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Summary

There has been a large development on safety related issues and methods during the last 50 years since oil production started on the NCS. There has been a shift from prescriptive regulations towards today´s functional requirements. Several major accidents have contributed to this development. Risk analysis and emergency preparedness disciplines have emerged and is still evolving to meet the lower tolerability from authorities and the public for accidents and losses.

In order to prevent accidents there has been put a large effort in design, implementation and maintenance of physical barriers. Their function is to intervene in the accident chain such that an initiating event does not escalate to major accidents. The implementation of such barriers has been a success story on the NCS, preventing many major accidents. There has not been an ignited gas leak on the NCS since 1993.

However, on a yearly basis, many (100-200) gas leaks still occur on installations on the NCS. Good ignition control, luck and coincidences are the main causes of no ignition. With so many releases it is only a question of time before circumstances allowing ignition occurs.

It seems to be a common understanding in risk and safety related communities in that the main potential for risk reduction lies in preventing HC leakages. Much research has been conducted to reveal their imminent and underlying causes. One of the main conclusions has been that HC leakages are often caused during manual override, implying some sort of human error an underlying cause.

It has for a long time been recognized that the risk analyses and QRA´s does not in a sufficient manner consider human errors as a cause and part of the accident chain. Several scientific reports have documented this weakness. There has also during the last 15 years been developed several tools and methods for modeling of human errors, but they has not been applied by the industry.

The objective of this thesis has been to develop a framework for consideration and incorporation of human and organizational factors in the lifecycle of an engineering project. That is, a recipe for what methods to implement at different project stages in order to make sure that the risks of human errors are reduced as much as possible. Both the concept, design and operation phase are considered. In the design phases a method taking the form of a brainstorming session is applied, which is developed by Trevor Kletz and called “User Friendly Design”. The purpose it to stimulate creativity and solutions through improved design that are user friendly for the personnel responsible during operation and maintenance. A much debated issue has been that safety experts are involved at a too late stage, such that they just have to add safety systems and equipment to the design in order to make them safe. That will make the design extrinsically safer, but it would be better to make the intrinsically safer by improving the design and design process. Risk analysis and QRA´s will still have to be conducted in order to verify RAC´s and suggest improvements. They should consider human errors and their risk influencing factors. A recently developed method called BORA is judged to be best suited for this purpose and practicable to use. By applying this method in the QRA it should give better decision support because measures not only of technical nature, related to increased reliability etc (barrier perspective) are considered, but also in relation to improved safety culture and risk awareness (operational conditions).

Another important part of this thesis has been to identify the regulatory requirements specified in PSA guidelines and standards (NORSOK Z-013) related to handling of operational issues in risk analyses. There are specific requirements that HOF shall be considered, and the extent depends on the criticality for the risk picture.

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Preface

Risk and safety management is an important part of all engineering projects and project phases and should be implemented by the use of different methods that is well suited for and fits the projects characteristics in their respective phases.

The focus of this thesis has been towards the relationship and treatment of barriers and operational conditions in risk analysis. Thus, the study of methods for integration of human and organizational factors in risk analysis has been an essential part.

The objective of this thesis has been to identify and study methods suitable for consideration and integration of operational conditions/human and organizational factors in both design and operation phases, including risk analysis, and to present a framework comprising of different methods that together constitutes an overall framework for HOF integration. The framework is not a general risk and safety framework and will have to be expanded in order to represent an overall framework for risk and safety management.

It has also been an objective to identify and present the regulative requirements with respect to incorporation of operational conditions/human and organizational factors in risk analysis. This is presented in chapter 2.

A literature search identifying current practice with respect to content of risk analysis has also been conducted, identifying several weaknesses. This topic is discussed in chapter 5.1

Finally, I would like to thank my Faculty supervisor Terje Aven for fast, valuable and precise feedback and comments.

Stavanger, June 2012

Filip Angell Løge

1. Introduction

1.1. Background

The background for this thesis is the lack of industry attention and industry practice regarding the incorporation of human and organizational factors in risk analyses. This has been documented by several authors. (Skogdalen and Vinnem 2010) It has also been demonstrated that a large proportion of the accidents related to hydrocarbon releases can be traced back to manual override and human errors.

1.2. Purpose

The purpose of this thesis is to present and develop a new framework for consideration and integration of human and organizational factors that are applicable for the entire life cycle of an engineering project.

Another objective is to present the legislative requirements related to HOF consideration and integration in risk analysis together with a discussion of available methods and approaches.

1.3. Content

Section 1.5 presents two ways of defining the different phases of a project. In section 1.6 the term human and organizational factors is discussed.

Section 2 identifies the legislative requirements for HOF consideration and incorporation in risk analyses and QRAs. Section 3 presents some of the most important tools and methods available for HOF integration with a brief discussion.

In section 4, a new framework for HOF consideration through all phases of a project is presented and defined. The framework focuses on the distinct phases of a project with key words describing methods suitable at each phase. Section 5 consists of visualization and a discussion of the framework. The thesis ends with a few conclusions on the work done and what is left for the future in chapter 6.

1.4. Abbreviation

Table 1 Abbreviation

QRA	Quantitative Risk Analysis
HOF	Human and Organizational Factors
RIF	Risk Influencing Factors
BORA	Barrier and Operational Risk Analysis
MACHINE	Model of Accident Causation using Hierarchical Influence Network
WPAM	Work Process Analysis Model
SAM	System- Action- Management
ORIM	Organizational Risk Influence Model
ISM	Integrated Safety Model
OTS	Operational Conditional Safety
HAZID	Hazard Identification
HSE	Health, Safety and Environment
DSHA	Defined Situations for Hazard Analysis
SoTeRiA	Socio – Technical Risk Analysis
NPV	Net Present Value
FPSO	Floating Production, Storage and Offloading unit

1.5. Life cycle process

When considering the life cycles of a project, which is split into several phases, there are distinct decision gates governing whether a project will enter the next phase or not. At these decision gates, supporting analyses and documents are produced to establish credible decision support. A core element in this respect is risk analyses including quantitative risk analyses (QRAs). The purpose of the QRA´s is to establish a credible risk picture including different risk reducing measures that can be implemented if the decision maker wants to.

The decision gates are very important and govern what analyses and documents that are necessary, what they should comprise of and what level of precision is required. In order to reach the next phase, the decision maker must be convinced that the project has sufficient business value and that the risks are properly taken care of.

The case situation is related to the life cycle processes shown in figure 1 and figure 2, and will be used later in this thesis. The project is split into specific phases, each ending with a decision gate, ref figure 2.

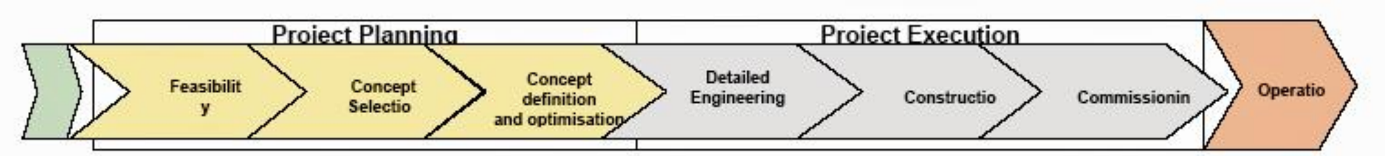


Figure 1 Definition of life cycle phases. (NORSOK 2010)

A more comprehensive and informative life cycle model is illustrated in figure 2. Here the decision gates are integrated in the life cycle and more specific phases are defined.

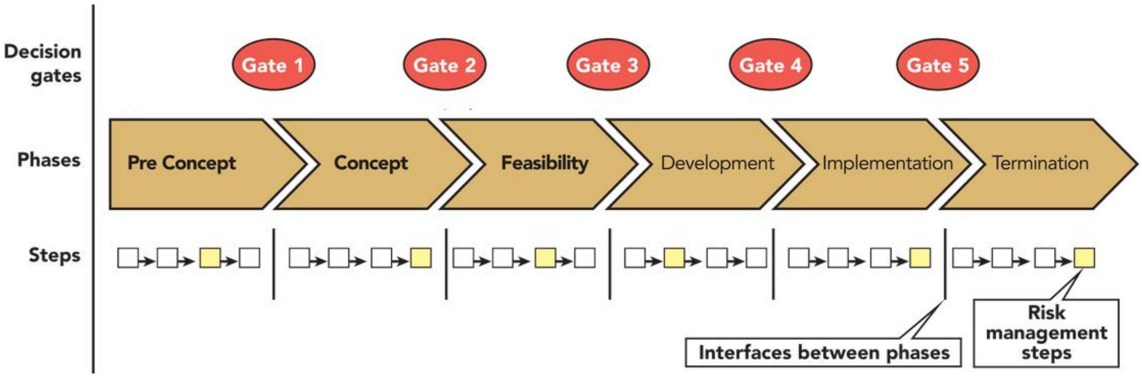


Figure 2 Life cycle process with integrated decision gates. (Randall 2010)

1.6. Human and organizational factors

Human and organizational factors (HOFs) are understood as factors that influence the performance of barriers and the overall risk level. Physical and non – physical barriers are identified and through fault trees and basic events, risk influencing factors are identified.

