency Shut-Down) button is activated upon detection. This assumption contains implications on organizational, operational and technical barrier elements as illustrated by the example in section 3.4. Since these three sentences together perform a barrier function, that if one of them fails, the barrier function will fail, we will treat them together. This is because they will have the same sensitivity on the leakage time.

The procedure relates to the task of pushing the ESD button as an operational barrier element. The quality of this operational barrier is determined by the quality of the procedure. The training relates to the organizational barrier element which is the person performing the task. The quality of this barrier element is determined by the quality of the training this person receives. There could also be other risk influencing factors for this organizational barrier element such as time pressure, being overworked and stress. Such factors and their implications are covered by the BORA project (Aven, Sklet, & Vinnem, Barrier and operational risk analysis of hydrocarbon releases (BORA-Release)Barrier and operational risk analysis of hydrocarbon releases (BORA-Release): Part I. Method description, 2006), but without proper data in this case study, we choose not to make any assumptions and disregard them. The quality of the technical barrier element is determined by the technical quality of the button and is referred to as PFD (Probability of Failure on Demand). This technical quality and minimum requirements must be communicated to the project engineers through technical specifications to hold true. In this case, we will assume this is done and that the button is working according to specifications.

As the definition of sensitivity is with regards to the outcome of a risk assessment, i.e. if the barrier changes a little bit, how will that affect the RM? In real life, there will be more than one single barrier to prevent an unwanted event or to mitigate the consequences. If this is taken into modelling the end result might not change because the other barriers still prevent a change in outcome, leading to the conclusions that it is not sensitive. Uncertainties with regards to barriers could be viewed a little different than the definition of sensitivity described by Flage and Aven (Flage & Aven, 2009), as the barriers are in place with a minimum requirement for a specific reason as a risk reducing measure. The definition by Flage and Aven (Flage & Aven, 2009) is with regards to the change of input to a model, but barriers are not, or rarely, included in models for a QRA per today. If a barrier is not to minimum requirement, it could be regarded as sensitive in the purpose of communicating uncertainties since risk managers cannot accept one being below minimum standard.

Strength of Knowledge

Strength of knowledge on this assumption we will classify as moderate as the assumption is seen as very reasonable that proper procedures will be made and training carried out. This assumption is made before such is performed and no evidence is presented, therefore the assumption should not be considered with a strong knowledge.

Sensitivity

Sensitivity can be consider as significant as these are related to the performance of a barrier function that is consequence mitigating and we don't have the model tools to assess the actual sensitivity with regards to the risk metric. Without this function working, the leak time can be much larger than the assumption, and the leak time is sensitive to the risk metric as mentioned in the QRA. It is a relative small change in the base case, a little bit weaker procedure or weak training, can result in altered conditions. This is of course purely hypothetical in this thesis, as we do not have the resources to check the actual sensitivity.

Belief in Deviation

Belief in deviation we set to low. This is a qualitative judgment based on the fact that the information on the implications of these factors, are properly communicated and there are no obvious reasons why procedures and training should not be performed.

With a moderate SoK, high sensitivity and low belief in deviation, this assumption is put into setting 4 according to (Berner & Flage, 2014).

4.3.2 Assumption 2 – Gas detection on trucks

The bunkering will be done by the trucks on-board pumps through a manifold and further through a flexible hose connected to the ships LNG tank inlet. If a leak occurs, the trucks pumps must be stopped either by previous mentioned manual stop button or that the trucks gas detectors automatically shuts down the operation. This way this automatic shut-down is a second line barrier for the same function. In other words, the assumption of 90 seconds leak time depends on a minimum of either manual or automatic shut-down. Since the manual and automatic shut-down performs independently of each other we will treat the automatic shutdown as a separate assumption.

Strength of Knowledge

Strength of knowledge we regard as strong since the assumption made is seen as very reasonable. As this is an automatic system, it has little human influence and much reliable data are available on such technical system and the technical part is well understood.

