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MASTER'S THESIS

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Preface

This master thesis is the result of my master degree and the final step in graduating with a Master of Science degree in Risk Management at the University of Stavanger. The master thesis has been written in collaboration with GDF SUEZ EPN AS.

The report is written with the idea that people in safety and risk management will be able to read and understand the content, without the need to use additional literature.

I would foremost like to thank my faculty supervisor Roger Flage, who kept me focused on the goal and provided me with good ideas and insight. Thanks to his support, challenges, and thorough follow-up this have motivated me throughout the whole semester.

I would also like to thank my external supervisor in EPN, Anders Roushan Tharaldsen that made this thesis possible. I would further use the opportunity to thank Kai Solheim, for his support and guidance, which have provided me invaluable insight in maintenance and modifications through this semester.

Finally, I want to thank Sandra Tollaksen for her patience and support in good and bad times. Without her care, dinners and expertise in Excel, the last six months would be much harder.

Incentivize risk
in various disciplines
for stunning results

- Unknown

Summary

Decision analysis has a central role in decision-making as it aids the decision-maker in identifying the most suitable alternative, matching the decision-makers preferences.

Several of the tools used today focus to some degree on particular outcomes and do consequently provide the decision maker with a one-dimensional answer. Statutory requirements state that the decision analysis performed should take multiple stakeholders preferences and knowledge into account when evaluating Risk-Reducing Measures. From this, it is assumed that a more balanced perspective that goes beyond expected values is required to aid decision-making.

The use of modifications to retain performance on existing safety barriers and systems is presented, as modifications often are performed to compensate for unreliability and loss of quality affected by; human errors, accidents, unreliability and/or changes in statutory requirements.

With the starting point of the thesis is to make a tool for decision support in the selection of modification proposals, there has been performed a minor review of commonly used methods for evaluations in decision-making. The multi-attribute theory appears to be a reasonable approach, which may be used when there is limited knowledge regarding future consequences.

As a result, the thesis has suggested a framework for implementation of a multi-attribute analysis that reflects different stakeholders concerns based on strategies and philosophies generated by an E&P company. A relative weighting index has been suggested to reflect various stakeholders concerns. It has also been performed a case study on previous modification proposals to see how the framework aligns in practice, and various stakeholders preferences affect the prioritisation.

A suggestion on how Multi-attribute theory can be implemented into a decision-making process, to reflect possible lack of knowledge and creation of alternatives to enlighten key points of disagreement are further presented.

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1 Introduction

1.1 Background

Decision analysis has a central role in decision-making as it aids the decision-maker to identify the most suitable alternative, matching the decision-makers preferences.

Several of the tools used today do to some degree, only focus on particular outcomes and do consequently provide the decision maker with a one-dimensional answer (Aven & Kørte, 2003). Statutory requirements state that the decision analysis should take multiple stakeholders preferences and knowledge into account when evaluating the implementation of Risk-Reducing Measures (PSA, 2014).

Traditionally, the use of upper limits and acceptance criteria has been used as an important part of decision-making. The implementation of upper limits of acceptable risk was introduced on the Norwegian Continental Shelf for more than thirty years ago. In recent years, several scientists have challenged the use of such criteria's, Aven & Vinnem (2004), and Aven & Krohn (2013), acknowledge that a more balanced perspective should be undertaken exceeding expected values and upper limits for acceptable risks.

One of the results of this research is that the definition of risk has changed from that: risk is the combination of probability of an event and its consequences (ISO, 2002) to; risk is the consequences of a business and its associated uncertainty (PSA, 2015). The latter definition carries with it fundamental practical and philosophical changes as the Petroleum Safety Authority (PSA) supervise and consolidate the risk level on the NCS. This new way of thinking challenges both new developments, and existing fields in production.

Maintenance has also changed from being a cost, to a measure to reduce costs (Raza, 2015). This has made processing more reliable and predictable, although the purpose still is the same; process and safety assurance. Maintenance can be defined as "Combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" (ISO, 2010, p. 5)

Changes in regulations and legislations, new technology or societal requirements may result in maintenance requirement going beyond routine work. Such changes may result in modifications, which are characterized by complex actions, with the involvement of special competence or industrial support (Raza, 2015). Such activities with the purpose to change one or more functions or processes will be referred to as modifications. Modifications can be defined as (Norsk Standard, 2010);

- Technical improvements that are going beyond the original state of process, equipment and structures, which are initiated top prepare for tie-ins, capacity increase, re-adjustment and to retain technical integrity or safety.
- Modifications are a part of a continuous improvement as a result of supervision, inquiry, investigations or as a part of enterprise development.

In the petroleum industry, different requirements are set for risk acceptance and risk exposure. One of these requirements is continuous risk reduction, better known as the ALARP (As Low As Reasonably Practicable) principle. Constraints as budget and available resources may limit which risk reducing measures that can be implemented. By applying decision making and portfolio management theory, selection of projects can be done as an integrated decision-making process to identify, evaluate, select and prioritize one or more projects for implementation through allocation of resources, aiming to achieve corporate profile, visions and strategies (Wyoscki, 2014). Three relevant examples are presented below; all have been initiated in response to the development of technology and because of requirements that not were available when installations were constructed. All have the purpose of increasing the overall safety level.

Fire and Gas Detection Projects

Fire and gas detection systems have an anticipated lifetime of 10-15 years depending on the equipment in use. The use of old equipment and an increase of incompatible spare parts have resulted in high load on the Central Processor Units, which has led to that the response time are not as required. This has reduced the technical integrity of the F&G systems, as their ability to detect and limit hazardous events are weakened (Sintef, 2006).

Firewater projects

PSA have made several changes in requirements related to redundancy and capacity on firewater systems. The changes in requirements have resulted in that many existing facilities have had to modify and upgrade their existing firewater systems. For facilities constructed in the 1980's, adjustments of the regulations have affected several occasions when operators request to extend the lifetime of existing facilites e.g. Frigg central complex. (Vinnem , 2007).

Davit lifeboat projects

During summer 2005, some serious faults in freefall lifeboats were discovered, on several installations in the North Sea and Norwegian Sea. The conclusion was that both the hull and deck of several lifeboats would fail the strain under a free fall. The findings have resulted in several improvements. New regulations for lifeboats are effective from 2015. (PSA, 2015)

The consequence of the projects presented above may be significant in a decision context. If an operator were to prioritize the projects mentioned above for implementation, many questions might be asked;

- What are the consequences if an undesirable event occurs?
- What is the largest contributor to risk?
- What risks will project A and B mitigate?

At the same time, it is difficult to compare different modification proposals to one another as the available data is limited, and the uncertainty is high. Project type, new technology, and discount rates will also influence the quality of the evaluation. By defining a useful tool/practice at an early stage, this can contribute to improved certainty/assurance in a decision context.

1.2 Present situation

In this section, it will be looked further into the development of modifications projects on the Norwegian Continental Shelf (NCS) and the development within the safety discipline.

In contrast to the oil and gas prices, the level of cost in the petroleum industry has grown the past years. Because of this, costs and resources are challenged both in smaller and larger projects (E24, 2014).

Estimates for cost development in the maintenance and modifications segment are flat (NPD, 2015), and the principle actors on the NCS has indicated the same (Offshore.no, 2014). Changes from concept throughout a project lifecycle increase the costs and make profitable projects less profitable (Deloitte, 2014).

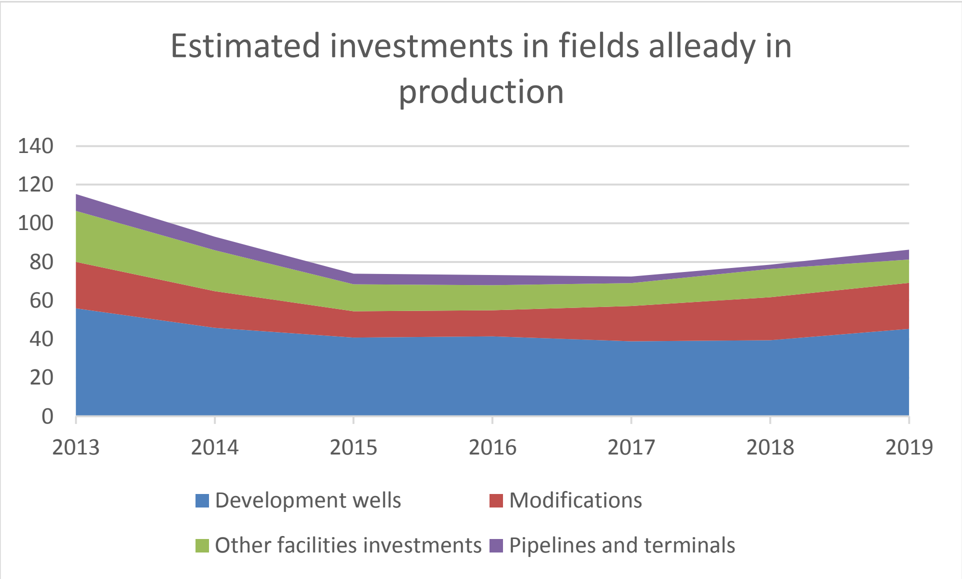


Figure 1- Estimated investments in fields already in production from 2013 to 2019 (NPD, 2015)

From Figure 1 it can be indicated that the investments in fields in production reached a top in 2013 with 155 billion NOK. 24 of these were modifications, in 2016 comparable 14 billion NOK of investments are estimated invested in modifications.

It may, therefore, seem like a sensible thought that it can be assumed that cost efficient solutions in a safety and production assurance setting will have a higher priority than before. The following citation is a recently collected from the PSA director.

"Næringen er inne i en meget viktig periode på flere områder. Avgjørelser som fattes nå, skal vi leve med lenge. Derfor er det viktig at selskapene tar valg som ivaretar sikkerhet og arbeidsmiljø både på kort og lang sikt»

Anne Myhrvold – PSA Director (PSA , 2015)

To make sure that the safety level remain high, PSA have taken initiative to focus on aging facilities and lifetime extension on two occasions. From 2006 to 2009 when focusing on enhanced knowledge, standardisations and procedures were initiated to ensure safer execution of projects related to lifetime extension. Now, in 2015, to ensure high safety levels in all phases of facilities.

A general problem acknowledged by the industry is cost overruns, complex projects are overrepresented in this category, and do include modification projects (Deloitte, 2014). The main reason for the cost overruns is mainly due to assumptions, clarifications, and poor planning during the initiation phase of the projects.

In this thesis, assumptions are made that operators will have a rational approach to decision-making and prioritize the most efficient projects.

Development technology and standards

Both continuous developments of internal requirements (performance standards, business rules) and external requirements have changed the focus on the implementation of risk-reducing measures. Many of these risk-reducing measures are a consequence of technology development and research. The general risk level is at its lowest since the year 2000 (PSA, 2015). However, the effect of aging equipment and lifetime extensions cause a constant change in the risk picture.

The use of predefined acceptance levels of risk has been criticised. Academics are challenging the utilization of these expected values and risk acceptance criteria's. Both Aven & Vinnem (2004), and Aven & Flage (2009), are suggesting that decision-making should search for alternatives to the use of expected values and use of predefined acceptance criteria's.

There is also a significant amount of research related to, "Black Swans" and "Collective Mindfulness". This research emphasizes that technical solution in a dynamic risk environment should meet requirements related to robustness, vulnerability and resilience rather than specific requirements and acceptance criteria's. (Norsk Olje og Gass, 2014)

A wide range of the theoretical approaches to decision-making exists, some of these theories may be difficult to use in practice due to high uncertainty and lack of available data. Some of these theoretical approaches will be enlightened further in chapter 3.

1.3 Definition, Scope and Limitations

The assignment text is defined as, «The purpose of this thesis is to make a tool for decision support in the selection of modification proposals. The tool will be used on an existing modification portfolio in EPN to see how it suits its purpose. » From the introduction and description of the problem, the following outcomes of the thesis are expected.

Review

1. Review of applicable external and internal requirements.
2. A literature review of relevant theories covering decision-making.

Recommendations

3. A recommendation for selection criteria that can be used in a modification context.
4. Development of a model on how modification proposals can be evaluated.
5. Other recommendations based on the findings.

Case study

6. A case study on finished modification proposals from a 1-year period, investigating how modification proposals fit the model.

The limitation of the thesis is related to the *evaluation* of the different modification proposals, as indicated in Figure 2.

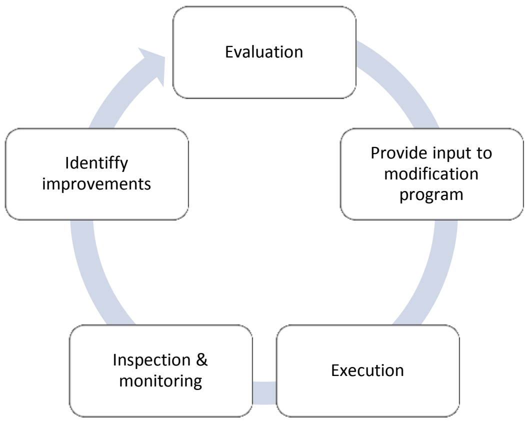


Figure 2- Phases of an operation and continuous improvement

Modifications are usually carried out, as a part of the following steps during operation; inspection and monitoring carried out, if improvements are required these are identified and reported. An evaluation is required to consider whether the proposal is appropriate for implemented in the modification program or not.

1.4 Starting point for this thesis

In this section, a description of the challenge in GDF SUEZ E&P Norge AS (EPN) will be provided.

Some maintenance and modifications projects are urgent and have to be carried out immediately to maintain production and safety level. In contrast, some maintenance and modification proposals require an evaluation to ascertain which are to be approved and prioritized within the constraints of; budget, capacity or other operational limitations. It is assumed that these constraints are used to limit the amount of maintenance and modifications carried out.

By collecting improvement proposals from operators, engineers and other independent third parties (which include governmental supervision), compliance with internal and external requirements can be achieved. Naturally, some improvements proposals require more work and evaluation than others do.

The motivation to look further into this is that the aging of facilities will contribute to an increase of modification and improvement proposals. It will, therefore, be necessary to distinguish the good from the less good proposals, so that these can be prioritized and implemented.

In EPN, when an improvement proposal or modification proposal (formalized as an EV05 request) is registered, a management of change (MOC) process is initiated. The MOC process, include all technical changes. The present situation is that a work process is established, but evaluation of the proposal and linking them to ALARP theory are challenging.

At a point, this may lead to non-profitable investments, or investments that do not lead to cost efficiency, increased safety or production assurance. Another issue may be when evaluating two apparently similar projects; constraints may only allow one of the projects to be carried out, the potential consequences the measure will mitigate should, therefore, be taken into account before initiating call-off on the project.

During three workshops, with different disciplines, a matrix (Figure 3) was used evaluate the criticality and impact of several proposed modification projects. Some challenges were identified using this approach.

The basis for the approach is to weighted different proposals on a set of criteria’s, summarizing the applicable importance and proposing the implementation of the projects with the highest sum.