Human factors relate to personal characteristics and organizational factors to organizational characteristics. Human and organizational factors can relate to individuals, groups or the entire organization.

Examples of human and organizational factors are shown in table 1:

Table 2 Human and organizational factors

Human factors:	*Organizational factors:*
Motivation	Change management
Communication skills	Safety culture
Cooperation skills	Management involvement
Analytical skills	Training quality
Problem solving skills	Procedure quality
Risk awareness	Risk awareness

2. Norwegian legislation & guidelines

The legislation and guidelines for integration of HOFs in risk analyses and QRAs are identified and discussed in this section. The focus is on the Norwegian regulations and applicable standards. The Norwegian legislation is based on functional requirements.

The regulations are divided into five sections:

- Framework regulations
- Management regulations
- Facilities regulations
- Activity regulations
- Technical and Operational regulations (Petroleum Safety Authority Norway 2012)

The framework regulations are studied in order to present some important principles related to risk management. The management and facilities regulations govern the incorporation of HOFs in QRAs.

In order to fulfill the requirements given in the legislation, it is current practice to use established standards. Regarding risk analysis and HOF integration in QRAs, NORSOK Z-013 is the reference standard. The requirements sketched out in this standard are identified and discussed in section 2.4.

It is important to remember that the regulations considered in section 2.1 and 2.2 are functional requirements. That means that they state what is to be done and what the results should be. It is then up to each responsible duty holder to comply with the regulations. In order to standardize the solutions or interpretations of the regulations, the NORSOK standards have been developed.

In appendix A the requirement text from the regulations is quoted.

2.1. Framework regulations

Section 11 states that: concerning risk reduction, the technical, operational and organizational solutions that offer the best results, provided that the costs are not in gross disproportion, shall be chosen. (Petroleum Safety Authority Norway 2011)

This should result in systematic identification and evaluation of technical, operational and organizational factors. Those factors could be viewed as risk influencing factors, and part of these is the human and organizational factors. It is widely acknowledged that HOFs influence the risk level, and then in order to provide the best solutions concerning risk reduction, it would be reasonable to identify and analyze them.

2.2. Management regulations:

Section 4 is more specific regarding the objectives of technical, operational and organizational solutions. It is to reduce the probability that harm, errors and accident situations occur. It also states that principles that provide inherent safety should be used. (Petroleum Safety Authority Norway 2010)

In order to reduce the probability of errors, inter alia human and organizational errors, consideration of HOFs is important.

Section 5 states that barriers shall be established in order to reduce the probability of failures and hazard and accidents situations developing. It also states that barriers can be physical, non- physical or a combination. (Petroleum Safety Authority Norway 2010)

Barriers to reduce the probability of human error can be implemented through the design process or by strengthening human and organizational factors.

Section 17 set requirements related to the risk picture. It should present a balanced and most comprehensive possible picture of the risk associated with the activities. In fulfilling the requirements for risk analysis the NORSOK Z-013 is normally applicable. (Petroleum Safety Authority Norway 2010)

Working environment analysis is considered in section 18. The analysis shall ensure a sound working environment and support in decision making regarding technical, operational and organizational solutions. The analysis shall contribute to prevent mistakes that can result in hazard and accident situations. (Petroleum Safety Authority Norway 2010)

In fulfilling this requirement, working environment analysis would strengthen certain human and organizational factors. Experience from such analyses, methods and models could be important knowledge to consider when constructing a new framework for HOF consideration and incorporation in risk analyses.

In order to incorporate human and organizational factors in QRAs or risk analysis, data is essential. Section 19 states that: data for significance of health, safety and the environment shall be collected in order to monitor and update technical, operational and organizational factors. (Petroleum Safety Authority Norway 2010) If such practice already exists in the offshore industry it means that certain data is available, but methods to make full use of them are lacking.

2.3. Facilities regulations

In this part of the regulations the different project phases are considered in some detail.

Section 4 states that important risk contributors, organization and working environment should be considered in the concept selection phase. (Petroleum Safety Authority Norway 2010) Thus it is necessary to at least identify them in the concept development phase and a structured approach is required.

Section 5 states that facilities shall be based on the most robust and simple solutions possible. (Petroleum Safety Authority Norway 2010) This also sets requirements to the design process.

For equipment design requirements and objectives, section 10 states that robustness and simplicity shall be provided such that: the probability for error is reduced. This must also be supported by the design process.

In order to find out what are the more detailed requirements related to HOF consideration and integration in risk analyses for different project phases, it is necessary to study the NORSOK Z-013 standard in detail.

Kletz´s concept of “user friendly design” is judged to be a suitable method sharing the principles and focus areas set out in these requirements. The method is implemented in the design process and further outlined in section 3 and part of the framework presented in chapter 4.

2.4. NORSOK Z-013

The NORSOK standards are developed by the Norwegian petroleum industry. The NORSOK Z-013 standard is used in order to fulfill the legislative requirements regarding risk- and emergency preparedness assessment, ref section 17 in the management regulations.

The standard focuses on requirements related to the process of conducting risk analyses rather than detailed descriptions related to the process of producing them. In such a way, the standard can be seen as functional or flexible. However, the requirements are also specified for different life cycles/phases. A project is split into a planning, execution and operation phase, ref figure 1. (NORSOK 2010)

The standard defines a risk assessment process that should be followed throughout the life cycle of a project:

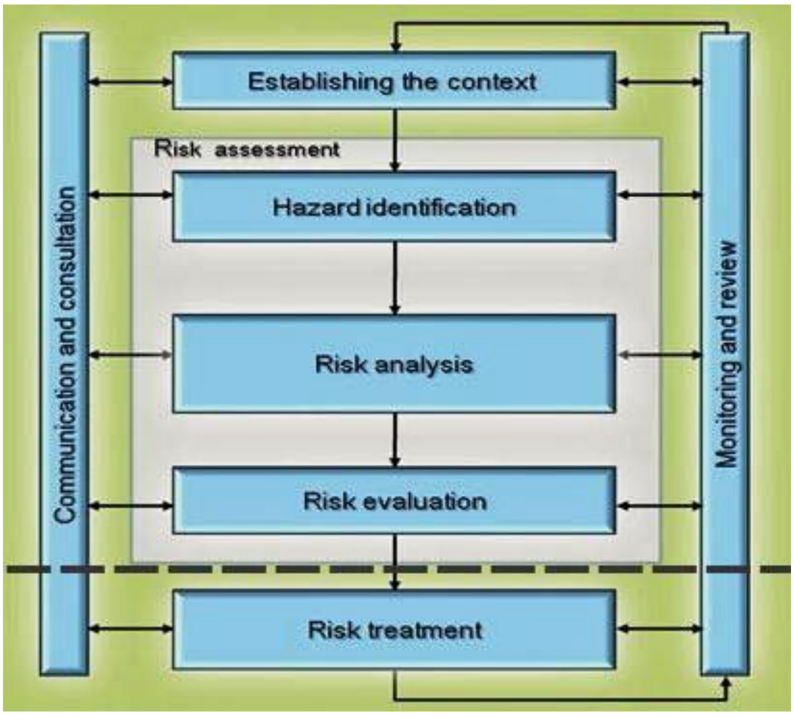


Figure 3 Risk assessment process. (NORSOK 2010)

A more detailed illustration of the process is given in figure 4.