Sensitivity

The sensitivity we will still consider as high since this is also a barrier function and if it fails, the leak time can be much different from the assumption, this is the same reasoning as in assumption 1.

Belief in Deviation

Belief in deviation we set to moderate/strong because the gas detectors are located on the trucks and for them to be able to detect a gas leak the cloud has to reach the trucks. That means that the further away from the trucks the leak occurs, the more difficult it will be for the detectors to detect.

The strong knowledge, high sensitivity and moderate belief in deviation put this assumption in a setting 5 according to (Berner & Flage, 2014).

4.4 Robustness of the QRA

With a setting 4 and 5 on the assumptions, as shown in Table 3, we don't regard the QRA as robust. Of course the QRA contains many more assumptions that would have a low setting and the total view could be an overall robust QRA. Since the scope of this case study is not to perform a full evaluation of the QRA with regards to the total, but focusing on the communication of uncertainties, we will only consider these two factors and base the robustness only on these two.

If we consider this QRA with low robustness performed in a concept selection phase, i.e. before the equivalent of detail engineering and operation phase, it will be natural to have uncertainties with settings 4 and 5 and a low robustness. Then these high settings can be communicated to all relevant personnel into the next phase, not only the decision makers, in order to improve the robustness and potentially improve safety.

When the equivalent of detail engineering is performed, which would be the phase where procedures are written and technical details are finalized, these assumptions could be updated with new knowledge and receive an even lower setting, making the QRA more robust. It is important to note that with new and stronger knowledge, the settings can become lower, but the new knowledge can also reveal that the risk is higher than previously assessed. As mentioned in section 2.8.3, reducing uncertainty doesn't necessarily mean reducing risk. But with stronger knowledge, and if the risk is increased, the result is still more robust.

Table 3: Assessed settings for assumptions 1 and 2 in early phase

<table>
<tr><th rowspan="2">Belief in deviation from assumption</th><th rowspan="2">Sensitivity of risk index wtr to assumption</th><th colspan="2">Strength of Knowledge</th></tr>
<tr><th>Strong</th><th>Moderate / Weak</th></tr>
<tr><td rowspan="2">Low</td><td>Low</td><td></td><td></td></tr>
<tr><td>Moderate / High</td><td></td><td>Assumption 1 (Setting 4)</td></tr>
<tr><td rowspan="2">Moderate / High</td><td>Low</td><td></td><td></td></tr>
<tr><td>Moderate / High</td><td>Assumption 2 (Setting 5)</td><td></td></tr>
</table>

Let's say that in a in a middle phase, or detail engineering phase, more detail knowledge is available and leads to the new uncertainty assessment of the assumptions:

- For assumption 1 the procedures are made and a training plan with content has been made, leading to an increase to strong knowledge, still a low belief in deviation and the sensitivity is still unchanged.
- For assumption 2, the knowledge is still strong and the sensitivity unchanged. The belief in deviation is reduced to low because detail engineering has revealed that the trucks detectors will not register a leak on the ship side quick enough. Therefore they decide to put remote detectors on the ship side that connects to the trucks ESD system.

Due to these two updates in the assumptions, assumption 1 and 2 is now a setting 3 as shown in Table 4**.**

Table 4: Assessed settings for assumptions 1 and 2 in middle phase

<table>
<tr><th rowspan="2">Belief in deviation from assumption</th><th rowspan="2">Sensitivity of risk index wtr to assumption</th><th colspan="2">Strength of Knowledge</th></tr>
<tr><th>Strong</th><th>Moderate / Weak</th></tr>
<tr><td rowspan="2">Low</td><td>Low</td><td></td><td></td></tr>
<tr><td>Moderate / High</td><td>Ass. 1 and 2 (Setting 3)</td><td></td></tr>
<tr><td rowspan="2">Moderate / High</td><td>Low</td><td></td><td></td></tr>
<tr><td>Moderate / High</td><td></td><td></td></tr>
</table>

When entering the operational phase, where bunkering is performed, operational data of barrier performance could be used to further update the robustness of the QRA. Not necessarily in a positive way, but a negative way would still have the positive effect of indicating where recourses are needed to improve safety.