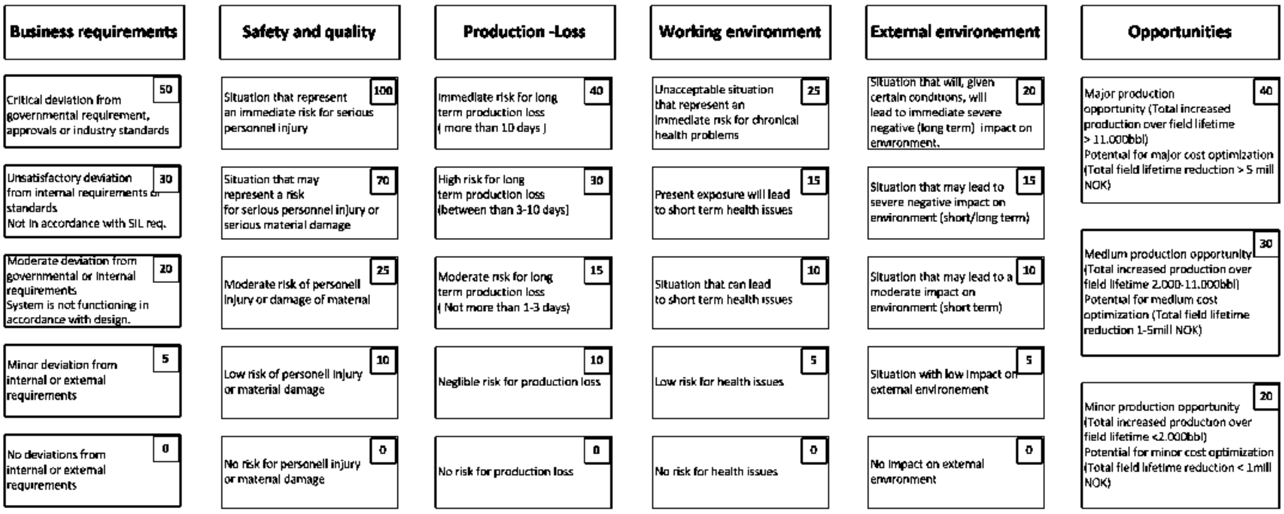


Figure 3 - Starting point used to evaluate modification proposals

Findings related to the use of scoring in the evaluation of modification proposals

- The result may be based on and numerical value, which may prove difficult for the decision maker to understand. It would also be difficult to know whether it conflicts with the ALARP philosophy or risk acceptance criteria.
- Subjective evaluations can lead to manipulation of results as uncertainty regarding the consequences is reflected in a small manner.
- The root cause can be neglected in complex systems.
- Benefits and burdens are not addressed in a sufficient manner at this stage
- Documentation of potentially reduced risk is difficult.
- Actual requirements are not referred to; this may lead to misconception regarding the necessity of the improvement.
- Evaluation of risk and opportunity is not done in all stages.
- Influences of the different categories (safety, health, environment or production) are indistinctive.
- Some interference between the various attributes may be a problem, as business requirements often are affected. A consequence may be double counting.
- No input to «health-check», or similar of the general integrity of the installation in question.

This thesis will not answer all these challenges, but the findings above will be the basis for the different areas that will be investigated further.

- How can subjective evaluations be used?
- How can manipulation be avoided during evaluation of modification proposals?
- How can the anticipated consequences that measure may mitigate be split between risks and opportunities?
- How can decision-making be performed to enable a transparent, and versatile process enabling the decision maker considering its risk appetite?

2 Context

EPN is the company used as a basis for the thesis. Consequently, some of their internal requirements will be reflected in the development of the solution.

When addressing the context, several areas have to be investigated to provide sufficient background information. The purpose of this is to highlight internal requirements, statutory requirements, and industry standards that may influence the result.

Development of decision alternatives is primarily driven by the boundary conditions of the decision problem, settled by experts and management (Keenay, 1992). The boundary conditions include stakeholders' values, organisational goals, criteria's, standards and preferences, as well as governmental and societal concerns.

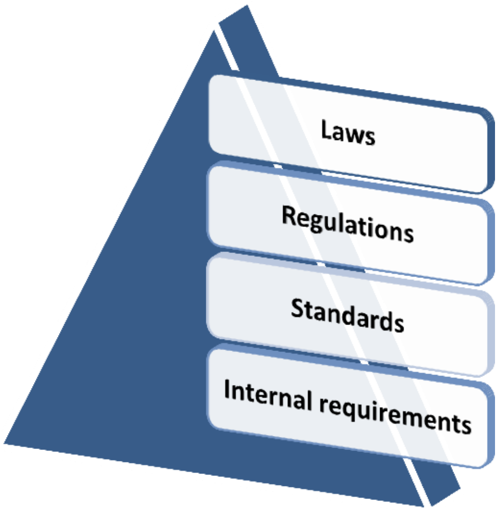


Figure 4- Hierarchy is describing the relationship between laws, regulations, standards and internal requirements.

Figure 4 illustrates the hierarchy of requirements affecting decision-making, both directly and indirectly. It has been simplified as appendixes and instructions to regulations not are included in the illustration. In the upper end, we find the legislation as e.g. the health and safety work act and petroleum law, that is applicable both onshore and offshore facilities (PSA, 2015). The framework, -management, -facility and activity regulations, consist amongst other things, of risk and performance-based requirements (PSA, 2015). There also exist several guidelines to these; which not legally binding. Standards provide requirements for functionality, quality, safety and environment in various areas, systems and equipment. These are mainly based on applications from industries and other standards.

The operator is also legally obliged to establish internal requirements; these may be based on the regulations mentioned above. An example of this is the establishment of performance standards given by § 17 in the Management regulations (PSA, 2014).

2.1 GDF SUEZ E&P Norge AS

EPN is part of the ENGIE Group and has been present in Norway since 2001. The company is the operator of the GJØA field and partner in several fields on the Norwegian Continental Shelf.

The GJØA oil field was discovered first in 1989; however, the production started first in November 2009. The connected reservoirs will continue producing in at least ten more years. The recently discovered Oil and Gas reservoirs found close to the GJØA platform makes it to a favourable location in the North Sea and may increase the operating lifetime to its full potential, which is about 30 years.

A tool for decision-making should capture the most distinct aspects of an organisation; therefore some internal requirements have been included, as these may give requirements for handling of "operational risk".

2.1.1 Management of Change

Technical Changes are a part of the Management of Change process, which cover all changes (organisational, technical, operational and administrative)

A process is established to manage technical changes. The figure below is collected from EPN management system.

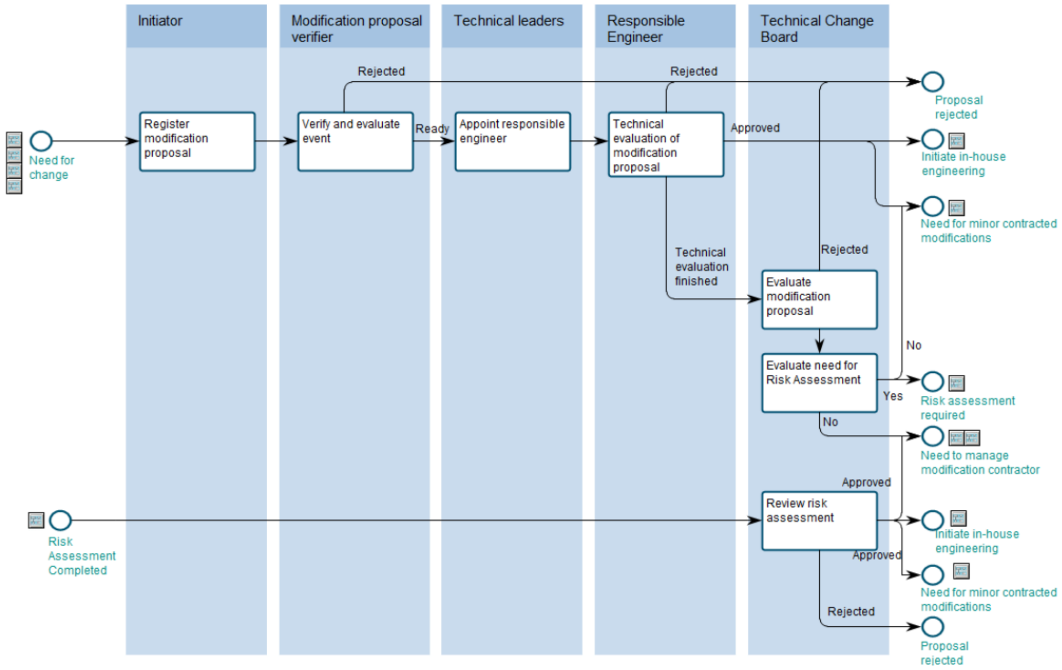


Figure 5 - Existing process for evaluation of technical changes (GDF SUEZ EPN , 2015)

The initiator of the modification proposal creates an EV05 event in COMOS, which is EPN's unified software platform for their operatorship. COMOS are a computerized maintenance management system (CMMS) and are used to structure information regarding maintenance and work in complex systems (SIMENS , 2011). The system has several purposes.

- To help operators and engineers to do maintenance more efficiently
- To help engineers and managers making informed decisions

In EPN the initiator of a modification proposal should include enough details such that the evaluation process can be done based on the input provided. The next step is that the manager shall evaluate the quality of the proposal. If the quality and relevance are considered acceptable, the proposal is forwarded to a *discipline* engineer. The appointed engineer performs a technical evaluation of the proposal, at this stage the proposal can be rejected or sent for further evaluation. When the technical evaluation is finished, the modification proposal is evaluated in a Technical Change Board. If the proposal is accepted, it is evaluated whether a risk assessment is required or not. Risk assessments should be conducted to give the necessary support to decision-making or further detailing of a proposal. Depending on the outcome, the proposal is; rejected, sent to in-house engineering or contractor.

2.1.2 Risk Management

This section does not cover all the aspects of risk management in EPN. This section covers relevant requirements in an ALARP process. The identified requirements are related to risk reduction measures and risk acceptance criteria's (GDF SUEZ, 2011). Where risk reduction principles gives guidelines on how to implement risk reducing measures, and risk acceptance criteria's indicates what "acceptable" risk is.

Risk-reducing measures (RRM)

Internal requirements state that RRMs shall be implemented without further assessments of benefits and burdens if the RRM is required to comply with internal or external requirements, including internal risk acceptance criteria and regulatory requirement. (GDF SUEZ, 2011)

However the implementation of RRM, are split into three stages described below.

Direct implementation; shall be performed if compliance with internal or external requirements not are achieved. Internal requirements include internal risk acceptance criteria and regulatory requirements.

Coarse analysis; shall be performed as a coarse qualitative analysis to evaluate the burdens and benefits of a risk-reducing measure. *"perform a coarse analysis of benefits and burdens, addressing attributes related to feasibility, conformance with good practice, economy (costs), strategic considerations, risk, social responsibility, etc. The analysis should be qualitative and its conclusions summarized in a matrix with performance shown by a simple categorization system such as 'Very positive', 'Positive', 'Neutral', 'Negative' and 'Very negative'."* (GDF SUEZ, 2011, p. 8)

More detailed analysis; "*if the costs are considered as large, the risk-reducing effect should be quantified, and an economic analysis performed (cost-benefit or cost-effectiveness analysis). If the expected net present value of a measure is positive, the measure is to be implemented. Otherwise, the expected cost per expected number of averted fatalities of the measure shall be calculated and evaluated."* (GDF SUEZ, 2011, p. 9)

Further, it is stated that; "*RRMs shall be selected based on an individual as well as on an overall evaluation. RRMs may, for example, be related based on the common influence on*

DSHAs, safety barriers, area at the facility, activity, and a group of personnel exposed." (GDF SUEZ, 2011, p. 9)

Risk acceptance criteria

EPN has established both Semi-quantitative and quantitative risk acceptance criteria's; however quantitative criteria's are not relevant for the purpose of this thesis as they are based on accurate tolerance limits. The semi-qualitative criteria's are providing a measurable scaling of the severity in the following consequence categories; risk to people, the environment, financial assets and reputation.

Harm to people categorizes how accidents and occupational illness to people may affect them. The category covers multiple fatalities to small injuries that can be solved on site by medical treatment.

Assets include damages or other consequential business losses up to a month.

The category related environmental damage includes both financially and commercial effects and vary from international assistance to local clean up.

Impacts on reputation are related to public attention, and should not be confused with environmental damage. Reputation is related to policies, licenses, and taxes.

	RISK ASSESSMENT MATRIX								
SEVERITY	CONSEQUENCE				LIKELIHOOD				
	People	Assests	Environment	Reputation	A Unlikely Never heard of in E&P industry	B Possible Heard of in E&P industry	C Sometimes Incident has occured in DEP	D Regularly Happens several times per year in DEP	E Often Happens several times per year in the afiliate
0	No Health effect / injury	No Damage	No effect	No reaction			**Low Risk**		
1	Minor Health effect / injury (first aid / MTC)	Minor damage Production loss non record table Cost < k€	Minor effect Onsite response/Fully contained Spill < 1 bbl	No public concern - Local Echoes			**Medium Risk**		
2	Moderate health effect / injry (Single LIT without PPD (1)	Moderate damage Production loss less than 1 day Cost < 100k€	Moderate effect Onsite response Spill > 1 bbl	Local Public concern - Local Press - Regional echoes				T?	T?
3	Serious health effect / injry (LTI with PPD/Multiple LTI)	Serious damage Production loss less than 1 week Cost < 1000 k€	Serious effect Third Party assistance Spill > 500 bbl	Regional public concern - Regional Press and TV - National echoes			**High Risk T?**	T?	T
4	Major health effect / PTD (2) or Fatality or Multiple LTI with PPD	Major damage Production loss less than 1 month Cost < 10 000 k€	Major effect National assistance Spill > 5 000 bbl	National public concern - National Press and TV - International echoes		T?	T?	T	T
5	Catastrophic health effect / Multiple Fatalities or multiple PTDs	Catstrophic damage Production loss lover 1 month Cost > 10 000 k€	Catastrophic effect International assistance Spill > 100 000 bbl	International Public attention - International Press and TV	T?	T?	**Intolerable Risk T**	T	T

Figure 6 - Qualitative risk acceptance criteria's (GDF SUEZ EPN , 2015)

Figure 6 illustrate the Risk Assessment Matrix, which standardizes qualitative risk assessment and facilitates the categorization of risks in the four domains: people, assets, environment and company reputation.[1]

[1] PPD = Permanent Partial Disability
PTD = Permanent Total Disability
LTI = Lost Time Injury

2.1.3 Maintenance strategy

A set of main principles for maintenance strategy are established. The general rule is that maintenance shall be performed in accordance with modern principles of maintenance management (GDF SUEZ EPN, 2013). The section below covers the main objectives for Maintenance Management on the GJØA facility.

Maintenance strategy can be summarized as the methods used to achieve the maintenance objectives. Objectives are the targets accepted by the management and maintenance department. These targets may include availability, cost reduction, product, quality, environment, preservation and safety (Norsk Standard, 2010).