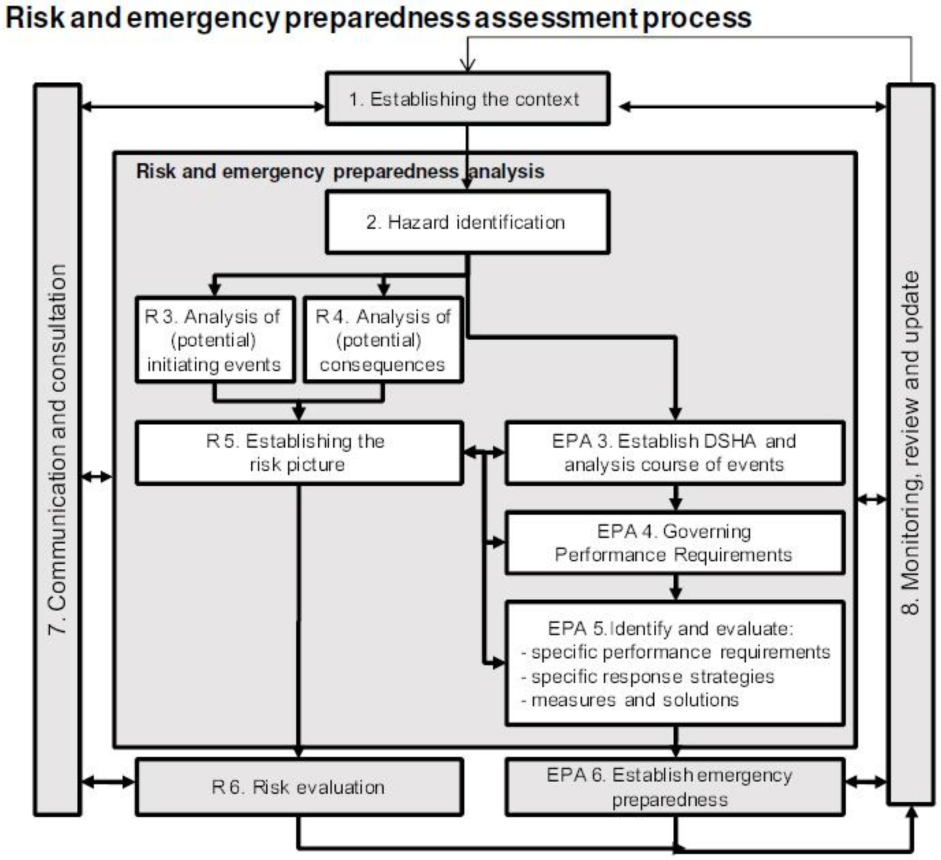


Figure 4 Risk assessment process in 6 steps. (NORSOK 2010)

The process consists of 6 steps. Attention will be given to steps 2, 3 and 4 in particular. They are the core part of risk analysis and many different approaches/methods exist.

The standard specifies a set of general requirements related to the content of risk assessments:

a) *"Identify hazardous situations and potential accidental events,*
b) *Identify initiating events and describe their potential causes,*
c) *Analyze accidental sequences and their possible consequences,*
d) *Identify and assess risk reducing measures,*
e) *Provide a nuanced and overall picture of the risk, presented in a way suitable for the various target groups/users and their specific needs and use. "* (NORSOK 2010)

The requirements related to HOF evaluation in the risk assessment process is explicitly expressed in section 5.2.2.5 e):

"An evaluation of the effect of human and organizational factors shall be performed. This may range from a qualitative discussion to detailed analysis of human and organizational errors, depending on the criticality of such aspects for the risk picture (…) ". (NORSOK 2010)

So the standard makes it absolutely clear that HOF consideration is required. But the extent of the required analysis relies on the criticality of such aspects for the risk picture. The risk picture shall provide the most important information relating to the decision situation/problem. The level of HOF consideration or integration in risk analyses will thus depend on the decision situation and thereby what phase the project is in. As more information becomes available the precision of the analysis considering HOF should increase.

Regarding the content of the risk picture, section 4.6.3.3 states that:

"The risk picture shall include:

1. *ranking of risk contributors,*
2. *identification of potential risk reducing measures,*
3. *important operational assumptions/measures in order to control risk".* (NORSOK 2010)

In order to rank different risk contributors, the use of sensitivity analysis is a suitable method. It is clear that listing the assumptions acting as background knowledge for the analysis is very important, and this is stated several places in the regulations. An important part is related to operational conditions, including the state of the HOFs. Systematic sensitivity analysis on critical parameters should be carried out. Section 5.6.3.4 states that:

1. *"Sensitivity analyses shall be carried out to include*
2. *identification of the most important aspects and assumptions/parameters in the analysis,*
3. *evaluation of effects of changes in the assumptions/parameters, including the effect of any*
4. *excessively conservative assumptions,*
5. *evaluation of effects of potential risk reducing measures".* (NORSOK 2010)

Annex C in the standard provides a checklist for hazard identification (HAZID). Part of this is human and organizational failures. This means that the standard acknowledges human and organizational factors as potential contributors to accidents. If they function as intended they may prevent accidents or reduce the consequences, thus acting as operational safety barriers. However, the NORSOK standard does not provide a requirement to identify HOFs at any stage.

2.4.1. Incorporation of human and organizational factors in different phases

As previously mentioned and illustrated in figure 1, the NORSOK standard defines a life cycle, consisting of distinct phases, and provides requirements to the respective phases. The requirements outlined above are general requirements and apply to all phases. However, because of the different decision situations, availability of information and uncertainty, the methods for incorporation or consideration of HOFs must be adjusted to accommodate the given situation.

In the planning phase limited information is available and large uncertainties exist. Decisions regarding design solutions and functionality will dominate. In this process several needs must be balanced against each other's; functionality, reliability, serviceability, cost, safety etc. At this early stage it is important that the focus of the designers is not completely set against functionality and costs. Other aspects such as reliability, robustness, resilience, serviceability and safety should be considered and be part of the early design process. In such a way, the alternatives that are produced and that will make the foundation for the concept selection phase will be of much higher quality in several dimensions.

Several important attributes comprising including those described above should be part of an overall process and considered from the beginning. Safety experts have gained a reputation for being someone who adds to the cost and complexity of a project. (Kletz 1991, Chapter 2.1) The reason for this is that they are not part of the early design process, and thus many important decisions related to safety are already made. The expression, "safety as an add- on characteristic" stems from this situation.

One way of meeting this challenge would be to integrate a method that is used throughout the design stages by the designers to establish inherent safe and user friendly solutions. Trevor Kletz´s user friendly approach is the recommended method in this thesis.

2.4.2. Requirements related to the concept selection phase

In the concept selection phase several alternatives are presented and evaluated. Risk analysis is often used in order to compare different alternatives against each other. The comparison could be related to risk level and possibility for risk reduction. (NORSOK 2010)

By using a common procedure, models etc. in the risk analysis or QRA, credible comparisons can be made. Both qualitative and quantitative methods are applicable, and it would be the risk analyst in cooperation with the decision maker to decide on what approach to use. Of course the characteristic of the project, complexity, applicable hazards, exposed systems and availability of information together with the decision situation will give important input. (NORSOK 2010)

The objectives of the risk analysis at this stage are stated as:

a) *"identify potential showstoppers for concepts and risk challenges for any of the concepts under evaluation i.e. evaluate if it is likely that the authority and acceptance criteria for any of the concepts cannot be met,*
b) *describe and characterize all risks that are significant for the facility, in order to assist the concept selection and optimization process,*
c) *identify possible significant risk reducing measures, so that safer, more environment friendly, more cost- effective design and/or inherently safe options can be adopted,*
d) *provide a risk ranking of the proposed concepts. The risk may be expressed as risk to people, environment, assets and impairment of safety functions,*
e) *evaluate the robustness and uncertainties of the proposed concepts with respect to possible changes during design development,*
f) *identify need for any further risk assessments or detailed studies that should be performed,*
g) *identify need and scope for further risk assessments during the next phase,*
h) *establish preliminary DSHAs,*
i) *evaluate the layout of main areas,*
j) *establish preliminary dimensioning accidental loads and/or safety zones/separation requirements".* (NORSOK 2010)

First the risk analysis must consider if the proposed concepts are feasible according to predefined criteria's. Then the most important risks are identified and risk reducing measures are considered. The result of the risk analysis is a risk ranking of the proposed concepts.

The HAZID shall focus on identifying hazards that contribute to major accidents risk, which will be dimensioning or the most critical hazards for the concepts. The objective is to identify risks that are important for the development of design solutions, costs or schedule, or otherwise impact the concept selection. (NORSOK 2010) The identification process should be organized in some structured process. The use of Hazard and Operability Study (HAZOP) is widely used in the offshore industry, but in order to perform such an analysis the P & ID´s must be available. In the concepts selection phase they are usually not available, so another approach is needed.

With reference to section 5.2.2.5 e) the level of HOF consideration or integration in risk analyses depend on the criticality for the risk picture which again reflects the decision problem and project phase.