For example in assumption 1, the belief in deviation was in early and middle project phases set to low. Let's imagine a late phase or operational phase, where internal unwanted events reported that the training performed and the content did not properly reflect the needed competence. The setting could be updated to a moderate belief in deviation based on this new knowledge, changing assumption 1 from a setting 3 to a setting 5. This would be shown in a negative way of the robustness of the QRA, and it would be a more transparent need to put resources on the case to bring it back down to a setting 3.

If we look at the robustness of the QRA quantitatively as described in chapter 2, we would have the results shown as in Figure 8**.** We see the early phase skewed to the right and the middle phase moved to the middle. Ideally we would have further reduction in settings so that the late phase update would show a left skew, but in our example we adjusted the settings of assumption 1 with knowledge from operational phase to a setting 5, decreasing the robustness with a small right skew.

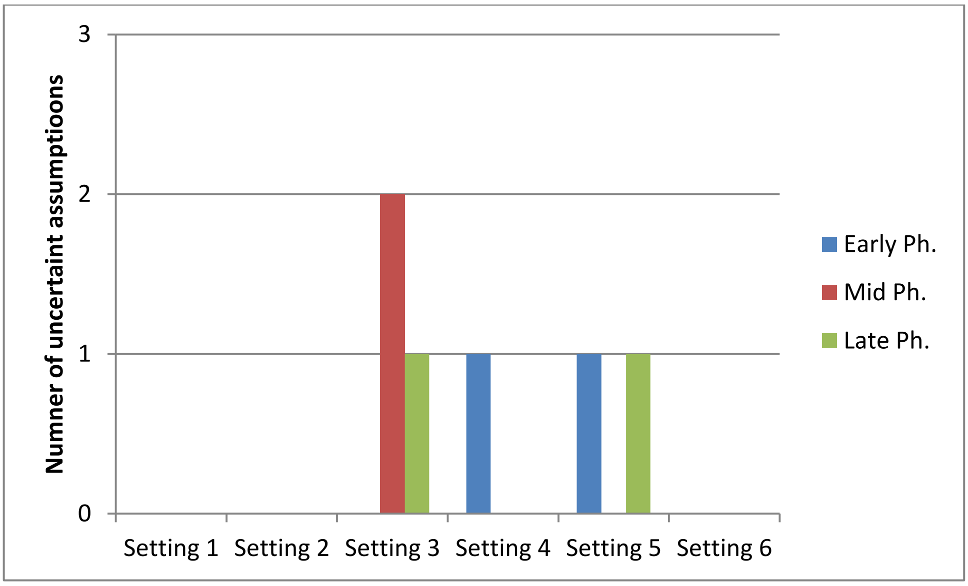

Figure 8: Quantified robustness of the QRA in early, middle and late phases.

Another positive effect that shows in these result, if uncertainties about barriers are considered having a moderate or high sensitivity, they will never get a lower setting than setting 3. This way, they will not disappear in the number of assumptions with low settings, not even when all uncertainties are reduced to ideally minimum. This way they will not lose their priority in operational phases and barrier management is an important life cycle continuous process.

4.5 An incident occurs

There was an incident at this particular plant where a leak occurred during bunkering. The flexible hose had been transferred to the ship side for connection with a crane. During the bunkering the hose stayed fixed in the crane and the ship started leaning to one side. This ship movement caused the strain on the hose to become too high and the hose broke away from its connection on the ship side. LNG started leaking and came out the ship side through drip trays. The leakage is detected by the ships onboard cameras surveying the bunkering and shutdown of the bunkering happens manually. The incident did not lead to injuries to personnel or material damages.

The incident investigation shows that the automatic ESD did not function according to requirements. It is not clear if the ESD systems onshore- and ship-side were connected, but since the pumps were on the truck sides and the QRA states that the gas detectors on the trucks will shut down the pumps, we will assume they were not connected. As this leak occurred on the ship side, the furthest away from the trucks detectors, it would be very difficult for the trucks detectors to function as the assumption dictated.