Safety for Personnel and Environment

> *EPN's HSE vision is to strive towards no harm to people, environment or assets.*
>
> *Maintenance shall aim to prevent major accidents, and safety critical equipment shall be prioritized. Necessary procedures shall be established in order to keep control with this equipment.*

Facility Integrity

> *Technical department is responsible for the technical integrity of Gjøa platform, systems and equipment.*
>
> *Technical department shall be kept at a high level. Necessary systems for inspection/maintenance and reactive efforts shall be implemented to secure the integrity.*
>
> *The risk aspect is managed through an ALARP approach and is to be mitigated through the inspection and maintenance program.*
>
> *Life Cycle Cost evaluations shall form a strategy throughout the lifetime of the facility and is used to decide which activities are to be performed at what stage in this cycle.*

Reliability on Equipment

> *Functional failure on safety critical equipment shall be risk assessed, documented and necessary actions to be taken. Corrective tasks shall be performed within the time limit.*
>
> *Functional verification of safety functions shall be done within the interval of the task. If the job is not done in time (backlog), the risk shall be assessed; documented and necessary actions shall be taken.*

System Regularity

> *Design regularity is given by the regularity analysis.*

Actions shall be taken to optimize the regularity based on historical date and cost benefit.

Maintenance Effectiveness

Maintenance effectiveness shall be evaluated systematically based on recordings in CMMS. These results shall be used to continuously update the maintenance program or to initiate modifications-

Cost Effectiveness

Cost effectiveness shall be the basis for all maintenance activity decisions concerning production or other critical equipment.

For HSE issues, cost-effectiveness shall be used utilizing the ALARP-principles.

Several of the above-mentioned requirements are high-end goals and do not give a straight answer on how to perform an evaluation. The use of ALARP as an approach is transparent in the maintenance strategy and will therefore be essential to the discussion of implementation.

Cost efficiency in the selection of solutions and alternatives are defined as an important contributor to achieve; availability, cost reduction, product quality, environment preservation, and safety.

2.2 Statutory framework

The supervision of the Norwegian legislation is divided between different supervisors. Both NPD (Norwegian Petroleum Directorate) and PSA are subjected the Oil and Energy Ministry. NPD has the responsibility for resource management, and PSA has the responsibility supervising the working environment and safety level on the NCS. They have relevant requirements that "cross" each other that needs to be highlighted.

Act about petroleum activates, which is enforced by the NPD, states the following (NPD, 2015).

Chapter 9.
Special requirements to safety

§9-1 Safety; The petroleum activities shall be conducted in such manner as to enable a high level of safety to be maintained and further developed in accordance with the technological development.

This indicates that the safety level shall be developed in accordance with available technology whenever possible to reflect an acceptable safety level.

PSA have the responsibility for the Framework Regulations and give requirements regarding continuous improvement, and that all operators on the NCS shall establish a process to reduce operational risk to a level lower than required (PSA, 2013).

§11
Principles for risk reduction

Harm or danger of harm to people, the environment or material assets shall be prevented or limited in accordance with the health, safety and environment legislation, including internal requirements and acceptance criteria that are of significance for complying with requirements in this legislation. In addition, the risk shall be further reduced to the extent possible. In reducing the risk, the responsible party shall choose the technical, operational or organisational solutions that, according to an individual and overall evaluation of the potential harm and present and future use, offer the best results provided the costs are not significantly disproportionate to the risk reduction achieved. If there is insufficient knowledge concerning the effects that the use of technical, operational or organisational solutions can have on health, safety or the environment, solutions that will reduce this uncertainty, shall be chosen. Factors that could cause harm or disadvantage to people, the environment or material assets in the petroleum activities, shall be replaced by factors that, in an overall assessment, have less potential for harm or disadvantage. Assessments as mentioned in this section shall be carried out during all phases of the petroleum activities.

The principle mentioned above is usually referred to as the ALARP principle. Some of the benefits and burdens related to this process are highlighted in Chapter 3. However, the concept and intention of this process is to identify risks independent of assessment type or consequences. ALARP gives nor guidance for how to achieve goals stated in laws, regulations, standards, best practice, etc. (Vinnem, et al., 2006).

The management regulations is also enforced by the PSA and demand that the company shall develop acceptance criteria's requirements for major accident risk and environmental risk (PSA, 2014).

§ 9

Acceptance criteria for major accident risk and environmental risk

The operator shall set acceptance criteria for major accident risk and environmental risk.

Acceptance criteria shall be set for:
a) the personnel on the offshore or onshore facility as a whole, and for personnel groups exposed to particular risk,
b) loss of main safety functions as mentioned in Section 7 of the Facilities Regulations for offshore petroleum activities,
c) acute pollution from the offshore or onshore facility,
d) damage to third party.

To clarify, the risk acceptance criteria can be defined as "criteria that are used to express a risk level that is considered as the upper limit for the activity in question to be tolerable, Risk acceptance criteria are used in relation to risk analysis and express the level of risk tolerable for the activity, and is the starting point for further risk reduction according to the ALARP-principle" (NORSOK, 2001, p. 13)

The connection in interest between the Framework Regulations and the Management regulation is that the Management regulation gives a maximum allowance for risk acceptance criteria. Hence, the ALARP regime applies first after the risk acceptance criteria have been defined.

For reference the Management Regulations §5 can be included, which gives requirements for maintaining quality of barriers throughout the whole lifetime of a facility, and §11 that state that decisions problems concerning HSE are versatile and should be considered from several stakeholders view. Decision criteria's should, therefore be based on common measures, strategies and requirements to HSE. All assumptions form the basis for a decision to be expressed so that they can be followed up.

Stakeholders may be defined as "people, groups, owners, authorities etc. that have interest related to the decisions to be taken. Internal stakeholders could be the owner of the installation, other shareholders, the safety manager, unions, the maintenance manager etc., whereas external stakeholders could be the safety authorities, environmental groups, research institutions etc." (Aven & Vinnem, 2004, p. 5).

2.3 Industry standards.

At the beginning of the 1990’s, the government and industry joint together in an attempted to reduce the cost on the NCS. The purpose of this was to increase NCS competitive ability in the world market (Raza, 2015). The result of this is what today is referred to as the NORSOK standard (NORsk SOkkels Konkurranseposisjon).

The NORSOK standards are developed by the Norwegian petroleum industry to ensure satisfactory safety, value adding and cost effectiveness for petroleum industry expansions and operations. Moreover, NORSOK standards are in so far as possible intended to replace oil companies specifications and serve as references in the authority’s regulations. Many of the requirements are based on NS, ISO, IEC, API and DNV standards.

However today, 20 years later there exist no effective requirements for selection how to proceed with the choice of risk-reducing measures. NORSOK Z-008 expresses “*Risk-based decisions have to be done against defined criteria. The definition of the criteria should be done by overall company policy for HSE, production and cost. The criteria shall be properly defined and communicated.”* (NORSOK, 2011, p. 13). With further reference to both NORSOK Z-013 and ISO 17776.

NORSOK Z-013 gives reference to a traditional risk matrix. However, the use of these not avoided criticism in regards to evaluating how the risk-based decisions should be handled.. Both Abrahamsen & Aven (2008), and Aven & Flage (2009), express the opinion that risk-based decisions should exceed expected values. A more detailed presentation is provided in Chapter 3. It should be noted that NORSOK Z-013 sets a minimum requirement of areas that should be evaluated for in the ALARP evaluation process.

A wide range of standards are available, which set technical requirements for planning, design, construction and operation. HSE, for example, are covered by the following NORSOK Standards; S-001, S-002, S-003, S-005, S-006 and S-012.

3 Theory

This chapter introduces several topics that are of interest to make a tool for decision support in the selection of modification proposals. This will require looking further into;

- The importance and interface of operation and maintenance management. The purpose of this is to describe why we should focus on maintenance and what consequences that can be expected if maintenance and modifications are ignored.
- How ALARP and risk acceptance criteria are applied in decision-making. Identifying challenges and applications based on previous research.
- Theories regarding Multi-attribute theory and the steps required for implementation.
- Decision theory.

3.1 Operation and maintenance management

To understand the problem it has to address the current situation from a specific risk management point of view. Traditionally risk management is defined as "*all measures and activities carried out to manage risk*" (Aven, 2009, p. 6). However, it would be too extensive to cover all areas in this thesis, as there are three areas of risk management (Aven, 2009).

- Strategic risk, which include the long-term strategy and plans that can compromise the organization's visions and goals.
- Financial risk: that is limited to the factors outside the entities control, which can affect the financial situation to the enterprise.
- The last theme that will be covered is Operational risk. To get a broader understanding of the term the BASEL II definition can be applied, "*risk of a change in value caused by the fact that actual losses, incurred for inadequate or failed internal processes, people, and systems, or from external events (including legal risk), differ from the expected losses*" (BASEL, 2001, p. 43). Which indicate what the actual consequences can be large, but ultimately leading to financial loss.

Hence, operational risk is related to day-to-day operation and the conditions that can lead to changes in the planned operating situation. This may be related to shortcomings or errors related to barriers.

The use of barriers as a conceptual approach to the management of major accidents has been an established practice in the industry for a long time. In connection with the handling of major accidents, barriers are used to prevent accidents and minimize the consequences of an accident that could develop into "major accidents". Barriers are implemented to reduce the likelihood of an event occurring, or reduce the consequences (PSA, 2013).

By simplifying, we can say that barriers are designed to prevent undesirable events. Barriers have several different definitions. Many definitions have been used to define what barriers really are, NORSOK S-001 defines barriers as a safety function that is a “physical measures that reduce the probability of a situation of hazard and accident occurring, or which limit the consequences of an accident” (NORSOK, 2008, p. 10). ISO 17776, defines barriers as; “Measure which reduces the probability of realizing a hazard’s potential for harm and which reduces its consequence Note: Barriers may be physical (materials, protective devices, shields, segregation, etc.) or non-physical (procedures, inspection, training, drills, etc.)” (ISO, 2010, p. 1) and thereby include non-physical barriers. The PSA refers to barriers as **t**echnical, **o**perational and **o**rganizational elements that individually or in combination will reduce the possibility of specific errors, accidents and emergencies occur, restrict, or prevent damage / disadvantages. (PSA , 2015)

Technical barriers are the most common barriers. These are mainly divided into active and passive barriers (Statoil, 2010). Examples of these can be process control systems, fire and gas detection systems, explosion protection and ship collision barriers. Examples of probability reducing barriers may be related to containment. Consequence reducing barriers may be firewater systems that minimise the escalation of fire. In some contexts, the terms preventive (reducing probability) and reactive (consequence reducing) barriers are used.

None of the technical barriers are fully functional on their own. Humans are necessary both for design and for the operation of the technical systems. (PSA, 2013). Human and operational barriers are an essential part of a risk management system and are linked to competence, communication, and compliance with procedures.

The last barrier is the organizational barriers. These reflect the way business is organized and the strategies and methods used to prevent e.g. major accidents. Examples of organizational barriers are work processes, procedures, reporting lines and responsibilities.

The term barrier strategy can be described as the result of a process that, on the basis of the risk picture, describes and clarifies the barrier functions and elements to be implemented to reduce risk (PSA, 2013). The requirements for the different individual barriers are set performance requirements. The performance requirements give specific requirements for how the various barriers shall work. It can include parameters as availability, capacity, effectiveness, integrity, mobilization time, reliability and robustness.

For further reading regarding principles for barrier management in the petroleum activities and human and organizational aspects of barriers and fault tolerance, see e.g; PSA (2013), and Sintef (2002).

3.1.1 Why maintenance?

One of the main purposes of maintenance activities is to reduce the risk of accidents, which may influence health and safety, environment or assets. In a production assurance and safety setting, "*risk refers to uncertainty about and severity of the consequences (or outcomes of) and activity with respect to something that humans values*" (Aven & Renn, 2009, p. 2).

To make sense to the definition, three consequence dimensions of consequences can be defined, and summarised within the following categories, and represent the main categories of consequences within an offshore production context (Vinnem , 2007)

Personnel risk

- Fatality risk and injury risk, which respectively are highly related to major accidents and occupational accidents.
- Impairment risk, which is chiefly related to the impairment of physical mechanisms as safety functions or barriers.

Environmental risk

- Expected value of spilled amount
- Frequency of events with similar consequences for the environment, this includes leaks from production and contamination from produced water and other releases.

Asset risk

- Material damage risk which include structures and equipment
- Production risk, with focus on production delay (loss) or events with similar consequences.

These are all incentives for performing maintenance and modifications.

Equipment, systems, and processes degrade due to wear or time. (Raza, 2015) Hence, we can say that the when the risk exposure increases the technical integrity decrease and can ultimately lead to non-desirable consequences.

Design life is defined based a system's various features, operation, and maintenance. A system will as a result of time or use, be exposed to degradation processes. Degradation processes intensify towards the end of the design life and into life extension. Aging can be divided into aging needs, aging technology and functional aging. Aging of the needs arise from the development requirements that are beyond the assumptions that the system was designed for, aging technology by new technology that challenge the old technology and functional aging by the system's function and / or performance decrease. (SINTEF, 2008)

In reliability engineering, the bathtub curve is widely used. Figure 7 describes that a functions failure rate z(t) may vary through its lifetime of a component, or equipment.

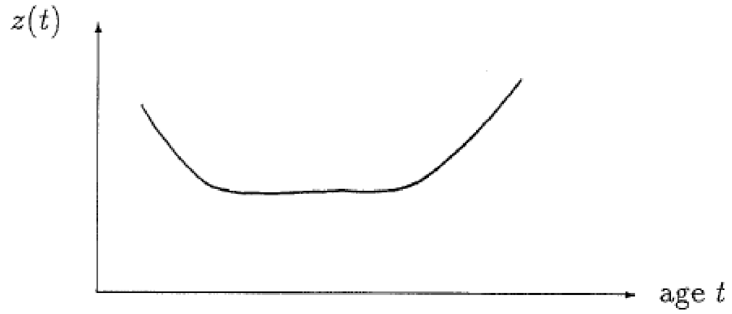


Figure 7 - Bath-tub figure is describing failure rate z(t,) as a function of time t. (Aven, 1991, p. 256)

The first part is a decreasing failure rate, the infant failure rate is high but decreases as defective sources are identified and discarded, known as early failures. After this, it is shown a constant low failure rate, through the main lifetime of a function. During the wear out time, it is possible to see that the failure rate is increasing.

It should be noted that this not are a valid concept for all functions, but can representative in the fire and gas detection example provided in Chapter 1.

Therefore, looking at maintenance activities from another perspective, the role of maintenance and modifications is to compensate for unreliability and loss of quality affected by, human errors, accidents, unreliability and/or statutory requirements. This may be linked to Asset Integrity Management (AIM) which can be defined as "the ability of an asset to perform its required function effectively whilst safeguarding life and the environment" (Rao, et al., 2012).