The final risk picture in the concept selection phase will consist of the different alternatives with the associated risk contributors. The risk contributors considered are mainly related to functionality, layout and design related to the different alternatives. HOF will probably not be a critical element to consider when deciding what alternative to choose. HOFs have an impact on the safety level, but they can probably be optimized regardless of what concepts that are chosen. One factor to consider however is the user friendliness of the concepts and equipment, which influence the probability of human error.

Thus the factors must be handled in a simplified and preliminary manner. It should however be investigated in what situations human intervention is critical and identify measures to prevent or reduce the probability of human error.

2.4.3. Requirements related to the concept definition, optimization and detailed engineering phase

The next phase, called the concept definition, optimization and detailed engineering phase follows from the concept selection phase. A decision has been made to what concept or which concepts to further investigate. In this phase all the planning required for construction and installation are made. The level of detail rapidly increases allowing for more detailed risk analyses to be made.

At this stage several critical decisions that impact safety are made. It could be related to what equipment to use, layout of different modules and the entire installation, control room specifications, escape routes, geometry etc. Designers base their decisions mainly on functionality and costs, and then it becomes the job of the safety expert to add complex and expensive equipment to make it safe.

This structure conflicts the principles of inherent safety which is highly appreciated in the regulations. It is not cost- effective and other perhaps more suitable solutions may be overlooked. To obtain inherent safety, a throughout process ensuring that safety aspects are considered must be in place.

The principle of inherent safety is based on 5 measures in particular: intensify, attenuate, substitute, limitation of effects and simplification. The goal is to design plants that are user friendly so that they can tolerate departures from ideal performance by operators or maintenance workers without serious effects on safety, output, or efficiency. Designers have a second chance, to review their solutions, operators often don't. (Kletz 1991) In order to follow the regulations on inherent safety, such a process should be embedded in the design process at this stage.

The NORSOK standard set out the following requirements to the objectives of the QRAs conducted in this phase:

"To provide input to decisions relating to:

a) compliance with acceptance criteria,
b) ALARP evaluations,
c) establishment of DSHAs,
d) layout of main areas and equipment,
e) site layout, including location of traffic routes and ignition sources (e.g. furnaces, flares, transformers etc),
f) design of systems and equipment,
g) DALs and/or safety zones,
h) requirements to barriers,
i) operational restrictions and conditions including restrictions applicable to simultaneous operations". (NORSOK 2010)

The standard assumes that layout drawings and P & IDs for process and essential safety systems are available when the QRA is to be conducted.

The HAZID process conducted in this phase should build upon the main findings from the previous phase. However, because of the increased level of detail new hazards related to activities, systems and equipment should be identified. The normal procedure in this respect is to conduct a HAZOP analysis.

In a HAZOP study, the process or system considered is “tested” by the use of predefined guide- words from a checklist. These guide- words result in forces acting on the system or abnormal situations to occur and the possible consequences is identified. If the consequences are unacceptable of severe, the group brainstorms different risk reducing measures that are available to reduce the probability or consequences, or the increase the robustness of the system.

The process can handle human error as an “initiating event” and feasible measures to reduce the probability or possibility for such action can be identified. This could include improved training or procedures, improved equipment design/marking etc. The process is well suited for identifying technical and operational causes in a systematic manner and produce improved solutions.

However the process is limited to the system considered and not able to handle all types of human and organizational factors/limitations that may contribute to major accidents. For example safety culture, change management, management involvement, risk awareness, problem solving and communication skills is hard to relate to a specific system. To assess their influence, potential consequences and to produce effective measures another method is required.

It is a weakness of the NORSOK Z-013 standard that the list of initiating events that shall be analyzed does not comprise of human and organizational factors related to human error. The focus is on accidents related to equipment, structures and transportation. This results in a low priority to evaluate and consider human and organizational factors or human error in general. It may also have contributed to the lack of involvement by safety experts in the design phase and create a culture where the focus towards technical barriers dominates.

Human and organizational factors should be considered through design and through risk analysis. The design should assist in preventing human error and the risk analysis should identify critical situations for human intervention and produce measures to reduce the probability of errors.

The proposed method to use in order to design equipment, structures and systems in such a way that the risk of human error is minimized is Kletz´ “user friendly design” method.

The integration of RIFs in risk analysis can be done through the BORA method and this is the recommended approach in this thesis.

2.4.4. Requirements related to the operational phase

In the operational phase the decisions related to layout, functionality, use of equipment etc. are already taken and implemented. The purpose of risk analyses in this phase is according to the standard to:

a) *“assess overall risk level in the operational phase, reflecting modifications and operational status, e.g. activity level and manning;*
b) *provide input to operational decisions may affect the risk on the facility;*
c) *identify how operational tasks and special operations may be safely carried out;*
d) *identify important improvement areas for operation;*
e) *identify adequate maintenance strategies;*
f) *assess barrier performance and demonstrate effects on the risk level of barrier deterioration;*
g) *review status of assumptions and effect of changes during operations and modifications;*
h) *communicate risk results and important factors to the workforce”.* (NORSOK 2010)

It is important that the risk analyses carried out in the operational phase has an element of proactivity. The objective should not only be to update the risk analyses to reflect the current situation, it should also analyze and suggest improvements on the operational working environment.

By recognizing human error as a possible initiating event, barriers should be identified and implemented to prevent such events. As stated in section f) above, barrier performance should be evaluated on a regularly basis and the influence on risk should be demonstrated.

"The general objective for the risk assessment during operational phase is to verify previous risk results, update the risk picture according to changes and to provide input to decisions concerning further risk reduction through technical modifications and operational and administrative measures. The QRA shall provide input to:

- *a) compliance with acceptance criteria,*
- *b) ALARP evaluations,*
- *c) verification/update of DSHAs,*
- *d) verification/update of requirements to barriers,*
- *e) operational restrictions and conditions including restrictions applicable to simultaneous operations,*
- *f) minor modifications,*
- *g) assessment of operational barriers".* (NORSOK 2010)

The standard states that the QRA shall provide input to "assessment of operational barriers". Unfortunately a precise definition of the term "operational barrier" does not exist, but it seems reasonable that they should consist of HOFs.

This interpretation does however lead to some inconsistency in the NORSOK standard. If it is required that the operational barriers shall be assessed in the operational phase, there should be a requirement to identify and analyze them at an earlier stage, and possibly give some guidance on how to do so. The underlying structure of the NORSOK standard is that the risk analysis are done step by step, updating the risk analysis as more information becomes available. That's why the main objective in the operational phase is to verify different risk results. It assumes that the previous work, including identification of hazards is done properly. Then, when in the operational phase the objective is to assess operational barriers, it is assumed that these are identified, analyzed and evaluated properly at an earlier stage. Such requirements are lacking in the NORSOK standard.

The standard focuses on technical barriers, experience and statistics, which has functioned well and is important. However, it is obvious that two hypothetically equal installations, shifts or modules, should not be assigned the same risk level when the operational conditions are very different. Also for an installation that has been operating for several years, the risk updating should consider the change in the operational conditions. To do this properly a structured method for identification, analyzing and evaluation is required. Existing methods like HAZOP analysis is not appropriate. However, a new method called BORA has been developed to integrate non- physical barriers in QRAs. The method is further elaborated in the next section and part of the proposed framework for HOF consideration throughout at projects lifecycle.

There should be consensus confirming the rationale for incorporation or at least evaluation of these aspects. Several concepts dealing with these issues has been proposed and used in other industries, but the offshore industry has been reluctant to implement any. The improved safety level the last decade may have acted as a "sleeping pillow". The next section identifies and discusses some of the concepts and methodologies available for HOF integration.

3. Existing concepts for integration of HOFs in QRA

3.1. Barrier and Operational Risk Analysis (BORA)

The BORA approach is a methodology for incorporation of technical and operational conditions in qantitative risk analyses. The concept integrates risk influencing factors(RIF´s) including HOF´s in the QRAs.