The investigation also found no documented training of the personnel performing the bunkering operation. It is stated that those performing the operation is of significant importance for the safe execution. Without this documented training, the assumption made in the QRA is not fulfilled.

The failure of the two important barrier functions lead to the time from first detection, probably by camera, to shutdown of operation was a total of 2 minutes and 18 seconds. The time from the leak occurred until the detection is not clear, so the total leak time is more than the 2 minutes and 18 seconds. This is a large deviation from the assumption of 90 seconds, due to failure in the underlying assumptions of gas detection and shut-down by either automatic or manual action.

It is not the scope of this thesis to theorize why these assumptions where not followed up on. The uncertainties were properly communicated, and their importance well stated in the summaries in the QRA. Like previously mentioned, this was a relatively small QRA designed to clarify the potential change in the overall risk based on a single operation. The operation had a relatively small and simple technical design with clear boundaries. This makes the information about the uncertainties easy to find and communicate. There was no requirement to update the QRA in later project phases as we have done theoretically in this case.

If this was a large production installation in the North Sea, the QRA would contain a large number of initiating events and an event such as a process leak can be evaluated several times for different areas and the total report could span over a four digit number of pages. This would make these critical assumptions difficult to find and the assumptions made in this case could have easily been made for an offshore facility.

5 Discussion

5.1 Risk perspective and risk description

We have reviewed the difference between the traditional risk perspective $R = (C, P)$ and a new risk perspective $R = (C, U)$ where R is risk, C is consequence, P is probability and U is uncertainty. The difference between them can at first glance seem to be only the probability and uncertainty, but as we have seen, a probability can have epistemic uncertainties based on the knowledge used to derive the probability, but the probability alone does not communicate this. When we regard probability as only a tool to measure uncertainty, as described in section 2.2, we need more tools to express the uncertainties in a transparent way to decision makers and rest of the project organization that will need and use this information.

The probability approach can, in many ways, be a good way of describing risk. It is easily relatable and visually easy to communicate. Changes in risk can easily be quantified by probability and put into other calculations, such as a cost-benefit analysis, to verify that the cost is reasonable or not according to the expected gain. But the probability is based on a set of conditions that are not necessarily directly communicated by the probability alone. These conditions can represent uncertainties as well, in the form of assumptions, presumptions or presuppositions. The traditional way of communicating these uncertainties, is through the risk analysis or assessment report where these are written in text and/or represented by a list. These reports can be quite extensive, and even if they did cover all uncertainties, a good amount of resources and experience may be needed to keep track of all the details. Another downside of only having the uncertainties, expressed in text or as a list, is that it can be difficult for another person in a later phase to know exactly what the assessor was thinking or knowing at the time, as the level of detail and quality in writing depends heavily on the skill of the assessor and the interpretation depends heavily on the reader.

The new risk description focuses on background knowledge as what everything else is based on. In written text, the necessary background knowledge of one assessor is very difficult to transfer to another assessor or to the decision maker. If one assessor makes one assumption based on his or hers background knowledge, another assessor may make the assumption, or assess the importance of that assumption, different with different background knowledge. To ensure that the people draw the same conclusions, they would maybe need to have the same background knowledge or at least use extensive resources to communicate that information.

With a new risk perspective focusing on uncertainties, they are more easily communicated as the important information that the interested parties should focus on.

5.2 NORSOK Requirements

NORSOK Z013 standard still contains the old definition of risk, even though PSA has updated their risk definition in line with the theories presented in chapter two. Despite this fact, the intentions, purpose and requirements for risk assessment within the standard still reflects on many of the key parts of the new risk perspective.

NORSOK Z013 standard and ISO/IEC 31000 both focus on continuous communication and consulting one side and continuous monitor and review on the other side, through the whole risk assessment process. This process includes establishing the context, hazard identification, risk analysis and evaluation.