From this it can be deduced that AIM are related to several independent activities carried out in order to optimally integrate and maintain design, operational and technical integrity of an installation throughout its intended life to maximize return on the investment. (Raza, 2015)

It will not be the purpose of this thesis to suggest how this could be implemented in EPN, it is stressed that it is required to see this as important part of the overall evaluations as this may lead to achieving a better asset integrity program and higher levels of product assurance and safety. This also includes other operational goals and adding, extending the life of aging assets. (Rao et al., 2012).

Further, this may be seen against barrier management systems, which can be used to understand how barrier elements and different failures may influence barrier systems and barrier functions as a whole.

3.1.2 Types of maintenance

To control undesirable outcomes in operation, several types of activities can be carried out. Maintenance and modifications are two of these. Maintenance are divided into several categories (Norsk Standard, 2010), which also modifications are. Modifications are usually classified within cost categories based on investments, and maintenance is classified depending on urgency. Figure 8 illustrate how maintenance and modifications can be divided.

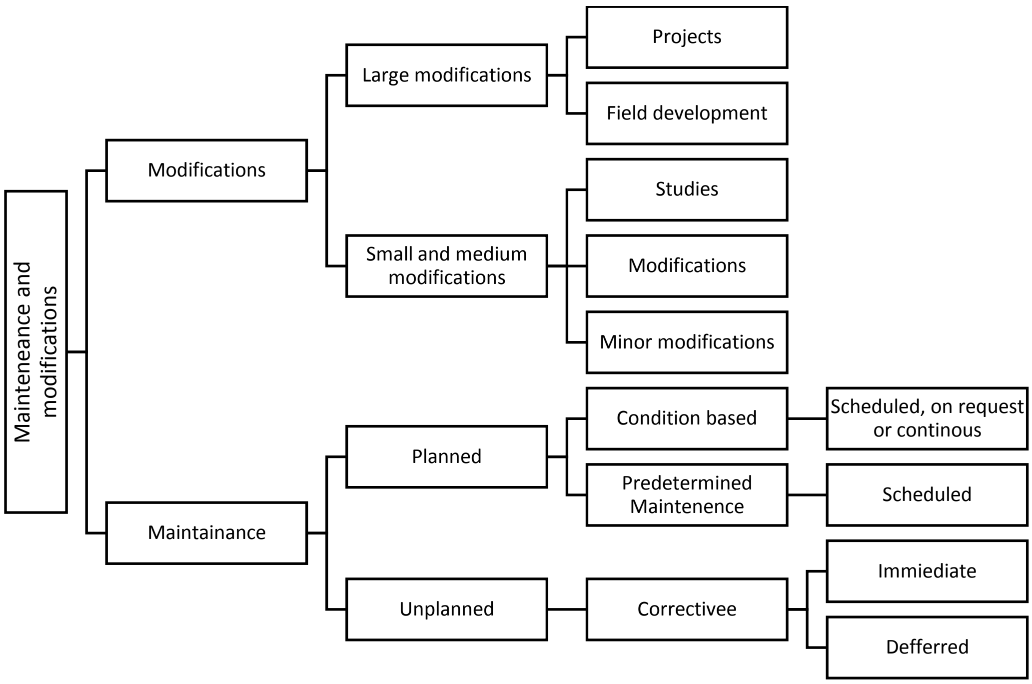


Figure 8 - Maintenance and modifications hierarchy are describing how different types of activities can be divided.

Maintenance can be distinguished into unplanned and planned maintenance.

Planned maintenance is carried out to reduce the probability of failure. Corrective maintenance is also a part of planned maintenance in a situation where preventive maintenance not is applicable. An example of this can be where redundancy and backup systems are available (Raza, 2015).

Unplanned maintenance is limited to corrective maintenance, which is carried out when a fault on equipment are detected. Unplanned maintenance is related to breakdown, repair or 1corrective work, and when backup equipment is not available (Norsk Standard, 2010).

- Planned maintenance
  - Condition based maintenance, which requires condition monitoring, inspection and/or testing to ensure satisfactory state.
  - Predetermined maintenance, which is carried out as a forecast, as per requirements, time or other known characteristics.
- Unplanned

- Deferred corrective maintenance is not immediately carried out, but delayed by given requirements. Where, e.g. Backup systems are available.
- Immediate corrective maintenance is carried out whiteout delay after a fault has been detected. This may be in situations where backup systems are not available.

There are several statutory regulations requirements affecting the maintenance, and maintenance management directly or indirectly, both the management regulation, activity regulation, and facility regulation give requirements that influence maintenance. However, it is beyond the purpose of this thesis to discuss how EPN should approach different types of maintenance (condition-based maintenance, risk-based maintenance, corrective maintenance and preventive maintenance) and how they could be applied. For further reading on this subject, see e.g. “Vedlikehold for å forebygge storulykker” (SINTEF, 2008).

Sometimes, it is not desirable to continuing regular maintenance; this may be when performance, reliability or cost are not achieving its requirements as illustrated in Figure 9. An alternative can then be to design out maintenance. This will include a trade-off between several factors, such as the cost (total), technology, reliability, capacity, willingness to pay, payback, discount rates, etc. (Raza, 2015).

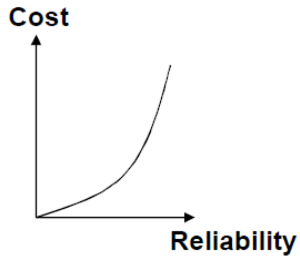


Figure 9 - Cost and reliability (Raza, 2015)

A third option may be in situations where the risk and criticality may not be found acceptable. Risks can be treated differently; avoidance, reduction, retention, and transfer can be done depending on the organisational strategies and preferences (Aven, 2009). In an operational context, this can be translated into one the following potential actions.

- Ignorance
- Maintenance
- Re-engineering
- Engineering

By summing up all the activities above, we can see that maintenance management are used to keep a facility “healthy”, by utilizing knowledge about disturbance constraints to prevent anomalies and unwanted events. Factors as capital, competence, resources and information are used to ensure quality, reliability, and availability in the process. (Raza, 2015)

Figure 10 provides a qualitative representation of the importance of maintenance to maintain the desired system performance. By the system's desired performance, means both maintaining the desired performance level and protecting the safety aspects. (SINTEF, 2008)

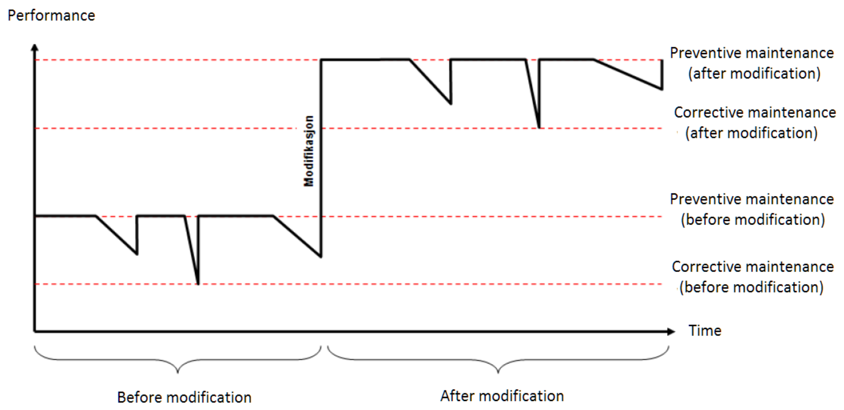


Figure 10 - Performance and modifications (SINTEF, 2008)

Before a modification, preventive maintenance ensures the desired performance. When unforeseen events occur, corrective maintenance is performed to restore the desired performance. A modification may cause the performance level to increase. The modification can, for example, be a replacement of an engine. After modifications, the performance of the engine may be found at a higher level than before the modification. Preventive and corrective maintenance still have the same function as before the modification.

The reduction in performance is a consequence of the degradation mechanisms occurring. The challenge is to have good maintenance management, which makes it possible to detect error development at an early stage. In this way, preventive measures should be set in motion to bring the system back to the desired performance. Modifications are not considered to be part of the maintenance management but are nevertheless an important part of improvement efforts (SINTEF, 2008).

3.1.3 When needs meet opportunity

By applying theory regarding project management, modification proposals may be classified as successful by meeting one of the following criteria's (Wyoscki, 2014)

- Increasing revenue
- Avoiding cost
- Improving service

Modification proposals can be proposed as need-based or opportunity based, proactive and reactive trough on of the following substances (Raza, 2015);

- Operational conditions; which require changes as the process or other external conditions change over time. An example of this may be Low-Pressure production, or gas lift to increase production from existing wells or reservoirs.
- Change in Requirements; which are given by changes in internal requirements, standards or authorities. See Chapter 1.1 for examples.
- Input from personnel; if there are concerns regarding the existing solutions or the current solution not can be found acceptable, personnel can provide proposals.

These changes can be divided into categories such as risks and opportunities. Handling of decision risk can be done as mentioned in the previous section trough; avoidance, reduction, retention or transfer and decision opportunities can be handled in two ways (Keenay, 1992).

- Converting an existing decision problem into an opportunity.
- Create opportunity from scratch.

The first alternative may be considered as more demanding than the latter one, as problems usually are related to negative outcomes. However, we will introduce some theory regarding this issue in Chapter 3.4

Opportunity may be defined as "*an uncertainty that could have a positive effect leading to benefits or rewards*" (Hillson, 2010, p. 28). Which may be seen as another angle of risk, where risk are related to negative impacts and opportunity is related to positive impacts. A broader discussion regarding that it is a misconception that risk refers to only negative outcomes only can be found in e.g. Aven (2010).

3.1.4 Portfolio management

Maintenance and modifications have a common link; organizations are required to enable plans to prioritize investments and available resources (people). The money necessary to realize projects can exceed the funds available. The allocated resources set clear restrictions on the amount and size of maintenance and modifications that can be carried out. As a consequence, the organization (from now on described as decision-maker) should distinguish between which proposals are to be funded or not.

Prioritising between projects require consideration of several factors as money, resources and strategies. This is the basis for portfolio management, which can be defined as; "*…establishing the investment strategy of the portfolio, determining what types of projects can be incorporated in the portfolio, evaluating and prioritising proposed projects, constructing a balanced portfolio that will achieve the investment objectives, monitoring the performance of the portfolio, and periodically adjusting the contents of the portfolio to achieve the desired results*" and consist of the following five phases (Wyoscki, 2014, p. 596).

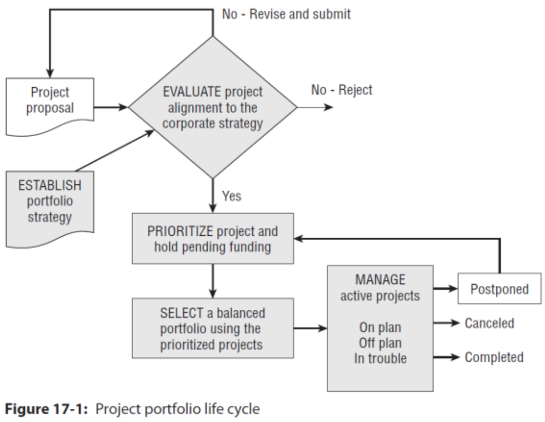


Figure 11 - Project portfolio life cycle (Wyoscki, 2014, p. 597)

1. Establish – A portfolio or project strategy should be enabled to see which projects fit into the portfolio.
2. Evaluate – Each project should be evaluated with regards to the portfolio strategy (ex. maintenance strategy). Determining whether the project is aligned or not.
3. Prioritize – the identified projects that are aligned with portfolio strategy should be evaluated against a set of criteria's to establish a prioritization. (See Chapter 4.1 and 4.2 for further reading).
4. Select – based on the information gathered, urgency, risk, resources, etc. have to be considered. The mix of projects in the portfolio, which is linked to the skills and resources required to achieve the goals. This can also be used to ensure a healthy mix of projects.

Table 1 - Portfolio overview management

Project focus	New	Enhancement	Maintenance
Strategic			
Tactical			
Operational			

The columns refer to whether a project proposes to develop a new application, enhance existing process or to fix detected errors. The rows classifies projects based on role in the enterprise, strategic which is related to critical elements, tactical which is related to changing or replacing existing processes, and operational which is related to improvement of efficiency of existing business processes.

5. Manage – follow up the status of projects and control deviations from the plan through KPI's (Key performance index), etc.

Projects are usually split between a planning phase and an implementation phase. In the planning phase, all clarifications regarding the scope of work are prepared. Through feasibility studies, concept studies and front-end engineering design, the project is matured such that the projects are ready for a decision. An important part of the preparation phase is providing good, realistic estimates, and that should reflect scope, performance and cost for the project (NPD, 2013).

A collaborative project implementation model is used in the NCS and involves multiple decision stages during the project's lifetime. Various forms of quality assurance and support are carried out prior to the start of each phase, both internal and external. The internal assistance compromise technical quality, as well as multidisciplinary and commercial quality of the project based data from other projects the supervisor has insight into. Quality assurance can also include external support (NPD, 2013).

Figure 12- Typical phases of project lifecycle (NORSOK, 2004)

Figure 12 show a typical sequence of projects on the NCS. Starting with an appraisal phase where key info and executing unit are identified. Feasibility and Concept studies are performed during the maturing phase to ensure development of a design that is appropriate for the use. Front-end engineering (FEED) have a slight higher focus on technical requirements and are required to avoid significant changes during the execution phase.

Engineering is the execution of all relevant documentation and packages, construction are performed wherever the project is prefabricated and installed. Commissioning prepare the project for hand over to operation.

3.2 ALARP and Risk Acceptance Criteria

Chapter 2.3 on the use of risk reduction principles introduces the difference between ALARP and Risk acceptance criteria. Thus, this will not be repeated in this chapter. However, we will focus on the actual implementation and enforcement of the ALARP and risk acceptance criteria's in decision-making.

Several decision tools are available. However, they rely heavily on expected values and may be hard to use. They, therefore, might give the wrong understanding in a decision context. Aven & Flage (2009), mentions several approaches are commonly used to approach the ALARP principle;

- Expected Utility Paradigm
- Cost-benefit Analysis
- Multi-attribute Analysis
- Cost-effectiveness analysis

All of the tools above can be used in a decision-making process. However, they may be challenging to use, and their utilization may be limited. Another challenge is that some of the methods reflect opportunities in a low extent, that which may be crucial in a decision-making context.

In theory: if it were possible to use pre-defining requirements, goals and risk acceptance criteria it would be easy to decide whether costs were appropriate/corresponding to proceed with a modification proposal or not. However, the use of pre-determined criteria's have been criticized as the following two problems are identified (Aven & Vinnem, 2004)

- The introduction of pre-determined criteria's may give the wrong focus as satisfying these criteria rather than obtaining overall good and cost/effective measures are decisive.
- The risk analysis used to check whether the criteria are achieved does not in general have a sufficient precision level for such a mechanical use of criteria.