The basic building blocks of the methodology are barrier block diagrams, event trees, fault trees, and influence diagrams. Barrier block diagrams are used to illustrate the event scenarios and the effect of barrier systems on the scenarios. Event trees are used in the quantitative analysis of the scenarios, while fault trees are used to analyze the performance of the different barrier systems. Influence diagram are used to analyze the effect of risk influencing factors on the initiating events in the event trees and the basic events in the fault trees. The aim of the analysis is to reflect installation specific factors both with respect to technical systems, operational conditions as well as human and organizational factors. (Aven, Hauge et al. 2006)

The approach consists of 6 general steps:

1) Development of a basic risk model.
2) Assignment of industry average frequencies/probabilities of initiating events and basic events.
3) Identification of risk influencing factors (RIFs) and development of risk influence diagrams.
4) Assessment of the status of RIFs.
5) Calculation of industry average frequencies/probabilities of initiating events and basic events.
6) Calculation of installation specific risk, incorporating the effect of technical systems, technical conditions, human factors, operational conditions, and organizational factors. (Aven, Hauge et al. 2006)

For further descriptions of the methodology, (Aven, Hauge et al. 2006). For an example case see (Aven, Haugen et al. 2006) and (Aven, Vinnem et al. 2006).

3.2. Other methods for HOF integration in risk analysis

There are several different alternatives available in the literature for incorporation of human and organizational factors in QRAs:

- SoTeRiA (Mohaghegh and Mosleh 2009)
- Manager (Pitablo, Williams et al. 1990)
- MACHINE (Embrey 1992)
- WPAM (Davoudian, Wu et al. 1994; Davoudian, Wu et al. 1994)
- SAM (Elisabeth Paté-Cornell and Murphy 1996)
- I-RISK (Papazoglou, Bellamy et al. 1999)
- ARAMIS (Hourtolou and Salvi 2003)
- ORIM (Øien 2001)
- Omega Factor Model (Mosleh and Golfeiz 1999)
- ISM (Wreathall, Shurman et al. 1992)
- OTS (Vinnem, Kongsvik et al. 2007; Aven, Vinnem et al. 2008)

These concepts have been developed and described in the literature in the last 15 years. However, none of them are so far used as an integrated part of QRA´s. It is judged to be out of the scope of this thesis to further elaborate them. The interested reader can find more information through the references in the reference list.

3.3. Kletz Concept of Inherently Safer Design

The essence of the inherently safer approach to plant design is the avoidance of hazards rather than their control by added – on protective equipment. (Kletz 1991) For the offshore industry it would be challenging and in many cases impossible to avoid certain hazards. Nevertheless, an approach aiming at producing inherently safer structures and systems should be integrated in the design process.

The method identifies 11 measures for achieving inherent safety:

1. *Intensification* – reduce the inventory of hazardous materials
2. *Substitution* – substitute hazardous materials with a safer materials
3. *Attenuation* – use the hazards under the least hazardous conditions
4. *Limitation of Effects* – reduce possible consequences
5. *Simplification* – reduce possibility of human errors
6. *Avoiding Knock – on Effects* – reducing accident potential
7. *Making Incorrect Assembly Impossible* – prevent human errors
8. *Making Status Clear* – prevent human errors
9. *Tolerance* – increase robustness, increased tolerance for errors
10. *Ease of Control* – simplify to reduce possibility for human error
11. *Software* – supporting simplification and reduce possibility for human errors. (Kletz 1991)

Inherent safety and cost reduction may very well go hand in hand as visualized in figure 5. One of the steps towards inherent safety is to make design and operation less complex and more energy efficient. The result would be lower costs.

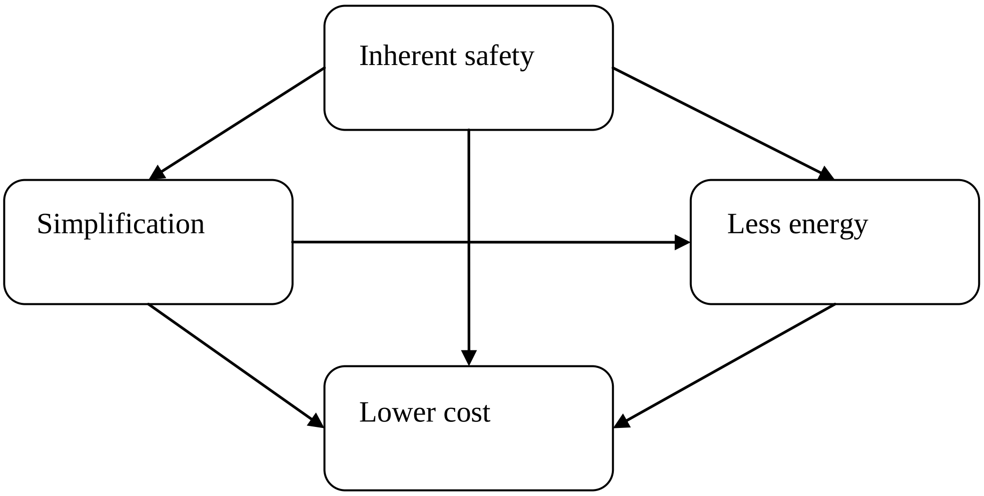


Figure 5 Connection between inherent safety, simplification, energy efficiency and lower cost (Kletz 1991 Chapter 2, page 17)

The different measures to provide inherent safety should be considered at different project stages during design. This is shown in table 2:

Table 3 Project stages at which each measure for friendly design should be discussed. (Kletz 1991 Chapter 10, Page 133)

Measures	Conceptual stage	Flow sheet stage	Line diagram stage
Intensification	X	X	
Substitution	X	X	
Limitation of Effects	X	X	
- By equipment design			X
- By changing reaction conditions	X	X	
Simplifications	X	X	
Avoiding knock – on effects			
- By layout	X	X	
- In other ways		X	X
Making incorrect assembly impossible			X
Making status clear			X
Tolerance			X
Ease of control	X	X	X
Software			X

During the development of a project it becomes harder to install inherently safer measures. Many important decisions are made at the early design phase and the cost of change dramatically increases as the project progresses. This is shown in figure 7.

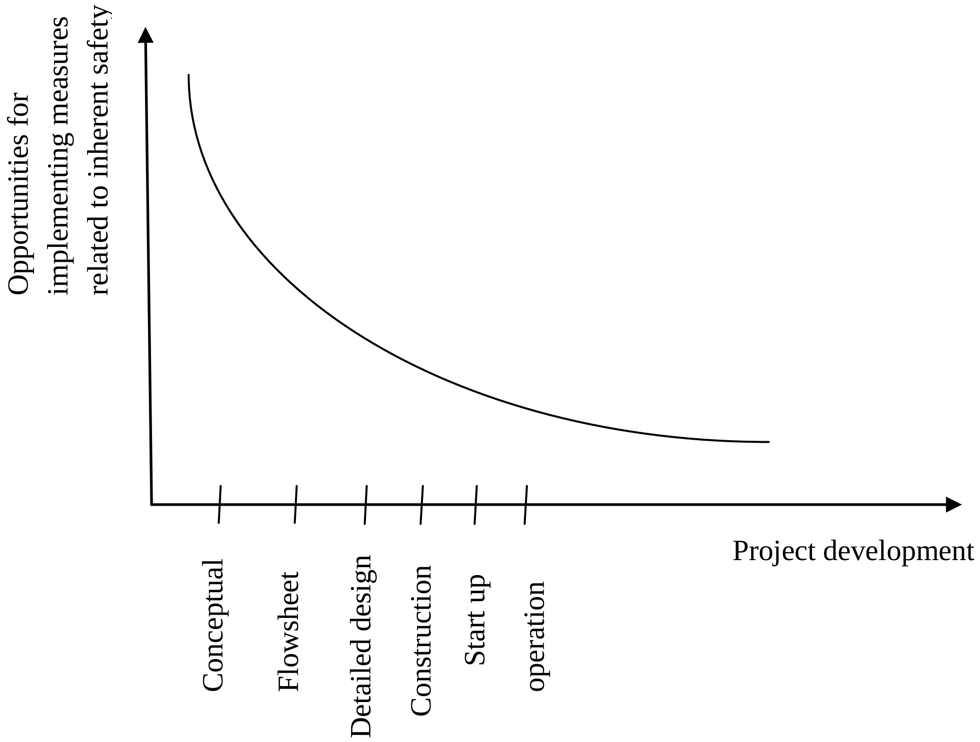


Figure 6 Opportunities to implement measures related to inherent safety during project development (Kletz 1991Chapter 10, page 134)

Kletz´s concept of inherently safer design is part of the framework developed in the next section. It is applied in the design phases; concept development, concept selection and detailed engineering design.