To communicate and consult, the information must be easy to understand in order to be as effective as possible. To monitor and review, the information must be concentrated in order to put the right resources on the right task at the right time. It can be a challenge to both concentrate the information and at the same time make it as understandable as possible.

The risk assessment process is then required to be done through all phases of an offshore project. The level of information grows rapidly in an offshore project, so will the complexity of that information. Another thing is that the number of relevant personnel that have an interest in the information also grows as the project moves forward. These facts support that is it can be increasingly difficult to keep focus on the right issues, at the right time to the right personnel as Z013 requires.

5.3 Assumptions and level of details

Uncertainties can be represented by an assumption, presumption or a presupposition as described in section 2.7. We have explained the difference between them but as and assumption and presumption are stated, a presupposition can be more difficult as it is not stated. To detect a presupposition, the reader must identify this based on their own competence. Failure to do so can lead to the presupposition to go untreated through the project. An assumption or presumption should also be divided down to the lowest practical level to uncover all necessary underlying assumptions that can represent a critical uncertainty.

When investigators do their investigations after an incident, they don't settle for the top level reason on why an incident occurs. They really go down to the most detailed level until they reveal the chain of events, including all the organizational, operational and technical issues that had arrived. In the same way, a QRA should not focus only on the top level uncertainties, but also put the efforts into the underlying assumptions in order to understand and manage risk.

As we saw in the case study, the assumption of 90 second reaction time was made based on another set of conditions that were important in order to make sure the assumption was correct. Each of these two underlying assumptions needed their own focus in order to maintain the risk picture. Since these underlying assumptions were written in text in a register of assumptions, this example also illustrated the difference in how it can be focused when communicated differently.

There are other examples from incidents on NCS where underlying assumptions has caused an incident to occur and where, under slightly different circumstances, lives could be lost.

One such example is the Big Orang XVIII ship colliding into the 2/4-W platform on the Ekofisk field om the morning of June 8th 2009. (PSA, 2009) On this morning the ship was entering the 500 meter safety zone around the platforms to carry out planned well-intervention work. During entering the ships autopilot was not deactivated according to the pre-entry checklist, causing the ship not to react to the captain's commands.

In this case we see that the risk has been identified and mitigating barriers, such as the pre-entry checklist has been created. We don't have access to the risk assessment for this scenario, but it is reasonable to think that this high potential accident was regarded as very unlikely due to the facts that the risk reducing measures were put in place. The investigation shows that the operator had not sufficiently followed the requirement to survey all activity in the safety zone. They had also not sufficiently made sure of the ship's compliance to safe entry of the safety zone. The reasons for this is stated in the investigation report (PSA, 2009) that the procedures did not specify such a scenario completely enough and that the maritime competence were not adequate. These findings could point the same underlying assumptions as in our LNG case, where the assumption could have been stated as "Procedures have been made and personnel have the relevant competence to handle ship emergency within safety zone".

Another example is the hydrocarbon leak on the ULA P production installation on September 12th 2012. (PSA, 2013) The direct cause for the leak was that the bolts that held the valve together broke due to chlorine induced corrosion. The bolt material was AISI 316 stainless steel which is sensitive to temperatures above 60deg Celsius. The process medium was 120deg Celsius.

There was previously found seeping on the valve and a risk assessment was done to see if the valve needed changing immediately or if it could wait until the next planned process shutdown the year after. The conclusion was that the valve could wait until the year after, but mitigating measures was put in place such as 2 week inspection and it was registered in a "seep register" for follow up. The operator's technical authority on material was not involved in this risk assessment. The valve was produced to a previous material specification, a newer specification requiring the bolt material to be 25% Cr superduplex had been implemented. The problem of chlorine induced corrosion was identified in the overall risk assessment.