Since the concept of ALARP and Risk Acceptance Criteria's were introduced on the NCS in 2002, companies have interpreted the Frame Agreement §9 differently. A study performed on behalf of the PSA concludes the industry practice the application of the ALARP principle different even though the requirements are clear (Vinnem, et al., 2006). Even though this study was performed nearly ten years ago, it is still relevant; as many new operators have entered the NCS since the report were made.

The ALARP principle implies an inverted burden of proof, i.e. that a risk-reducing measure that shall be implemented unless the burdens and benefits are of great disproportion (Vinnem, et al., 2006). However, it is hard to determine exactly where these boundaries are; companies are therefore required to establish a lower risk acceptance criterion. The connection between ALARP and Risk Acceptance Criteria is that Risk Acceptance Criteria give a maximum “allowance” for Risk. Hence, the ALARP regime is initiated after the risk acceptance criteria have been defined. Nevertheless, what determines what is reasonably practicable? Does it depend on what is physically possible? Alternatively, can it be scaled different way?

The crux of the matter is related to *gross disproportion.* The chance of having an insignificant risk compared to the sacrifice of implementing measure is the critical point of for decision makers. When is safety improvement costly to implement? Will the use of ALARP lead to a sub-optimal solution, as the society weight externalities more than a particular company? (Aven & Vinnem, 2004). As an approach Jones-Lee & Aven (2011), have made four justifications for the gross disproportion when the cost exceeds benefits,

1) Other possible benefits of safety improvement; which refer to indirect gains, e.g. externalities, which may not be apprehended adequately if only the direct gains of those who take advantage of the safety improvement are included
2) Uncertainty may not be apprehended satisfactory; this requires the decision maker to make margins beyond expected value connected with future benefits and costs.
3) When public are exposed to high levels of baseline risk, the Willingness to Pay should be adjusted, to reflect the increase in risk corresponding to the increasing risk level.
4) Some decision makers may try to avoid the implementation of RRM by exaggerating its costs. By adjusting the uncertainty related to the effect of the RRM, the ALARP principle may incentivising cost-efficiency and engineering of the improvement.

Several of the approaches to the ALARP as a risk management principal have been subject to strong criticism (Aven & Vinnem, 2004). Philosophical pitfalls related to the transformation of non-economic consequences are present, example; (expected) loss of lives, damage to the environment and objections to the formal treatment of values and weights. What is the value of a (statistical) life? What is the value of future generations? ALARP does not give a straight answer and the answer depending on a high degree of subjective judgments. Thus, two alternatives for an approach to the ALARP principle to support decision-making are proposed. (Aven & Kørte, 2003)

- Decision-making should be performed by identifying alternatives, outcomes, uncertainty and values, alternatives which maximize criteria related to certain objectives or goals should be chosen.
- Decision making should be performed as a process by formal risk and decision analysis followed by a management review.

Several methods used for decision-making in ALARP context are listed in the preface of this chapter. It will not be the purpose of this thesis to examine all available methods for implementing ALARP in decision-making. However, some of the surrounding tools for decision making on the NCS will be illuminated further.

Expected Utility Theory and Rank dependent theory

Expected utility theory is based on that a person will preference an alternative based on certain axioms. Von Neumann-Morgenstern introduced four axioms of the expected utility theory, which defines a rational decision maker (Neumann & Morgenstein, 1953). The following points are gathered from the Wikipedia article on Expected Utility Hypnotises (Wikipedia, 2015), as they are plain to understand in a practical coherence, the additional theory regarding rank dependent utility is collected from Abrahamsen & Aven (2008).

- *"completeness* assumes that an individual has well-defined preferences and can always choose between any two alternatives"
- *"transitivity* assumes that, as a person decides according to the completeness axiom, the individual also choose consistently"
- *"independence* also concerns to well-defined preferences and assumes that two gambles combined with a third one maintain the same preference status as when the two are presented individually for the third one"
- *"continuity* assumes that when there are three alternatives (A, B and C) and the decision maker favours A to B and B to C, then there should exist a reasonable order of A and C in that the individual is then indifferent among this mix and the alternative B."

Depending on the achievement on these axioms, the alternative with the highest expected "utility" should be chosen. The rank-dependent theory states that a decision maker always will select the alternative with "highest rank" as the best alternative. The idea of the rank-dependent utility is to overweight low probabilities and underweight high probabilities.

The Rank dependent utility is based on a set of axioms in the same method as expected utility theory. The difference is separating the independence axiom (expected utility theory), and the *conomotonic* axiom (rank-dependent lottery) is that given there are two lotteries A and B with a common consequence and lottery A are favoured above B, then the preferences may be changed if a consequence is replaced by a common consequence so long as the ranking of the common consequence changes. If preferences switch, monotonic independence is not disrupted. (Abrahamsen & Aven, 2008).

By approaching risk acceptance criteria (and the ALARP principle as mentioned in the previous chapter) with the expected utility theory and rank-dependent theory, the risk acceptance criteria may seem irrational, as it may not be irrational. Extreme consequences may therefore be found acceptable when comparing alternatives in a decision situation. (Abrahamsen & Aven, 2008) Expected utility theory does neither capture events with low probabilities and high consequences (Aven & Flage, 2009) which may be linked to Black Swans theory (Norsk Olje og Gass, 2014).

Expected utility theory and expected utility analysis should not be confused, as expected utility theory provide a normative view of how a decision should be undertaken, and expected utility analysis is the analysis being performed itself.

Expected utility analysis

The starting point of expected utility analysis (EUA) is to calculate the utility of each outcome and then calculate expected value of these utilities. It may be difficult to implement EUA in a decision context. Hence, the decision maker may not be aware of the effect of the investment. The solution often tends to approach the expected utility analysis by cost-benefit analysis or cost-effectiveness analysis (Aven & Flage, 2009).

Cost-benefit analysis

A cost-benefit analysis (CBA) tries to make a quantitative evaluation of the benefits and burdens of a given decision by expressing these in a universal unit: money. There are several approaches to the CBA, but they all share a common principle. The value of a decision equals net expected benefit, minus net expected cost in the same unit, often expressed as the expected net present value (ENPV). The unit are usually money, depending on the application, other units can also be chosen. Four challenges stand out in Cost-Benefit Approach to the ALARP principle (French, et al., 2007)

- determination of prices of safety gains or damage
- the value of group and individual risk
- calculations using ‘disproportionality
- the use of discounting to trade-off risks through time

CBA requires that prices are assigned to the available criteria for the decision problem. This is usually a tender issue, as many companies do not want to label a value of statistical life, environmental damage, etc. The prices assigned are defined as Willingness to Pay (WTP) and Willingness to Accept (WTA), the following challenges establishing these parameters are identified (French, et al., 2007).

- If a company aims is to get as near to the lower tolerability limit, Basic Safety Objective (BSO) as possible. The company should be willing to pay for a (commercial) benefit that may move the risk away from the BSO. The public will be agreeable to allow compensation for taking the additional risk.
- If a company aims to get under the upper tolerability limit, Basic Safety Level (BSL), the public will be willing to pay for additional risk reduction aiming for the BSO.

Note that the expressions above are applied to the ALAPR principles in the UK, where three areas are used, rather than the two used in Norway.

Uncertainties are present and have to be taken into consideration and quantified; hence, effects related to risk aversion should be highlighted after weighting. When the risks are ‘disproportional’ extra credit to consider, any legal requirements should be made.

Costs and benefit emerge at different time intervals and are discounted to a net present value. The discount rates are uncertain and do not take into account how they changing trough time.

The closing point for this introduction is; that cost/benefits evaluations often are dependent on assumptions that only focus on certain outcomes and consequences. (Aven & Kørte, 2003)

The practicality of these theories can also be discussed, as they often are dependent on high confidence on the information regarding the expected cash flow. This can incriminate/undermine the strength of the tool. Several variations of the ENPV formula have been discussed by Aven & Flage, (2009), however no good way of balancing uncertainties and different concerns using CBA are presented. From this it is possible to extract that CBA is an objective methodology and do not necessary take subjective considerations into account, and should not be used as a primary decision basis.

Cost-effectiveness analysis

A cost-effectiveness analysis (CEA) does have many of the same characteristics as cost-benefit analysis. The output can be used to see whether the predefined objectives are met or not, this may be a towards a particular goal ex. ICAF (Implied Cost of Averting a Fatality). If the implementation of a RRM cost 2 million NOK's and the measure is expected to reduce the number of fatalities by 0.1, then the ICAF is equal to 2/0.1= 20 million NOK's (Aven & Flage, 2009). Comparing several alternatives to one another, the efficiency can be evaluated.

The output can be challenged as the quality of input data can undermine the result. A challenge with this type of analysis is that it requires the cost of a statistical life, which also may be a potential pitfall, as both ethical and societal views have to be taken into consideration. Another challenge in this context is that implementation of such criteria or safety margins may result in a very low safety investment level, as the risk and uncertainty may be high. For further reading regarding the use of CBA and CEA see e.g. (Aven & Flage, 2009).

Practical context

The use of goals, quantitative criteria's and requirements has traditionally been used to manage safety and can be structured as (Aven, et al., 2006);

- Overall goals e.g. "no accidents."
- Risk acceptance criteria (may be defined as upper limits of acceptable risk) or tolerability limits FAR (Fatal accident rate) an IR (individual risk) are two examples of these.
- Requirements related to performance of barriers (briefly described in chapter 3.2)
- Special requirements design and operation of a component.

As mentioned by Vinnem & Aven, (2004) it is argued that the use of pre-determined criteria's should be avoided, as it may lead to meeting criteria's rather than creating alternatives. As an approach, alternatives should be generated using high-level goals and the evaluation of these. However, it is stressed that requirements are required to simplify the planning process; examples of these may be safety systems and safety functions. (Aven, et al., 2006)

3.3 Multi-attribute Analysis

Multiple criteria decision making is a part of operations research that have the purpose of improving decisions making that explicitly considers multiple criteria in decision-making environments (Department for Communities and Local Government, 2009). The basis for multi-criteria decision-making is that by structuring complex problems and considering multiple criteria clearly, this will lead to more informed and better decisions (Bedford & Cooke, 1999). It is possible to identify everyday applications of multiple-criteria decision-making, an example of this trough grading, in the educational system. Hence, a wide range of approaches and methods for multi-criteria decision-making are available. The Multi-Attribute Utility Theory (MAUT) is one of them, French, et al (2007), has argued that it may be useful in ALARP decision-making

To a certain degree, differences between individuals are reflected in the weights that they place emphasis on factors or determination the probability or consequence of a random event. The multi-attribute analysis is quite simple and does to a large extent take such subjective judgments into consideration. A “multi-measure value function” allows computing an alternative’s overall desirability based on a set of evaluation measures (French, et al., 2007). “Multi-attribute utility theory” or MAUT is the study about how to analyze multi-objective decisions and will be thoroughly gone into in this subchapter.

A relative swing weighting system characterizes the MAUT; it is a method based on analyzing the different decisions problems and their impact on individuals. It is essential to examine how each decision has an impact on different goals stated by stakeholders in concern. The relative importance of the goals is determined by asking which goals that could emerge; from the worst potential achievement of that goal to the best potential achievement.

Decision problems approached by the use of a swinging weighting system, can guide to the selection of the best alternative considering the goals in the specific decision context. However, it may have some disadvantage as different stakeholders may have different priorities achieving particular goals (Aven, 2009)

In addition, MAUT can be used either in retrospect, to evaluate actual resources and projects that have been allocated or prospectively to appraise resources and projects that are proposed for execution (Department for Communities and Local Government, 2009). It will not be the purpose of this thesis to review the different methods for implementing multi-criteria utility theory, however Zanakis et, al (1999), provide an analysis of various methods and how they influence the results when applied to the same problem.

The MAUT provide an alternative methodology to CBA and CEA. The fundamental reason for using MAUT is to ease constructive discussion and challenge the key points of disagreement. This may lead to more informed and better decision. Hence, by performing a subjective evaluation the decision makers can grasp the problem addressed in an open, transparent and clear way, in contrast to using the CBA and CEA method, which may lead to the use of obsolete values. This brings us to the overall difference between CBA& CEA and MAUT. CBA&CEA assume that a value is weighted equally for all stakeholders when MAUT allows the problem to be viewed and weighted from different stakeholders and decision maker's perspectives. By performing sensitivity analysis address, the perceptions of all stakeholder groups can be included in the MAUT (French, et al., 2007)

Other benefits of using MAUT are that it can provide internal consistency and logic within an organisation. The models are usually transparent and open, which make them easy to use. The available data can also be adjusted in the MAUT model, to that degree that the decision makers choose the consequence that it finds most likely to occur. The process can also by using the MAUT model be undertaken by using reasonable time and manpower in an auditable way (Department for Communities and Local Government, 2009).

3.3.1 Implementation of MAUT

MAUT are usually implemented as a part of the decision analysis. Several approaches for implementation of MAUT are available. However to serve the purpose of this thesis French, et al. (2007), has been found appropriate, as these is directly linked to ALARP decision-making. However, they do not give any straight directions on how to apply MAUT. An alternative source has been used to see to which steps that have to be followed.

As mentioned above several methods for implementing MAUT exists, a simple additive weighting model is an attractive mathematical concept that often is easy to apply in practice (Accorsi, et al., 1999). This is also the method described in an ALARP decision context by French, et al. (2007), and has therefore been chosen.

By proposing a normative procedure for how to derive criteria's, this will be beneficial when we are structuring objectives in chapter 3. The ideas in the following subchapters are mainly collected from Department for Communities and Local Government (2009), as neither Keenay (1992), nor French, et al. (2007), provide systematic guidance for implementation of MAUT. The purpose of this subchapter is not to deduce all available angels, but provide enough reasoning to conclude a procedure.

1. Structure objectives and create attribute tree
2. Assign scores and weights
3. Combine weights and scores to derive an overall evaluation arena.
4. Conduct sensitivity analysis to see whether preferences or weights affect the overall ordering of the available options and whether the values, scores, and weights should be adjusted.

3.3.2 Structuring objectives.

The first step is to create an attribute tree, which summarize and structure the organisational objectives. This point is crucial to the outcome as the objectives will vary among different the decision contexts and organisations.

One of the purposes of this is to see how consequences and attributes can be connected. Therefore, it is assumed that consequences are specific, measurable objectives. The objectives consist of qualitative and quantitative relationships coming from the decision makers, stakeholders, and other knowledgeable individuals.

In many circumstances, assessing options on a broad criterion may prove difficult, even though the notion of e.g. the environmental impact may be significant. Obscure criteria are generally not useful in MAUT, any more than they are in CBA. The number of criteria (hereafter named attributes) should be kept low, as it is consistent with making a well-founded decision. There is no 'rule' to guide this judgement, and it will unquestionably alter from application to application. More typically a range of six to twenty attributes are suggested.

We divide mainly between 3 types of assessing criteria's. The first way is to involve decision makers and stakeholders directly in all stages. The second approach is to examine existing policies, strategies or other statements to reflect their concerns. A third way is to include different key groups during deduce of the criteria (Department for Communities and Local Government, 2009). The second approach is evaluated as suitable in this thesis. The following steps can, therefore, be used to structure objectives (Keenay, 1992).