4. A new framework for HOF consideration and integration through the entire lifecycle of an engineering project

Human and organizational factors should be an integral part of a holistic process to ensure safety. That means that HOFs must be considered both at the design and operational stage. At the design stage, the conventional barrier functions to fulfill are:

- Prevent loss of containment
- Prevent ignition
- Reduce cloud/emissions
- Prevent escalation
- Prevent fatalities

However, the barrier functions should also include prevention of human and organizational errors/failures:

- Prevent human failures/errors
- Prevent organizational failures/errors

The two different types of barriers emerging should be treated in separate ways. The offshore industry have established good practice and procedures in identifying and analyzing barriers related to the first top five objectives. These barriers can be designed in the planning phase, be followed up and maintained in the operational phase. Such barriers are mainly physical barriers.

In order to prevent human- and organizational errors/failures, there should also be barriers present in this respect. This will often be in the form of non – physical barriers or through (user friendly) design. Non - physical barriers are influenced by RIFs.

The framework identifies and makes use of two different methods in particular in order to prevent human and organizational errors/failures; the “user friendly design” method by Kletz at the design stages and the BORA method for risk analysis at decision stages and at the operational stage.

Table 4 Proposed framework for HOF consideration and integration in different project phases

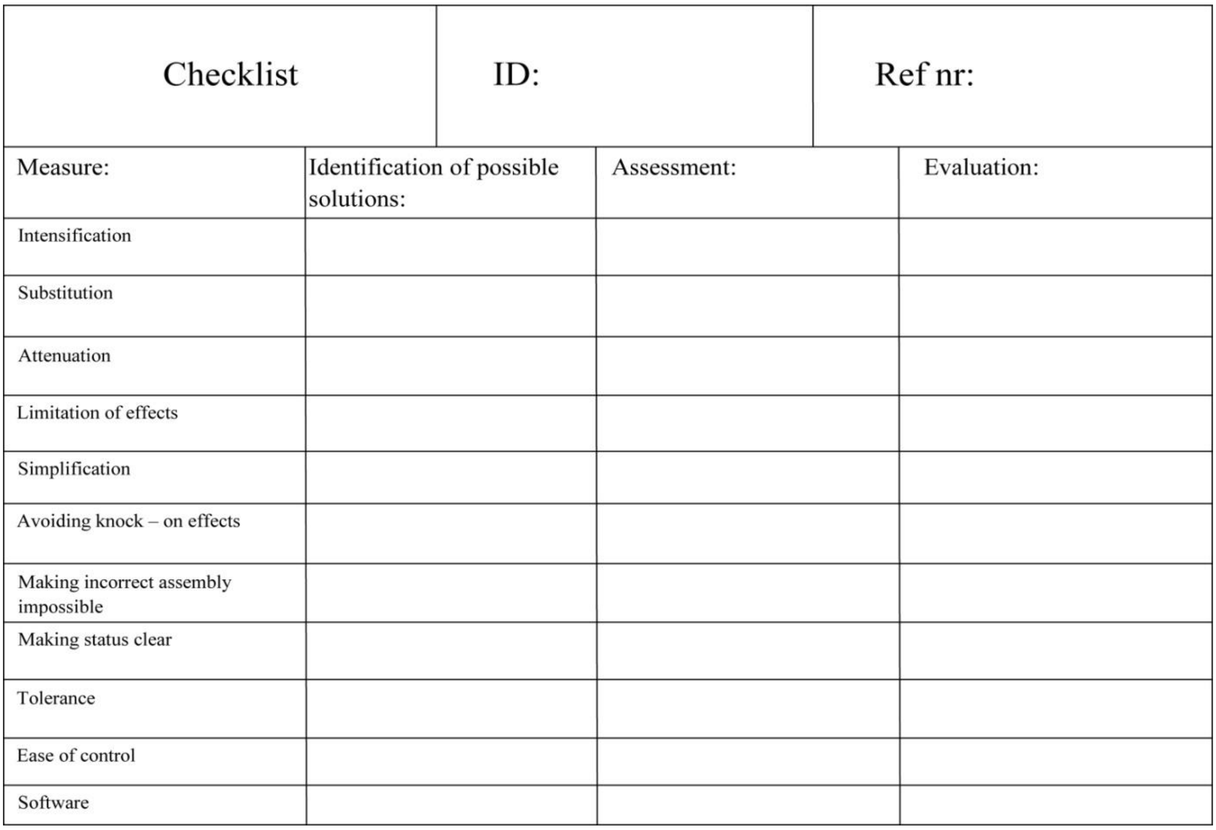
Concept development	Concept selection	Detailed design	Operation
Integrate Inherently safer design principles and method by Kletz (Kletz 1991) in the design process. The designer group uses a checklist, applied to the different modules, to identify ways of achieving inherent safety and user friendliness.	Qualitative analysis to identify scenarios with catastrophic potential with specific focus on situations requiring human intervention. Integrate BORA with the required QRA.	Continue to apply Inherently safer design principles by Kletz in the design process(Kletz 1991). Apply checklist. Further develop and update the analysis of RIFs in the BORA method.	Monitoring and communication of status of operational barriers Update BORA parameters/assumptions on a regularly basis to reflect current situation Inspections Questionnaires Interviews Testing

4.1. Visualization of the framework

The purpose of this chapter is to elaborate how the framework is intended to work and present examples of how the methods can be applied in a practical manner. In order to do so, a hypothetical field development project is used as a basis.

Assume that an oil company has found a new oil field in the North Sea. The next sections consider the different project phases that the project goes through.

The first project phase to consider is the concept development phase. The purpose of the framework in this stage is to make sure that the designer's considers the possibility of implementing different measures to their solutions/design in order to make them more user friendly and inherent safe. The identified concepts are studied individually. The different concepts could be subsea solutions, FPSO or a steel jacket platform for instance. The measures are considered through the use of a checklist consisting of the different relevant measures. Each measure is considered in turn and different solutions, measures or alternatives are brainstormed by the group. Thus the session takes on the form of a brainstorming process. The level of detail will vary as more information becomes available. At an early stage, applying the checklist to the different modules is recommended. This review process can be done on a regularly basis or when the design has reach a specific level of detail or completion. The system is intended to be used as an integral part of a digital system. That is, the system is computer based, such that the information in each boxes is stored in other checklist sheets, as the amount of information in each cells becomes very large. An example of a high level checklist is displayed in figure 7.



Checklist	ID:		Ref nr:
Measure:	Identification of possible solutions:	Assessment:	Evaluation:
Intensification			
Substitution			
Attenuation			
Limitation of effects			
Simplification			
Avoiding knock – on effects			
Making incorrect assembly impossible			
Making status clear			
Tolerance			
Ease of control			
Software			

Figure 7 Checklist applied in the design process

The next section focuses on the brainstorming process and the measures that are considered:

In the brainstorming session it is important to balance the need for structure with the need for flexibility in order to be creative. A structured approach ensures the first one but in order to promote creativity an environment characterized by open minded and curiosity is required. In order to facilitate that, the personnel responsible for the process and selection of personnel have to be aware of this issue and make decisions accordingly. The next nine sections explore how the different measures can be implemented:

The first measure to consider is *intensification*. The measure can be implemented through improved process or equipment design. The group considers a specific module and brainstorm different ways to reduce the inventory of hazardous materials in that module. This can be done through designing systems that utilizes less hazardous materials or that requires less storage of hazardous materials. It is acknowledged that this can be a major problem and perhaps impossible in many situations offshore, but it should nevertheless be considered by the design team.

If intensification is not feasible the designers should consider *substitution*. The hazardous material is then substituted with a less hazardous material. The designers should consider different processes, systems or equipment and evaluate if they can be modified or replaced by other processes that utilizes less hazardous materials.

The third option is to *attenuate*. Attenuate means to apply the hazardous materials under the least hazardous conditions or at their least hazardous states. Again, systems, processes and equipment should be considered and evaluated if they should be modified or replaced with other alternatives in order to improve safety and robustness.

The next measure is one of the most important ones, *simplification*. The objective to simplify rather than apply complex systems, processes or equipment is a very strong tool when considering risk and safety. When systems, processes, equipment, routines or other important features are simplified it results is less room for errors. Another important argument, often applied in the process industry, is that when simplified there is less for safety add – on equipment. This will also result in lower costs, ref figure 5.

In order to prevent escalation, systems, processes and equipment should be designed in such a way that the possibility of *knock – on effects* is reduced as much as possible. Examples are to separate hazardous modules from each other, install firewalls, reduce sources of ignition and install smart ventilation systems.

Next the designers should make sure that their systems and equipment is not possible to *assemble incorrectly*. It should be straightforward create such design and thereby remove the risk of human errors related to assembling.

Another way to prevent human error is to make sure that the systems or equipment *make their status clear*. That is, it should be easy to see in what position a valve is, what the status of a system is etc. This is also a task for the designers to consider when designing or choosing systems, processes or equipment.