In this case, the operator had a very good knowledge of the problematics, but the correct competence on material quality was not included in the risk assessment and they failed to identify the risk of this happening. It is a little unclear why, but it is reasonable to think that they thought the valve would be according to the material requirement of having superduplex. A reasonable assumption could have been "Valve is according to latest specifications and is not sensitive to chlorine induced corrosion".

In both the Big Orange XIII case and the Ula P case, we see that the personnel had a strong knowledge about the risk, so why did they still go wrong? We theorize that there are three main reasons why this happens:

1. There is lack of knowledge, i.e. the uncertainty is high
2. There are motives to not follow up on the uncertainties
3. The uncertainties and their sensitivity is not properly communicated

In all cases, the LNG, Big Orange XVIII and the Ula platform, the knowledge could be considered medium or strong, all the information was there and the threats were identified. It could be considered medium in the cases where not the expert where involved. However the barriers failed, this supports the thought that uncertainties about barriers should always be considered sensitive to the risk. If somehow an uncertainty about a barrier is not found sensitive, it is reasonable to think that the barrier is in reality not so efficient and maybe the effect other barriers could be investigated and implemented instead.

We do not believe anyone has the motivation to ignore threats and knowingly put themselves, others or assets at risk.

This leaves only the communication of these uncertainties to the right personnel at the right time. It is reasonable to believe that classifying uncertainties by what they are about, barriers, models, variables, parameters or output and grading them to the settings 1 to 6, will help the right personnel to identify them and take the right actions at the right time to prevent accidents to occur. The right time can be in any phase of a project, and the earlier the actions are made, the better effect they can have on the overall risk, cost and added value to an offshore project.

5.4 Classifying uncertainties

To classify the uncertainties with regards to the model, variable, parameter, barriers or the outputs can be useful in order to identify who, or which relevant parties, that have interest in those uncertainties. The interested parties can then more easily find the uncertainties. It is a little obvious that the risk managers and those who deal with the barriers are interested in the uncertainties regarding these barriers. What is not so obvious is who is interested in the other classes.

The uncertainties regarding the model would maybe be of most interest to the risk assessors as they describe the possibilities and limitations of their model, but these possibilities and limitations can also be of interest to the decision makers as a more detailed and maybe correct model would cost more and need more recourses. For the design engineers, barrier management or operating personnel the details of how the model performs would maybe be of less interest. It is thinkable that they would be more interested in the difference in output from the same model between one assessment and another where they have updated their inputs with new knowledge of detail design.

The variable and parameter uncertainty would maybe be of more interest to the design engineers, barrier management and operating personnel, as they describe the possibilities of and limitations of their design and organization. We differentiated between variable and parameter because a parameter that is uncontrollable, such as significan wave height, can only be mitigated through stronger design. An example of this is the structural design of a platform that should be able to withstand a one hundred year wave, a wave so large that it statistically would only appear once every hundred years. Another example of such parameter uncertainty is operating procedures for cranes, or MOB (Man over board) boats. The weather, which is uncontrollable, makes restrictions on operating these types of equipment, because of phenomena such as wind speed and wave height. The variable uncertainty goes into the category of what the project can control. An example of which is pressure reduction and/or pressure control. If a leak scenario is assessed and the uncertainty with regards to the leak size is due to a fluctuating pressure, this can be mitigated by either stronger pipe design or, since it is controllable, the process designers can use pressure reduction or pressure controlling valves to mitigate. We can still argue that these are two of the same, mitigating by design, but a parameter can only be mitigated by a stronger design, while a variable gives many more options. Because of the wider range of possibilities to mitigate the variable uncertainty, separating these and focusing on them can give the right resources the right time to come up with smarter and less costly solutions.

5.5 Robustness

In the progress of work on this thesis we have been unable to evaluate actual QRAs performed for offshore installations on NCS and because of that we have no data to support or deny how evaluations of a QRA's robustness have been, or if they have been, performed in the past. NORSOK Z013 standard has clear requirements to do a sensitivity analysis of the results. This can serve as an indicator of robustness. Another thinkable indicator can be the level of detailed information in the QRA itself. The level of detail in a QRA also has clear requirements in NORSOK Z013 standard to be adapted to the level of detail available in the project.