1. Define and understand the values and goals that are relevant to the decision context, this may be a strategy or a "wish list" to see what the company aims to achieve.
2. Identify additional values communication with decision makers, stakeholder and other individuals of interest. A 'top-down' approach should be chosen to reflect the aim, purpose, mission or overall objectives that are to be achieved.
3. Look for missing values trough communication and review. This can be done as a brainstorming exercise.
4. Translate into a common format (numerical measurement, monetary, rating, or qualitative description)

A structure can be considered as acceptable when it reflects a clear, rational and shared point of view about the criteria applies to the decision context. The criteria in a multi-attribute analysis do to some degree reflect the individual measurable indicators of performance relative to the issue at hand. The groups of criteria reflect sub-objectives to the single chief objectives that underlie the MAUT process together into sound groups, each of which labels a single component of the overall problem.

When a procedure for achieving the different attributes is set, it is possible to look further into how they should be identified and defined.

Define attributes

Structured objectives provide the basis for use of quantitative modelling (Keenay, 1992). A fundamental objective hierarchy can help identifying the set of objectives and then which attributes which must be defined to know whether it have been achieved or not. An objective is a statement of something that one desires to achieve. Three features characterize objectives (Keenay, 1992).

- A decision context, described in Chapter 2.
- An objective
    - Fundamental objectives are characterized by an essential reason for interest in the decision situation (which reflects the ends it is desirable to achieve.)
    - A means objective which interests are in the decision context because of its implications on the fundamental objectives. (which are important ways of achieving them)
- A direction of preference

An example of a means objective may be to reduce the downtime and maintenance time of any equipment, or to avoid downtime in the overall process. Implications of achieving this objective may be to maximise recovery, optimize resources and reduce the probability for accidents. These three last objectives are fundamental objectives because they are all essential reasons for operating an in the oil and gas industry.

The numbers of passive safety barriers are easy to count, but it would be a means objective, not an end in itself, so it would not be a fundamental objective.

The purpose of segregating between means objectives and fundamental objectives is that means objectives should create alternatives. Fundamental objectives should be established in the process of the evaluation of alternatives.

All organisations have strategic objectives, and some decisions are made to pursue these strategic objectives. If the strategic objectives are not explicitly defined and communicated, it will be difficult to make a long-term influence on the organisations achievement (Department for Communities and Local Government, 2009).

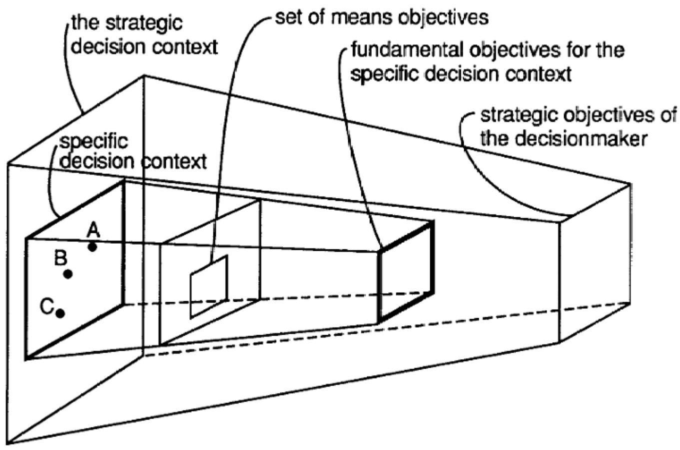


Figure 13 - Framework for value focus thinking and a how different boundaries for the stakeholders and decision makers correspond (Keenay, 1992 p.45)

Figure 13 illustrates the framework for value focus thinking and a how different boundaries for the stakeholders and decision makers correspond to each other. The purpose of this figure is to illustrate the concerns relevant to a specific decision situation from concerns to all decision situations.

By applying the framework from value-focused thinking, we can adapt to the following line of action in a decision-making context. This also gives guidelines for how to handle decision opportunities. Some strategic objectives for maintenance have already been identified, ref chapter 2.1. However, these strategic objectives will be vague to use as fundamental objectives, as they are not measurable by themselves. Hence, other fundamental objectives need to be identified.

Fundamental objectives have several desirable properties as shown in table 2. Their meanings are clear, hence supplying the definition of the desirable properties will note be done as a part of this thesis.

Table 2 - Desirable properties for fundamental objectives (Keenay, 1992 p.92)

1.	*Essential*, to indicate consequences in terms of the fundamental reasons for interest in the decision problem
2.	*Controllable*, to address consequences that are influenced only by the choice of alternatives in the decision context
3.	*Complete*, to include all fundamental aspects of the consequences of decision alternatives.
4.	*Measurable*, to define objectives precisely and to specify the degrees to which objectives may be achieved.
5.	*Operational*, to render the collection of information required for an analysis reasonable considering the time and effort available
6.	*Decomposable*, to allow the separate treatment of different objectives in the analysis
7.	*Non-redundant*, to avoid double-counting of possible consequences
8.	*Concise*, to reduce the number of objectives needed for the analysis of a

	decision
9.	*Undesirable*, to facilitate generation and communication of insights for guiding the decision-making process.

To see in which degree an objective is met, attributes are created. Attributes will be referred to as a “measurable scale” Examples of such scales are effectiveness, performance, and cost. Attributes can be defined in three different ways. (Keenay, 1992)

- *Natural* attributes do have a common interpretation for everyone. An attribute is not natural if it seems to have inappropriate built-in values. If the attribute is to save cost, the attribute “value measured in NOK’s” will be a natural attribute
- *Constructed* attributes, can be created if it is difficult to measure objective directly. Different from natural attributes, constructed attributes are developed for a specifically given decision problem. To improve the reputation of a company can be one. These constructed attributes may also be termed subjective scales or indexes. For constructed attributes, it is especially important to define what the objective actually means.
- *Proxy* attributes, can be used for attributes that it is difficult to identify. In such cases, it may be necessary to utilize indirect measures, which are named proxy attributes. An example of a proxy attribute may be to measure the overall CO_2 concentration in air. If including the concept of probability is to be included in MAUT, it can be included trough *Proxy* attributes see. e.g. (Bedford & Cooke, 1999), however this may be challenging to implement in practice.

By enabling an objective hierarchy, the relationship between the fundamental and means objective can be elaborated. If continuing structuring objectives to lower and lower levels, one ultimately will identify all the alternatives, and it is possible to find the essential reason for interest in the attribute and how it can be measured. However, it is critical to know when to quit. Money may eventually be the ultimate fundamental objective for the business.

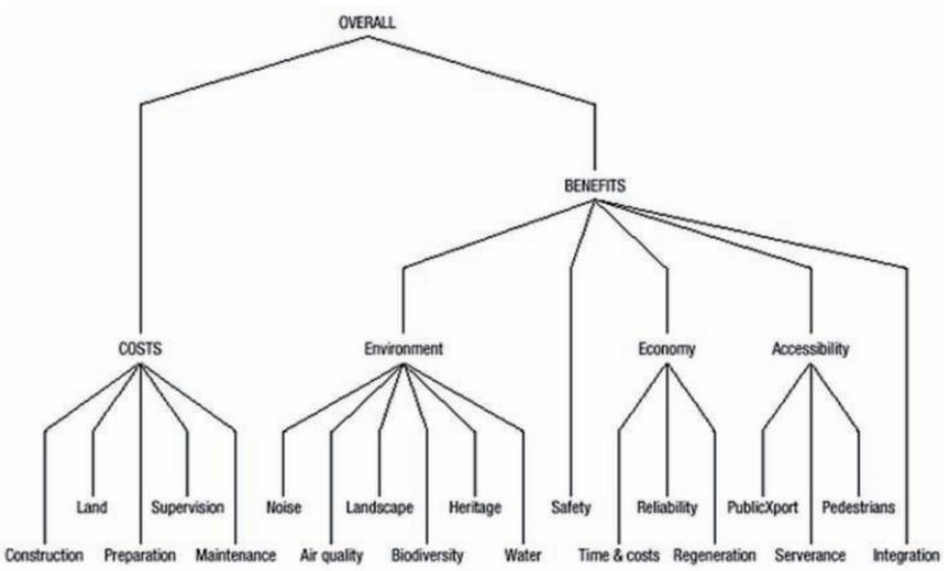


Figure 14 - Hierarchy for attribute tree p.58 (Department for Communities and Local Government, 2009)

To distinguish between categories of attributes (in our case dimensions of consequences), it can be useful to group together criteria's into subsets or classes which make it easier for the decision maker to separate and distinguish the different components. This is especially useful when there are a large number of criteria's. There are several benefits of grouping the criteria's into smaller sub-sets. (Department for Communities and Local Government, 2009)

- It helps the process of quality assurance when completeness when the desirable properties of attributes.
- To ease the process of calculating the weights, as these can be broken down. By settling main criteria's and then sub criteria's.
- Facilitate higher-level trade-off between different key elements.

With all these benefits in mind, structuring the value tree is considered as important for Multi-Attribute Theory. In for Oil and Gas context, there it is not identified a formal guideline to determine what is a 'right' structure and what is not. However, this can be linked to the significant objectives in the decision context. For many decision problems, there is arguably no unambiguously true structure or arrangement of the criteria.

After all these steps are completed, an attribute tree can be created.

3.3.3 Define values, scores, and weights

The next step in this process is to define the different consequences and opportunities as a vector of scores for the various attributes. An additive multi-criteria value function can be used. Where $c_i = (c_1 + c_2 \dots c_n)$ represent the values for the different attributes and w_i represent the weight of the i-th attribute.

Equation 1- Additive multi-criteria value function (French, et al., 2007)

$$v(c_1, c_2. \dots., c_q) = \sum_{i=1}^{q} w_i c_i$$

By applying a value function, it is possible to see how an option's values can be combined into one overall value. This is done by multiplying the value score on each criterion by the weight and score on that criterion, and then adding all the weighted scores together. (French, et al., 2007). There are several adaptions to this method; there are also several pitfalls that have to be taken into consideration. A description of how to deduce *scoring* and *weighting* is provided below. Note that these notations have been changed intentionally in the next chapter.

Scoring

Scoring is used to tell something about the strength of measure of achievement, performance or consequence of the attribute with a value.

The expected mitigated consequences of each option are assigned as a numerical score on a "strength of preference" scale for each option for each criterion. Scoring may apply to both risks and opportunities. The size of this scale is relative and are easily be adjusted, it is identified three ways to model scoring. (Department for Communities and Local Government, 2009)

The first of these uses the idea of a value function to translate a measure of achievement, performance or consequence on the criterion into a value score between 0 – 100. The value functions can be linear or exponential. In a risk context, it may be undesirable to use a non-linear function, as extreme consequences not are weighted by importance. It is possible to derive values for the different attribute levels through direct input trough risk averse, risk neutral and risk-prone value functions. These functions are either convex or concave depending whether they are respective risk averse or risk prone. Where a and b>0 are constants to ensure that u is scaled to the desirable scale and c is negative for increasing utility functions and negative for decreasing utility functions. (Keenay, 1992)

Equation 2 - utility functions taking risk appetite into consideration (Keenay, 1992)

- Risk averse $u(x) = a + b(-e^{cx})$
- Risk neutral $u(x) = a + b(cx)$
- Risk prone $u(x) = a + b(e^{cx})$

By applying value functions, it is possible to take time averse discounting into consideration. This is quite similar to the discounting rate we use in CBA&CEA, but also slightly different. The expression is derived from the time whet the outcomes are assessed. The purpose is to take into account possible “devalues in the future” (Keenay, 1992). An example is if we can decide to invest 1 MNOK now to increase the production by 1% the figures maybe will be changed if we do the investment in 5 years. However, the required amount of input in these utility functions may seem confusing for the decision maker when the available data is limited, hence not suitable for the purpose of this thesis.

The second approach to score the performance on direct rating. Direct rating requires the decision-maker to associate the performance in a 0–100 range with the value of each attribute. This can be applied when a scale of measurement for the criterion in question does not exist, or it is difficult to make a confident prediction of the performance. The main problem related to direct rating is that it may lead to inconsistency where different people are involved, and may change from decision to decision. This may make it hard when the decision makers not are involved in all stages (Department for Communities and Local Government, 2009).

Another problem is that a discipline expert’s and non-experts may weigh the judgements differently. When conducting the evaluations, this may/or may not influence the outcome of the decision in an undesirable way. In an ideal situation, the evaluator should both be an expert and a disinterested person. Otherwise, applying sensitivity to understand the robustness of the analysis has to be performed.

A third approach is to scoring the value of options indirectly, by eliciting giving the decision maker a series of pairwise verbal assessments expressing a judgement of the performance. A critical issue affecting the quality of the attributes is during the developing the attribute scales; input values will be essential to the success of the use. Value judgements are necessary to ensure that the scales are not out of range and are appropriate for their range of application. Ensuring measurable, operable (describe outcomes), and understandable (no ambiguity of consequence) scales will clarify the objectives. Classifying the different attributes in categories rather than exact values can therefore be helpful to the decision maker. An example is provided below. The use of attribute levels is not mentioned explicitly in the guideline these steps are based on. However, the work of Keenay (1992), suggest the use of levels for the different attributes.

Table 3 - Attribute levels

Attribute level	**Description of attribute level**
-3	*Extremely negative*, decrease recovery by more than 10%
-2	*Very negative*, decrease recovery by less than 5%
-1	*Negative*, decrease recovery by less than 1%
0	*Neutral*, No effect on the recovery rate
1	*Support*, Increase recovery by less than 1%
2	*Strong support*, Increase recovery by less than 5%
3	*Wide support*, Increase recovery by more than 10%

The applicable scoring is chosen by using a *swinging-weighting technique*, which makes the decision maker able to select the “impact” of an attribute (French, et al., 2007). Using this kind of weighting and scoring requires a mutual independence of preferences as briefly mentioned in the previous section.

Evaluation of Individual and group risk can be included easily, as these can be modelled by adjusting the adopted scale or level. This may effectively make an impact of the decision context (French, et al., 2007).

Weighting

Numerical weighting are assigned to define the trade-off between the different attributes and classes. Assessing weights for each criterion is to reflect a relative importance. This can be arranged it two ways; either by using a relative strength of preference, based truly on the decision maker. Alternatively, an Analytic Hierarchy Process can be used.

The Analytic Hierarchy Process (AHP) is a structured technique for classifying and analysing decisions, based on psychology and mathematics. It has application in group decision making and is applied in a wide variety of decision situations, in fields such as education, healthcare, government, and industry (Department for Communities and Local Government, 2009).

Rather than command a "correct" decision, the AHP supports decision makers find one that best accommodates the decision makers goal and understanding of the problem. A rational and comprehensive framework for structuring a decision problem, quantifying its elements, for relating those elements to overall goals, and for assessing alternative solutions (Accorsi, et al., 1999).