Another measure related to preventing escalation or hazardous situations is *tolerance*. The systems and equipment designed should be robust enough to withstand abnormal conditions caused by both human/operator errors and external forces. The most robust solutions should be preferred and alternatives for making their design more robust should be identified and considered. Designing systems that are *easy to control* also prevents human/operator errors and the likelihood of escalation. One way of doing so is through control room design or through logical manual override systems.

The final measure to consider is related to the term called *software*, interpreted in the wide sense to cover all procedures. To prevent errors the designer should consider methods for simplifying the procedures or make them more consistent on an overall level.

After the concept development phase certain approved alternatives are considered in the concept selection phase. In this phase it is assumed that no changes to design are made, just an evaluation of the different alternatives.

In the concept selection phase it is mandatory to conduct QRA. The QRA should consider the possibility of human error as part of the accident chain. The BORA method integrates human and organizational factors in the analysis and uses a structured approach for modeling and quantifying such parameters. The method should be integrated with the traditional QRA and influence the risk results relating to achievement of risk acceptance criteria´s.

In addition situations that are critically dependent on human performance should be identified and assessed. Scenarios like blowout or leaks should be considered. The results should be used in training programs for operators and in particular control room personnel.

When a concept has been selected for detailed design the method used in the design process in the concept development phase should be continued. The facilitator makes sure that all previous identified measures are implemented. The team applies the same procedure with checklist review at predefined times/events. Preferably a large portion of the designer team follows the entire design process and thus becomes more familiar with the procedure.

The BORA method is also extended and updated as more detailed information becomes available.

During operation the risk analysis should be updated on a regularly basis. The assumptions and parameters used in the risk analysis and in particular the BORA part should be monitored and used. This should be a continuous process and the risk analysis should act as a living document as recommended by the government.

Inspections, questionnaires, interviews and testing should be conducted on a regularly basis in order to achieve credibility for the assumptions and parameters used in the risk analysis.

5. Discussion

5.1. Current practice, methods, problems and challenges

The use of barriers to prevent, control and mitigate accidents related to; loss of containment, ignition, cloud/emissions, escalation and fatalities has proven a success for the last 20 years. However, there are still many gas leaks occurring on installations on the NCS every year that does not ignite, and a large proportion of them are caused by manual override. One of the main challenges in the offshore industry is to reduce the number of gas leaks. In order to do, so physical and non- physical barriers must both function appropriately. An increased focus on human and organizational factors is necessary. Due to good systems on ignition control, there has not been an ignited gas leak since 1993.

The design process typically utilizes a HAZOP process or any other similar analysis tool in order to detect hazardous situations, causes and consequences. At certain stages risk analysis is required in order to demonstrate that the project/activities etc. does not exceed the predefined risk acceptance criteria´s. As the design process reaches completion, larger emphasis is placed on the predefined RAC´s, which also applies to the operational phase.

The first main problem is that the HAZOP studies (or similar studies) are conducted with limited impact on design. They will (probably) not identify other more safe alternatives that perhaps should have been considered or selected. They simply accept whatever design they are provided and try to modify them in order to make them more robust.

Another related problem is that these studies doesn´t consider communication issues, human and organizational factors in a structured manner. Such aspect is of key importance as they are the foundation of a functional safety culture. The design process should have available tools in order to make sure that such aspects is welded into the design, making it more user friendly and safer to operate.

The third issue to consider is the use of RAC´s. The method has been heavily debated and criticized by many recognized authors. One of the most important arguments for is that it ensures that a minimum safety level is achieved and that it contributes to a more consistent safety level throughout the offshore industry. There is however several challenges related to this method. One of the most severe challenges is that the method can easily result in a superficial safety culture where attention is shifted from identifying solutions towards adjusting assumptions etc. in order to reach a specified number. Such a culture would also contribute to less focus on communication aspects and HOFs. Another challenge is related to the specification of the RAC´s.   There is, however, an alternative to the RAC method, which is highly appreciated and implemented in the UK. The method is called ALARP (As Low As Reasonably Practicable) and states that risk reducing measures shall be implemented unless it can be documented that the costs are in gross disproportion. The values of gross disproportion are developed through industry standards and recommendations from authorities. It is the author's opinion that it should be possible and favorable to integrate both these methods in regulations and industry practices.

5.2. Framework

5.2.1. General

The framework originates from two basic issues, and seeks to integrate them in the lifecycle of an engineering project. The issues are the design and risk analysis processes. In the design process the standard method to use in revealing weaknesses and identifying risk reducing measures is HAZOP. The technique focuses on the interaction between a system and the physical barriers for hypothetical scenarios. Reports on causes of leakages point at human factors and human error as a primary source and therefore an approach aiming towards user friendliness and inherent safety seems necessary. Such a procedure should be used throughout the design process in parallel with traditional HAZOP studies. Risk analysis is also required at certain stages. Their objective is often to verify that the risk level is acceptable and within predefined RAC´s, and to identify and implement risk reducing measures. Norwegian legislation requires that human and organizational factors are assessed, qualitatively or quantitatively. Either way, a structured approach is preferable. For quantitative assessment the BORA method is judged to be best suited. The framework applies these two methods and integrates them in the life cycle of a typical project. Both methods must be adapted to fit each unique project and experience will hopefully result in new industry standards and an increased focus on HOFs.

5.2.2. Concept development phase

During the concept development phase, several concepts should be considered and evaluated on a broad scale. Traditionally, cost, functionality and reliability are the main parameters considered by the designers at this stage. Safety experts attend at a later stage, when the cost of altering design is very high. Thus they have been given a reputation of being someone who adds to the complexity and costs.

The best way to meet this challenge is to incorporate methods in the design process that can guide the designers in choosing better and safer solutions, such that less safety equipment is required. The framework does so by introducing a method for “inherent safety” and “user friendliness”, proposed by Trevor Kletz and elaborated in previous chapters. The method suggests different measures that should be assessed at an overall level and at a more detailed level. The main function of the method at this early design stage is to prepare the minds of the designers to pay attention to safety and how to make them more inherent safe and user friendly. When different feasible concepts have been identified, a process to improve them with respect to safety is implemented. The process takes on the form of a brainstorming session where the different measures identified by Kletz is considered and evaluated for possible measures to implement. It may be feasible to consider the entire structure as a whole or divide it into specific modules for analysis.

5.2.3. Concept selection phase

It is assumed that during the concept selection phase, the main objective is to evaluate the different concepts that are presented. That means that no further decisions regarding design solutions are made. Analyses regarding NPV, costs, functionality, reliability, capacity, safety etc. are assumed to be complete and available for an overall evaluation. However, a high level analysis identifying and qualitatively assessing scenarios with catastrophic potential should be performed, with particularly focus on scenarios that require human intervention. Also a QRA need to be conducted to ensure confidence in that the predefined RAC´s are met and to identify cost – effective risk reducing measures. The QRA should consider the effects of human errors and be able to distinguish between a functional and dysfunctional safety culture. In order to incorporate HOF´s in the QRA it is recommended to apply the BORA method. Then by evaluating all relevant available information and considering their limitations, the decision makers decide which or what concepts to fund for further development/design through the detailed engineering phase.

5.2.4. Detailed design phase

During the detailed design phase the level of detail rapidly increases and all drawings are made and documented such that the concepts/structures can be constructed in a construction phase. In order to guide the designers in choosing inherent safe, robust and user friendly solutions/design the same process used in the concept development phase is applied. Because of the higher level of detail, the method should now be applied to smaller units. In order to ensure contingency, part of the same personnel should also be attending in the detailed design phase. It is important to consider the composition of the design team, assuring that at least one expert in risk/safety methods and operation is present respectively. A facilitator should also be used extensively with a broad and high competence.

The QRA applied in the concept selection phase should be further developed and updated as new features regarding design solutions is chosen. It can also be used to evaluate different alternatives, including using BORA to give guidance.

At this important stage, when important decisions regarding design are made, the framework combines methods for improving design and analysis of alternatives. These two features should be working together and enforce each other. They will also apply a control function to each other.

5.2.5. Operational phase

When a project enters the operational phase it is normal practice to reconsider the QRA on a regularly basis (1 -5 years). This is very important because the operational conditions can vary significantly and degradation on systems, equipment etc. also has to be accounted for. One of the main reasons for integrating BORA with the QRA is to be able to distinguish between different operational conditions. It is normally too expensive and complicated to change any design errors at this stage, such that safety experts can only add features to the existing design to reduce the effects of design errors.