There can be a downside to using only the sensitivity or the level of detail information as an indicator for overall robustness as it says nothing about the uncertainty, or in other words, the strength of knowledge about the risk influencing factors. The uncertainties would be expressed in text, within the report and the reader would have to deduct the quality of this information instead of getting it communicated in a more transparent way. In chapter two, we said that the sensitivity depends on the knowledge and so does the belief in deviation. Together the SoK, sensitivity and belief in deviation gives us the three dimensions in the form of the settings. These settings can give the reader a possibility to understand the quality of the background knowledge and the importance of the assumptions without knowing all the exact details.

We have not been able to find out if robustness have previously been quantified as described in chapter two and shown in chapter 4. With the possibility of quantifying the robustness, an overall monitoring and review of the QRA could potentially be done more efficiently. It is a requirement to update the QRA when modifications are done, and without the settings the cost of this may be reduced.

Say an existing offshore installation in an operating phase has a modification project, and they must update the QRA. The solution could be to send the entire QRA to a vendor performing such updates, together with the modification details. They would then assess the new risk picture with regards to those modifications, and maybe the result would not change. If however, a modification is to be done, and the operator can see themselves, that the modification only affects conditions or assumptions with a low setting, and that the modification itself does not change those settings, they could potentially justify that the robustness and thus the results will not change in order to not update the whole QRA. Which assumptions that could potentially be affected by a modification could also be more easily identified if they were categorized.

If the settings represent the level of uncertainty through the three dimensions, and uncertainty is regarded as the main component of risk, maybe the number of assumptions for each setting could be regarded as a risk metric themselves. This could be an interesting affair and bring the focus on updating and reviewing the QRA into another level of information as less recourse could be needed to perform such a task.

There can be a downside to such a scenario where the robustness through the settings are regarded or used as a risk metric. The downside being that it can be misused to justify savings, when in reality there is a real need to update the risk picture.

6 Conclusions

A QRA for an offshore facility on NCS can contain a large volume of information about uncertainties. This information is vital for the whole project organization, not only the decision makers. In order to produce a risk picture including the uncertainties, that represents the conditions the risk is based on, the uncertainties most be better communicated in a transparent way.

The effort a relevant person must put in to interpreting the results in a QRA should be reduced and a QRA should focus that information.

Describing the uncertainties by what they are about, the model, a barrier or design, will give the reader an understanding of which uncertainties are important to them and their role in the project.

Classifying the uncertainties by their degree of knowledge, sensitivity and belief in deviation will give a reader a quick understanding of the importance of those uncertainties and a tool to prioritize. This understanding by the relevant person can then happen without the reader needing to have the same or equal background knowledge as the writer.

This reduction in effort and simpler, more transparent way of communicating uncertainties can potentially reduce overall cost, increase safety and thus add value to an offshore project.

It is important to note, that for this effect to happen, the level of detail the uncertainties represent must be as low as possible so that the underlying assumptions also get highlighted and not only the top assumptions.

If the level of detail is low enough, it is thinkable that this will require more recourses than normal in an early or middle phase of a project, but it is also thinkable that the potential extra cost of that will be less in a late design phase or operational phase as the information will be there and changes easier to handle with less efforts.

We have, through the examples of the LNG plant, Big Orange XVIII and Ula platform, those uncertainties with high sensitivity, but still a strong knowledge can still produce an accident. It would be interesting if further research on past accidents could reveal a picture about strength of knowledge and sensitivity and if they have a correlation with the number or type of unwanted events.

We have also clarified that uncertainty is about the knowledge, with strong knowledge we have little uncertainty and vice versa. But knowledge can be compromised by motivation. If a preference for one solution exists, that motivation can prevent the assessor to use that knowledge correctly and this can happen unintentionally. Motivation is very difficult to understand and research, but maybe in the future, knowledge with regards to uncertainties could be replaced by competence where competence motivation is included.

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