There are several ways to proceed with the AHP, to weight and divide the importance of the different attributes in a successive way, a semi quantifiable AHP can be suitable. It is not perfect, but can give some indications on the trade-off between different preferences. The process requires the decision maker to ranked values for a set of criteria. The value describes the degree of the preference for a criterion over another criterion. This will give a pairwise comparison of the different criteria's.   Following steps should be followed.

1. Determine a matrix, based on the defined derived criteria's. Depending on the number of *n*, used criteria's the matrix will have an *n x n* size. The elements of the matrix are developed using $A=[a_{ij}]$

$$\begin{bmatrix} 1 & a_{12} & & & \\ 1/a_{12} & 1 & a_{23} & & \\ & 1/a_{23} & \ddots & \ddots & \\ & & \ddots & \ddots & a_{n-1n} \\ & & & 1/a_{n-1n} & 1 \end{bmatrix}$$

Figure 15 - AHP matrix (Kou & Lu, 2013)

2. Estimate the relative importance of the different pairs of criteria's. It is only necessary to make 1/2n (n – 1) comparisons to create a full set of pairwise judgements for n criteria's. Given that the decision maker is consistent in his or hers judgments. The importance can be scaled to a nine-point intensity scale as follows. (Kou & Lu, 2013)

Table 4 - Preference scale for AHP process

Subjective levels	a_{ij}
Overwhelmingly more important	9
Very strongly more important	7
Strongly more important	5
Moderately more important	3
Equally important	1
Less weakly serious (LW)	1/3
Less fairly serious (LF)	1/5
Less strongly serious (LS)	1/7
Less absolutely serious (LA)	1/9

3. Calculating the weight of each the weight of each vector by using the eigenvector or by applying a geometric mean approach.

   The alternative is to use AHP computer software, based on advanced ideas in matrix algebra and complex calculations. A wide range of such software are available online, for the purpose of this thesis the calculation provided by Goepel (2014), has been identified as useful.

There are a few concerns about using the AHP methodology; however the resulting weights may be more stable and consistent than if they were based on a narrower set of judgements. AHP also fits conveniently supporting circumstances where judgements, are the conclusive form of input of information. (Department for Communities and Local Government, 2009).

The concerns are mainly related to a) the relative inconsistency of the 1-9 scale, b) the linking between the scale and definitions c) electing weights before criteria's are set d) introduction of new options can change the ranking d) AHP is not empirically testable.

3.3.4 Combine weights and scores.

As presented Chapter 3.2 a number of axioms were presented by (Neumann & Morgenstein, 1953) on how individuals should make rational decisions. Claiming that the only way an individual could behave consistently using the above-mentioned axioms is by choosing the option, which possessed the highest utility.

According to Department for Communities and Local Government (2009), Neumann & Morgenstein (1953), and Savage (1954), suggested; a 3-step procedure to combine weights and scores into an overall evaluation arena.

i. establishing of a performance matrix (see Chapter 4.1.2)
ii. determine independent criteria's (see Chapter 4.1.2)
iii. estimate the parameters in a mathematical function. This allows estimation of a single number index, v; to express the decision maker's overall valuation of an option in terms of the value of its performance on each of the separate criteria.

In a decision context, when having a broad range of choices to choose between not all of the option are of interest. The uncertainty regarding what the future state will be, contribute to different potential values to the decision maker. For example, the value of investing in a new heating device may depend on future states of the climate.

The value of any option can be calculated by;

1. By identifying the probable future states relevant to the particular decision problem. Scoring the anticipated outcomes (w_i) of the state where the probabilities are the individual's subjective estimates of the probable outcome.
2. Weight the degree of attractiveness, associated with the outcome of the specific decision problem (c_i). Hence, this will be weighting of the attributes that are applicable to the decision problem.
3. Calculate the value of the alternative (v_i).

Equation 3 - Additive multi-criteria value function (Bedford, et al., 2005)

$$v_i = w_i c_{i1} + w_2 c_{i2} + \cdots + w_n c_n = \sum_{i=1}^{q} w_i c_i$$

Where:

v_i is the overall value of an decision problem
w_i is the value for option *i*,
$c_i$is the weight of a the importance of option *i*

In translation, this means that all an option's score is to be "*multiplied by the relative importance of the weight of the criterion. Then this should be done for all the applicable criteria's, and then a sum the products to give the overall preference score for the option. Then repeat the process for the remaining options and sub criteria's"* (Department for Communities and Local Government, 2009, p. 65).

More demanding methods are available which may be used to model risk aversion directly into to the value function, by using other value functions mentioned in the beginning of this chapter, however to keep this to the point, no further study of this will be performed as a part of this thesis.

Comparing result

After this, weights and scores are combined to derive an overall evaluation arena. The output can be used to rank different alternatives against each other. An alternative can outrank another if the sum of the criteria's weights is higher or the importance is more significant. All alternatives are then assessed in the decision-making context, and can then be measured by a threshold parameter. Hence, the outranking concept does capture some of the political concerns and social concerns of decision-making (Department for Communities and Local Government, 2009).

In a decision context, it is not unlikely that two alternatives are weighted equally or are "difficult to compare". By building decisions into a mathematical structure, allows the decision makers to have subjective judgements even though not all information is structured and available. Another feature of applying the outranking method is to see how weighting of the desirable effects influences the sum of the criteria's weights (Department for Communities and Local Government, 2009).

However, there are some considerations regarding the use of the outranking method. One of the problems is how arbitrary definitions may influence the result, and how the decision maker can manipulate the outcome. A third issue in a safety setting is that the value not necessarily captures unacceptable consequences.

3.3.5 Sensitivity analysis

The last step is to conduct a sensitivity analysis to check how preferences and weights affect the overall ordering of the available option. A sensitivity analysis are be used for examining how the different inputs or disagreements between the different stakeholders and decision makers contribute to the result of the analysis. This can be done in several ways for the MAUT analysis, it can also help checking the consistency for the scaled used.

An obvious way to perform sensitivity analysis could be to adjust the value for each criterion related to the decision problem, however this would not investigate the coherence between the different alternatives as it is assumed that the decision problem do not change.

Changing the weighting of different categories can help to see how the importance of the various attributes contributes to the overall value.

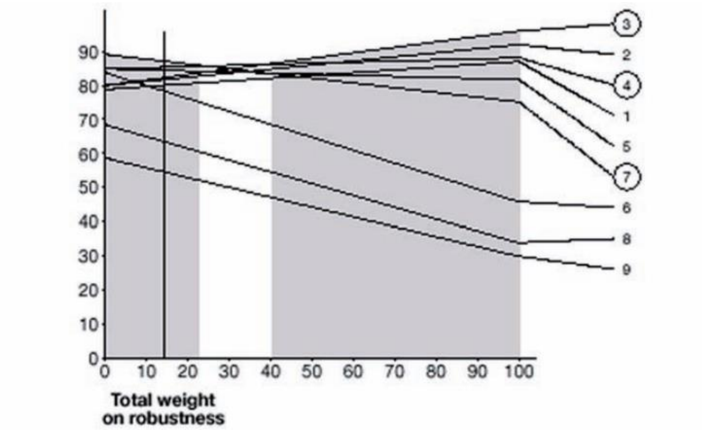


Figure 16 – How different weighting (sensitivity analysis) may change the overall desirability using MAUT (Department for Communities and Local Government, 2009, p. 100)

Figure 16 show how different weighting may affect the total score of a proposal.

Projects that attract public may be challenged to weight, as these may be difficult to determine. MAUT can help decision makers to prioritizing in such situation. Another opportunity is that the sensitivity analysis can helping to resolve disagreements between different interest groups.

By using such a model to examine how the ranking of options can change under different scoring or weighting systems, can demonstrate that a few options always come out ahead, though their order may be modified. The fundamental reason for this is that different stakeholders may have different disagreements, but also several areas where they agree. Hence, sensitivity analysis can help enlighten differences and resolve disputes between the various stakeholders.

An interesting feature regarding the use of multi-attribute theory is that it is less sensitive to changes weighing and, therefore, seems to be consistent when considering perspectives from different stakeholders (Department for Communities and Local Government, 2009).

3.3.6 Uncertainty, Risk, and MAUT

Several areas where the use of CBA is challenged in an ALARP decision context, first introduced in Chapter 3.2. The MAUT do at some degree answer these questions in a more satisfying way than CBA (Bedford, et al., 2005).

- CBA do take cost and benefit into the overall evaluation calculation, in practice uncertainties are removed by taking averages of preferences, and then disproportionality is checked. In contrast, MAUT approaches uncertainty and disproportionality as it is "averaged out" first after weighting the different consequences.

- Further, the use of MAUT may reveal the values of other stakeholder groups in contrast to the CBA, which assumes that there is an "objective" weight or trade- off all the stakeholders. By conducting a sensitivity analysis, weights applied to different stakeholders help to understand differences in values and perceptions by the various parties to the decisions. Hence, by using MAUT it allows the problem to be seen viewed the perspective of several stakeholders and then compared.

- CBA is required for the use of a discount rate to transform future benefits and burdens as it usually is expressed through momental equivalents. A problem with doing this is that societal concerns not are reflected and, therefore, that middle and long-term consequences.

- MAUT can easily include group risk and aversion to multiple fatalities when required. Aversion to multiple fatalities can be modelled by adjusting the scale of measurement (e.g., the values used in Table 3.) This may also help modelling the trade-off between individual and group criteria.

It is further claimed that MAUT afford an alternative methodology to CBA which enable the four problems described above to be addressed. By applying sensitivity analysis, MAUT can address several stakeholders, facilitating constructive discussion regarding the key points of disagreement.

In the use of evaluation of modification proposals, it may also be questioned whether it is possible for the decision maker to elect the values related to e.g. discount at an early stage.

3.4 Decision analysis.

Decisions problems appear in different ways, some as decision problems, and some as decision opportunities. Comparison between technical solutions to solve one or several problems is one example of a decision problem. Another decision problem is whenever the risk of ongoing activity is at such a level that actions have to be taken to reduce the risk, selecting the alternatives that maximise a set of successful criteria's are one of them. (Aven & Kørte, 2003). How to derive such criteria's have been presented in Chapter 3.3.

In an Oil and Gas context, decision problem often occurs because of events that not are controlled by the decision maker itself. Unlike decision problems, decision opportunities are identified and defined by the decision maker rather than actions not controlled by the decision maker. Often alternatives to the status quo are proposed, to solve the decision problem. The status quo alternative may be easy to communicate and perhaps other proposed alternatives as well. Sometimes the decision context for the problem is cast narrowly so that identifying all alternatives is easy; sometimes the problem is more complex, and the common cause has to be investigated further (Wyoscki, 2014).

However here, it is required to be cautious. By settling for alternative A over B to save money when the cost of alternative A is 1 million NOK and alternative B is 2 million NOK, we should be aware of implementing "extras" which will jeopardize or challenge alternative B. The point is that any alternative will require the use of a particular value of resources, but before expending these resources the desired outcome should be generated, and only alternatives that allow the decision maker to achieve them should be chosen. (Keenay, 1992)

Generally, all projects should start with; why execute this project? What is the business value of the project? Success criteria will have to be defined such that the decision-maker know when the goal is achieved. Success criteria can be categorised in three "stereotypes". (Wyoscki, 2014)

- Increased revenue – evidence of increased revenue can help the business proposal.
- Avoiding cost – Related to the loss of income. Risk related to people and environment should be included here.
- Improving service – this is very difficult to define as a number, but the purpose is to meet someone's needs.

Successful criteria may reflect the actual consequence and bottom-line impact. If opportunities are defined, this can be expressed trough increased margins, higher net revenues, reduced turnaround time, improved productivity and reduced cost.

3.4.1 Uncertainties and negative consequences.

In a production assurance and safety, setting uncertainty can be understood as the absence of information regarding quantities, and, therefore, be the fundamental component of risk. To understand the importance in this context the following risk components have to be enlightened (Aven & Flage, 2009)

- Consequences or outcomes, which may affect what stakeholders appreciate, especially negative outcomes.
- Uncertainty and probabilities are specifying the likelihood of the specified outcomes.

Type of project also influences what information is required in a project when uncertainty or the outcomes are high, we can divide into different types of project. As it changes from one project type to another, the complexity also increases. (Wyoscki, 2014) However, this will not be described further in this thesis.

As presented in Chapter 3.2 and 3.3 there are several pitfalls and challenges regarding the use of expected utility theory, cost-benefit analysis, and multi-attribute theory. One of the fundamental problems that have to be addressed is uncertainty regarding the input values.

Black swans can be understood as events (or a combination of events and states) that is unforeseen or surprising based on the existing knowledge and thinking (Aven & Krohn, 2013). Black swans can be divided into three subcategories (Aven, 2015)

- Unknown unknowns – unknown events for everyone
- Unknown knows – events that not are evaluated, either because the outcome is unknown or that it is evaluated as “unlikely”, these events may be known by other experts or stakeholders.
- Known unknowns, which are events that is expected to have a negligible likelihood of occurrence and, therefore, do not believe that such events will happen.

Such events with low probabilities and high consequences should not be defended by using expected values to support decision-making (Aven & Krohn, 2013). This prominent when uncertainty is high and large values are at risk. It is not desirable to over focus on all unthinkable outcomes but contribute to a continuous cost-efficient safety improvement.

Use of traditional risk matrix may also give the wrong understanding of risk, as uncertainty and knowledge not are clarified. Several challenges related to the use of expected values and matrix have been identified (Norsk Olje og Gass, 2014)

- High focus on probability and previous events. The main problem related to the use of historical data is that it may not capture all possible events that may occur.

- Probability may be the same, but the knowledge the probability is based on may vary from person to person. Probability predictions are based on different argumentation. However if the argumentation has clear errors this may affect the quality.
- Important aspect of risk and uncertainty is not transparent. As background knowledge may be of poor quality, the use of the analysis may be challenged.
- Risk may be understood different in different environments. Especially people working onshore may have a different risk perception than people working offshore.
- Deviation is not necessarily a negative factor, as this may be the beginning of new focus and improvement processes. Deviations and variance may also be the starting point for changing culture, improvement, etc.

If the problems in concern are an alternative between different solutions, different attributes should be considered to see how they get out with respect to the alternative being evaluated. A comparison between the various solutions can then be performed (Norsk Olje og Gass, 2014).

It will not be the purpose of this thesis to give recommendations on what is reasonable risk reduction or not. However, it is noted that the following three steps should be considered when evaluating whether risk is acceptable or not in ongoing activities (Norsk Olje og Gass, 2014);

1. Are there any changes in the probability for specific hazardous events? Identify the different measures, evaluate the pros and cons of the various measures and choose the best measures.
2. Is the knowledge these evaluations are based on reasonable? If not, the knowledge should be strengthened.
3. Are there any aspects regarding vulnerability that have to be taken into consideration?

Two examples gathered from Norsk Olje og Gass (2014). One is an event that can be characterized as Black Swan and the second having potential to escalate to a black swan.

Sleipner A, sunk in Gandsfjorden in 1991 during testing of the submerge system. The official cause was a miscalculation of forces and a reinforcement failure. This led to significant pressure on the material used and resulted in fracture and passage of water. This was evaluated as unlikely in the planning of the project.