Another important task to consider when revising the existing QRA is to verify critical assumptions and model parameters used in previous analyses. In doing so, inspections, questionnaires, interviews and testing are available options that can give guidance with respect to their validity. The results can also contribute to, or be part of a qualitative working environment analysis, supporting BORA. Such a study should then be conducted on a regularly basis.

Communication is also a key factor to consider. The operational personnel and the analysis team should have a mutual understanding of how, what and when to communicate important information. To ensure that, management has to be involved and take responsibility. In order to ensure good communication to the end users of QRA, it is important that they are operationalized. Operationalized here means that the end results is presented in such a way to make it easier for the end users to apply the results.

5.3. Authority regulations

The relevant regulations and guidelines regulating the offshore industry on the NCS are issued by PSA. PSA set out functional requirements that must be met by the responsible party. In order to clarify what is expected in order to comply with the functional requirements, industry standards and RAC´s is applied.

The requirements related to HOF consideration and integration is regulated through NORSOK Z-013. Section 5.2.2.5 e) is very clear on that HOFs should always be considered, and that the extent depends on the criticality for the risk picture. However, a strict requirement to identify such factors is missing, potentially resulting in a higher focus on technical factors and traditional physical barriers.

The review in section 2.4 indicates that the lack of specification in the regulations and acknowledged methods in the industry causes much confusion and arbitrariness in how to deal with human error and HOF´s in relation to accident prevention. Investigations by other authors have concluded that HOF´s is not properly handled in the analyses.

Finally it is important to remember that the proposed framework is not a general framework in relation to risk and safety. It only gives guidance on how to consider and incorporate HOFs throughout an engineering project. Other processes or methods used in design focusing on physical barriers must also be carried out in a more general setting. There are also several requirements that will have to be met in order for the framework to be effective, management involvement and effective communication channels are two examples.

6. Conclusions

6.1. Current practice

The safety level on installations on the NCS is recognized as among the highest internationally. Much work has been done in preventing major accidents by identifying and implementing chains of physical barriers. The industry has together with the authorities developed highly acknowledged standards and regulations. The tools applied in the design process and risk analysis reflects this high focus on physical barriers.

Unfortunately, history and statistics has shown that accidents still does occur. Several scientific reports have concluded that a large proportion of gas leaks are caused by manual override, thus implying some sort of human error. In order to reduce the number of leaks, systems must be designed in such a way that they minimize the risk of human errors. Implementing Trevor Kletz´s concept of “Friendly design” in the design process and utilizing the BORA method in risk analysis is the recommended approach defined in this master thesis. In such a way HOFs are evaluated and treated throughout a development project.

6.2. Legislation

The investigation of the legislative requirements pointed out that there are lacking requirements related to identification of human and organizational factors at the design phases. This, together with a very strong focus on physical barriers and RAC´s, (which does not include criteria´s related to human or organizational errors), results in a low priority, focus and consideration of HOFs in general. A primary cause to this situation stems from the lack of industry accepted methods and models. However, many methods and models have been presented over the last 15 years.

In order to reach a higher level, the presented methods and models must be further operationalized such that they are feasible and practicable to use in practice and the authority regulations must push forward towards applying them.

6.3. The new framework

The new framework applies scientific methods to the design and risk analysis process in order to effectively consider and incorporate HOF´s. It is a guide on how to incorporate HOF´s throughout a project´s life cycle. The applied methods are chosen because they are judged to be the best available tools for their purpose and because they are practicable to implement and use. They also have certain common elements with existing methods, such that personnel can familiarize themselves with them.

The framework is of a general character and will have to be adapted to fit each specific project´s requirements. This also applies to the models.

Probably the biggest potential for reducing accidents is within reducing the number of human errors. It is the purpose of this thesis and framework to add to that objective and propose a general framework for HOF consideration and integration.

Appendix A: PSA Regulations and guidelines

Framework regulations:

Section 11:

"In reducing the risk, the responsible party shall choose the technical, operational or organizational solutions that (…) offer the best results provided the costs are not significantly disproportionate to the risk reduction achieved". (Petroleum Safety Authority Norway 2011)

Section 15:

"A sound health, safety and environment culture that include all phases and activity areas shall be encouraged through continuous work to reduce risk and improve health, safety and the environment". (Petroleum Safety Authority Norway 2011)

Section 24:

"When the responsible party makes use of a standard recommended in the guidelines to a provision of the regulation (…) the responsible party can normally assume that the regulatory requirements have been met." (Petroleum Safety Authority Norway 2011)

Management regulations

Section 4:

"In reducing risk (…), the responsible party shall select technical, operational and organizational solutions that reduce the probability that harm, errors and hazard and accident situations occur". (Petroleum Safety Authority Norway 2010)

"When choosing technical, operational and organizational solutions (…), the responsible party should apply principles that provide good, inherent health, safety and environment qualities". (Petroleum Safety Authority Norway 2010)

Section 5:

"Barriers (…) can consist of either physical or non-physical measures or a combination". (Petroleum Safety Authority Norway 2010)

"Barriers shall be established that reduce the probability of failures and hazard and accident situations developing". (Petroleum Safety Authority Norway 2010)

Section 17:

"The responsible party shall carry out risk analyses that provide a balanced and most comprehensive possible picture of the risk associated with the activities. The analyses shall be appropriate as regards providing support for decisions related to the upcoming operation or phase". (Petroleum Safety Authority Norway 2010)

"The NORSOK Z-013 standard can normally be used to fulfill the requirements for risk analyses and emergency preparedness analyse". (Petroleum Safety Authority Norway 2010)

Section 18:

"The responsible party shall carry out necessary analyses to ensure a sound working environment and provide support in the choice of technical, operational and organizational solutions. The

analyses shall e.g. contribute to improving the employees' health, welfare and safety and to prevent personal injuries, fatalities and work-related illness as a result of

a) Mistakes that can result in hazard and accident situations,

b) Exposure and physical or psychological effects". (Petroleum Safety Authority Norway 2010)

"To ensure a sound working environment, the various analyses should complement each other so that they cover both hazard and accident situations and exposure to working environment factors. The analyses should include the use of data on

a) The personnel's individual or group workload and exposure to working environment factors, as well as data on how the employees experience the physical and psychosocial working environment,

b) Working environment factors in the respective areas of the offshore or onshore facility,

c) work-related illness and work accidents". (Petroleum Safety Authority Norway 2010)

"To satisfy the requirements for working environment analyses, the NORSOK S-002 standard, Chapter 4, should e.g. be used when engineering new facilities and in connection with modifications. Assessment of psychosocial factors during engineering can be in the form of comparative analyses using empirical data from operations phases with similar workplaces and work areas". (Petroleum Safety Authority Norway 2010)

Section 19:

"The responsible party shall ensure that data of significance to health, safety and the environment are collected, processed and used for monitoring and checking technical, operational and organizational factors". (Petroleum Safety Authority Norway 2010)

Facilities regulations:

Section 4:

"When choosing a development concept, the following shall be considered (…) major accident risk". (Petroleum Safety Authority Norway 2010)

"The following should be taken into account when choosing a development concept (…) important risk contributors, organization and working environment". (Petroleum Safety Authority Norway 2010)

Section 5:

"Facilities shall be based on the most robust and simple solutions as possible". (Petroleum Safety Authority Norway 2010)

"To fulfill the design requirements as mentioned in the first subsection, the standards NS-EN ISO 13702 with appendices, NORSOK and S-002 *should be used for the health and safety sections.*

For mobile facilities that are not production facilities and that are registered in a national shipping register, DNV-OS-A101 *can be used as an alternative in the area covered by the standard".* (Petroleum Safety Authority Norway 2010)

Section 10:

"Installations, systems and equipment shall be designed in the most robust and simple manner possible and such that

a) the possibility for human error is limited,

b) they can be operated, tested and maintained without risk to the personnel and with the lowest possible risk of pollution,

c) *they are suitable for use and able to withstand the loads they can be exposed to during operation".11*

"Installations, systems and equipment shall be marked so as to facilitate safe operation and proper maintenance". (Petroleum Safety Authority Norway 2010)

Section 20:

"Work sites and equipment shall also be designed and placed in such a way that the risk of mistakes that can have an impact on safety is reduced". (Petroleum Safety Authority Norway 2010)

Section 21:

"Monitor-based equipment and other technical equipment for monitoring, controlling and operating machines, installations or production processes, shall be designed to reduce the risk of mistakes that can have an impact on safety". (Petroleum Safety Authority Norway 2010)

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