In 2012, a Hydrocarbon leak occurred on the Ula platform in the North Sea. The cause of the leak was that the bolts one of the valves from the outlet separator busted. The bolts had been exposed to produce water from the valve, which resulted in corrosion of the bolts. These were discovered nearly six months before the leak occurred. However, the personnel involved in the evaluation of the measures were not aware of the potential consequences. It should be noted that this was issued as a problem on a corporate level. However, the personnel involved were not aware of the issues related to chemical reaction and composition of materials.

3.4.2 Approaches

As described in Chapter 3.2 and Chapter 3.3 there are several ways to evaluate the "value" of a project. However, the problem of transforming non-economic consequences into monetary values can be a problem. Especially when the input used in the evaluation is questioned. The remaining question will be how the decision makers should handle the result of the analysis in the decision context.

How different factors related to risk and uncertainty should be given attention in a decision-making process depending on several factors, including external stakeholders (Aven & Flage, 2009)

- Company's attitude and risk appetite.
- Available frame agreements.
- Money and compensation.
- Insurance and liability.
- Sustainability.
- Ethical.
- Political concerns (PSA, OD, etc.)

The problem with the methods in Chapter 3.2 and 3.3 are that they at some degree don't include these factors in the evaluation, independent on how "good" uncertainty and assumptions are incorporated into decision formulae.

As described in Chapter 2.2 there are two regions of approach to the ALARP principle in the NCS. The first region is at a level where the risk is considered to be at an intolerable level, which is referred to as the intolerable region. As an example, EPN's risk acceptance criteria indicate that events in this category shall go directly to implementation, regardless of the risks and opportunities other events may have. The second region which is defined to be the ALARP region, where it should be evaluated whether the risk is tolerable and does not need to be reduced any further.

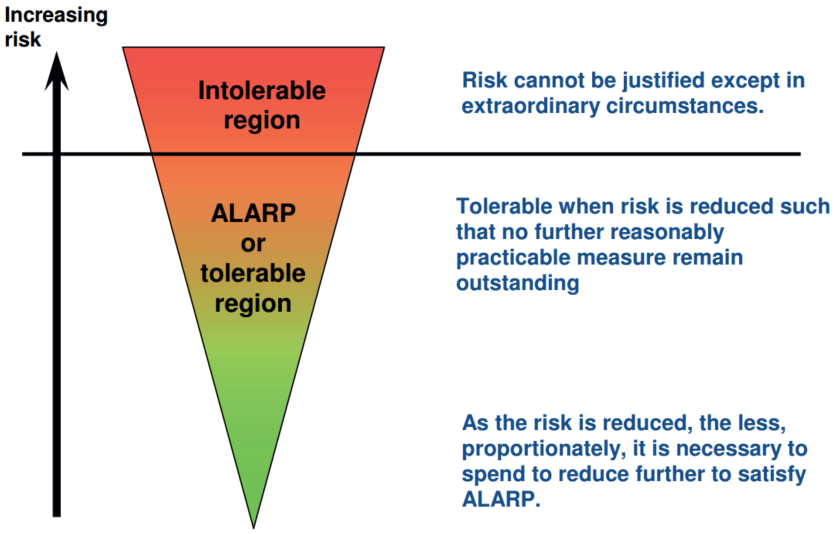


Figure 17 - ALARP process (NORSOK, 2001, p. 68)

The figure above illustrates how risk should be handled on the NCS. Two different approaches can be utilized to deduce a good decision and may be applied in an ALARP decision context (Abrahamsen & Aven, 2008).

1) Choose alternatives that maximise/minimize some special criteria, reflecting the performance of the alternative considered. Hence taking values and uncertainties into consideration.
2) See decision making as a process with a formal decision and risk analysis providing decision support, followed by an informal managerial judgement and review resulting in a decision.

Both Aven & Kørte (2003), and Aven & Vinnem (2004), provide a structure for how to proceed with risk and decision analysis, in the ALARP and risk environment. To serve the purpose of this thesis the second approach above has been chosen to elaborate further. The figure below provides an introduction to the following presentation.

It is worth to mention that the figure may be utilized both when comparing different alternatives in a particular decision context to one another, and when comparing different concepts, designs, activities, risk-reducing measures, etc. to one another.

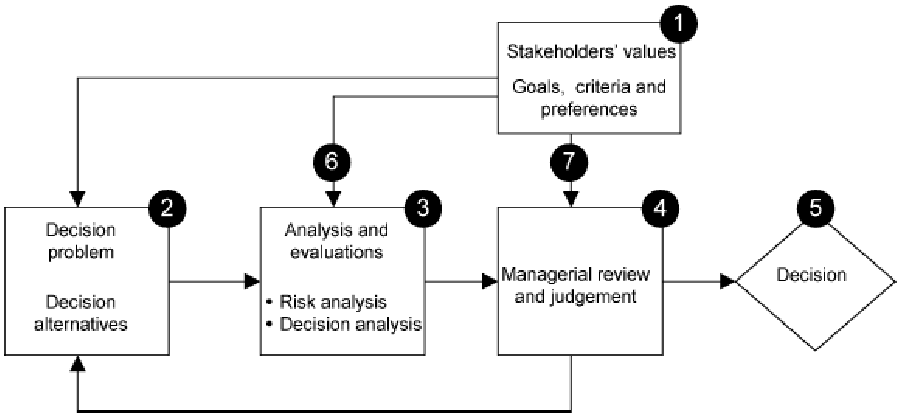


Fig. 1. Model of the decision making process [10].

Figure 18 - Proposed structure for use of risk analysis in oil and gas industry (Aven & Vinnem, 2004)

The first step (1) is to perform a crude analysis of burdens and benefits addressing various attributes, from this the crude analysis will eliminate some alternatives and include new ones.

Further, it will be necessary to identify and define decision problems, opportunities and alternatives (2). As mentioned at the beginning of this chapter, decision problems appear in different ways, the number of available alternatives should be therefore manageable and practicable. Types of project, complexity and success criteria's are important factors influencing the alternatives. The possible alternatives are also influenced by the boundary conditions of the decision problem; these are briefly introduced in Chapter 3, and may be linked. Decision problems identified by individuals may be influenced by personal motives, however by ensuring involvement of several of the representatives; the generated alternatives should reflect the basis of the organisation.

The third step (3) is by performing a more detailed analysis when required. Narrowing down the favourable alternatives through a formal process (e.g. as described in chapter 3.3), by deriving the expected future consequences. This will not be explained any further in this chapter. However, the presentation of potential future consequence should reflect the "reasonableness" between different alternatives. It should be bared in mind that these presented consequences necessarily reflect the acceptance or rejection of risk within an organisation, hence it provides input to the decision-maker, but do not attempt to prescribe which decision to be chosen.

Managerial review and judgement (4) should take into consideration assumptions and limitations the analysis does not cover. Background information related to gross disproportion and performance should also be considered as presented in chapter 3.2

During the selection of the alternatives considerations to the following factors should be included (Aven & Kørte, 2003)

- The decision alternatives actually being analysed
- The performance of the measures analysed

- That the results of the analysis represent judgement, to a large extent conducted by stakeholders and experts
- The difficulty of assessing values for cost, benefits, and uncertainties
- The fact that the analysis results apply to a model

These considerations are important as a model only may consider a few possible outcomes or events, depending on the model applied. It should also be decided whether other types of analysis should be provided. Cost benefits analysis, for example, usually only produce an ENPV value that is used in the evaluations.

By the use of cost-benefit analysis, if the decision maker prefers alternatives with high expected cost/benefit above alternatives with lower cost/benefit, even if the latter alternative may cause extreme and unacceptable events. Therefore, it is important that the outcome of an analysis is reviewed and evaluated (6), as certain factors not can be replaced by a one-dimensional formula, integrated with complex judgements. This does not mean that ENPV or ICAF should be avoided, but that that the decision process itself should ignore such problems and focus on the judgement itself.

Based on the finding the decision maker performs a review and judgement of the relevant data makes a decision (7), other factors such risk perception and reputation should be evaluated whenever relevant (5).

4 Recommendations and case study

The recommendations and case study is divided into three parts.

The first part is to propose a model that can be used to derive a value function for any modification project. The purpose of the model is to say something about the performance of a modification proposal.

The second part is performing a case study on a selection of modification proposals. The purpose of this is to a) see how actual modifications fit the proposed model, and b) see how different interest groups affect the desirability of the proposals. This is done by adjusting the relative weighting.

The last part considers applicable adjustments, recommendations, and practical implementation of MAUT.

4.1 Application of MAUT

Based on the literature study and context, application of MAUT is suggested as an approach to evaluating modification proposals. A systematic procedure is proposed to show how this can be implemented in a practical context.

1. Create an attribute tree
2. Establish the performance criteria
3. Create a value function
4. Determine weights

Several practical examples on how modification proposals can be evaluated, following the procedure mentioned above are included in this chapter.

4.1.1 Create attribute tree

The theory from Chapter 3 will be the basis to see which factors that may influence the overall desirability of a project.

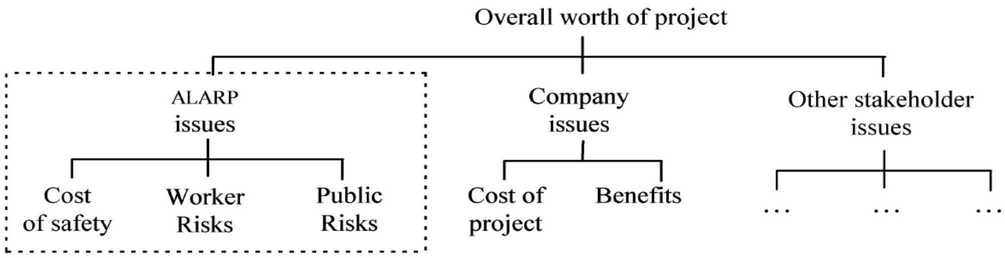


Figure 19 - Example of attribute tree in ALARP decision making (French, et al., 2007, p. 7)

Figure 19 describes several how an attribute tree may be constructed to reflect areas that affect a decision-making in an ALARP decision context (French, et al., 2007).

As mentioned in Chapter 3.3 there are three approaches on how to define attributes. The second approach is to examine existing policies, strategies or other statements to reflect the organisations concerns and is accordingly found appropriate for the purpose if this thesis.

By using the value space in Figure 13 as a starting point, a value model can be shaped. The purpose of this is to see which values and strategies that influence decision making. We divide between the strategic objectives for *all* decisions and *this* decision context (maintenance and modifications).

The strategic decision context within maintenance and modifications have been defined in Chapter 2.1 and consist of six items; Safety for personnel and Environment, Facility Integrity, Reliability of Equipment, System Regularity, Maintenance Effectiveness and Cost-Effectiveness. They are generally vast and should, therefore, be used to check whether the proposed attribute tree is consistent, rather than be nominated to specific attributes. Moreover, these are all "essential" objectives to carry out maintenance and modification work. They will not be recapped in this chapter but are critical to understanding the reason for implementing measures.

In the other end of the "value space", the strategic objectives of the decision maker are considered. In a maintenance and modification context, these are linked to the consequence categories defined by the company's risk acceptance criteria's to see which main undesirable elements and outcomes. These consist of the four categories; people, environment, assets, and reputation.

However, reputation is difficult to handle in this context. It is very hard to predict, and even more difficult to see the results, as these not are visible within a reasonable period. Therefore, it can be justified that this consequence category not is suitable for this context. Reputation may also be considered as a “proxy” attribute, which support that reputation may not be placed emphasis on in the creation of attributes.

By applying the consequence dimensions; briefly presented in Chapter 3.4, this is the starting point for the creation of attributes. These are mainly related to negative consequences (Vinnem , 2007), but it can be justified to modified the dimension of risk to consider opportunities as well as risks. We divide between; personnel risk, environmental risk, and asset risk, with their respective sub-categories. From these the following relevant consequences are identified, it should be mentioned that there may exist more consequences than the ones listed below, however from the point of this thesis these are found general and are found applicable in an ALARP decision context.

Table 5- Classification of consequences

Health and Safety
Risk for personnel injury
Risk for work-related diseases
Bad or inappropriate design
Fire and explosion danger
Risk for oil and gas leak
Absence of safety functions or barriers.
Environment
Risk for oil spill
Energy consumption and other discharges
Risk or chemical discharge
Assets (include reputation)
Strategy
Risk of reputation loss
Risk of production loss
Risk for quality loss
Deviation from external requirements and regulations
Deviation from internal requirements
Risk for material damage or other economic losses
Reduced lifetime of equipment

It should be noted that within e.g. Health and Safety, risk for Oil and Gas leak, fire and explosion danger and personal injuries may have the same consequences, however a personnel injury may occur and be caused by other factors than oil and gas leak, or fire and explosions. The next step is to sort the events in subcategories (hereafter-named *classes*) of consequences. The reason for this is that fundamental objectives can be structured better.

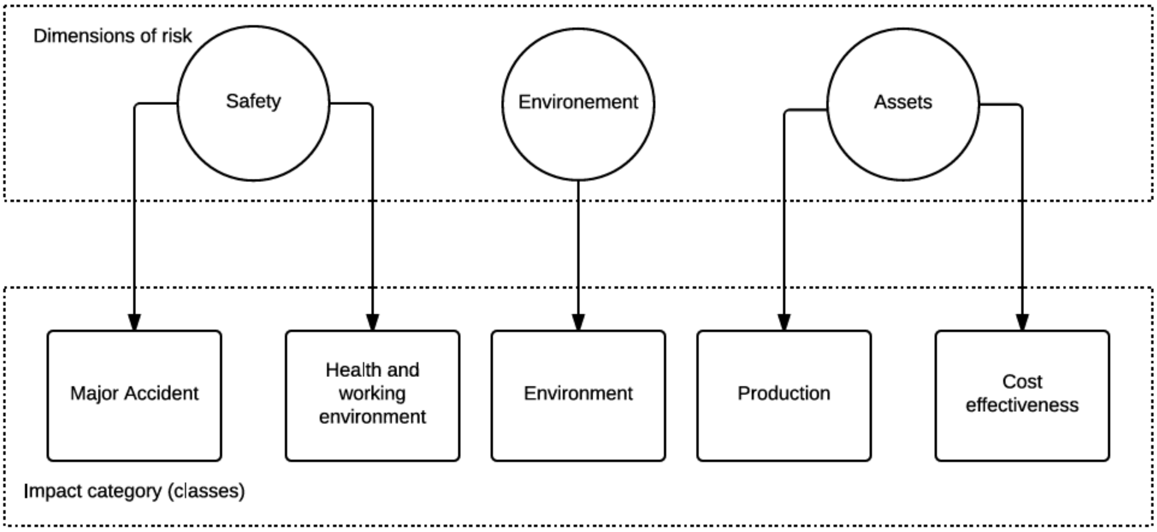


Figure 20 - Classification of classes and dimensions of consequences

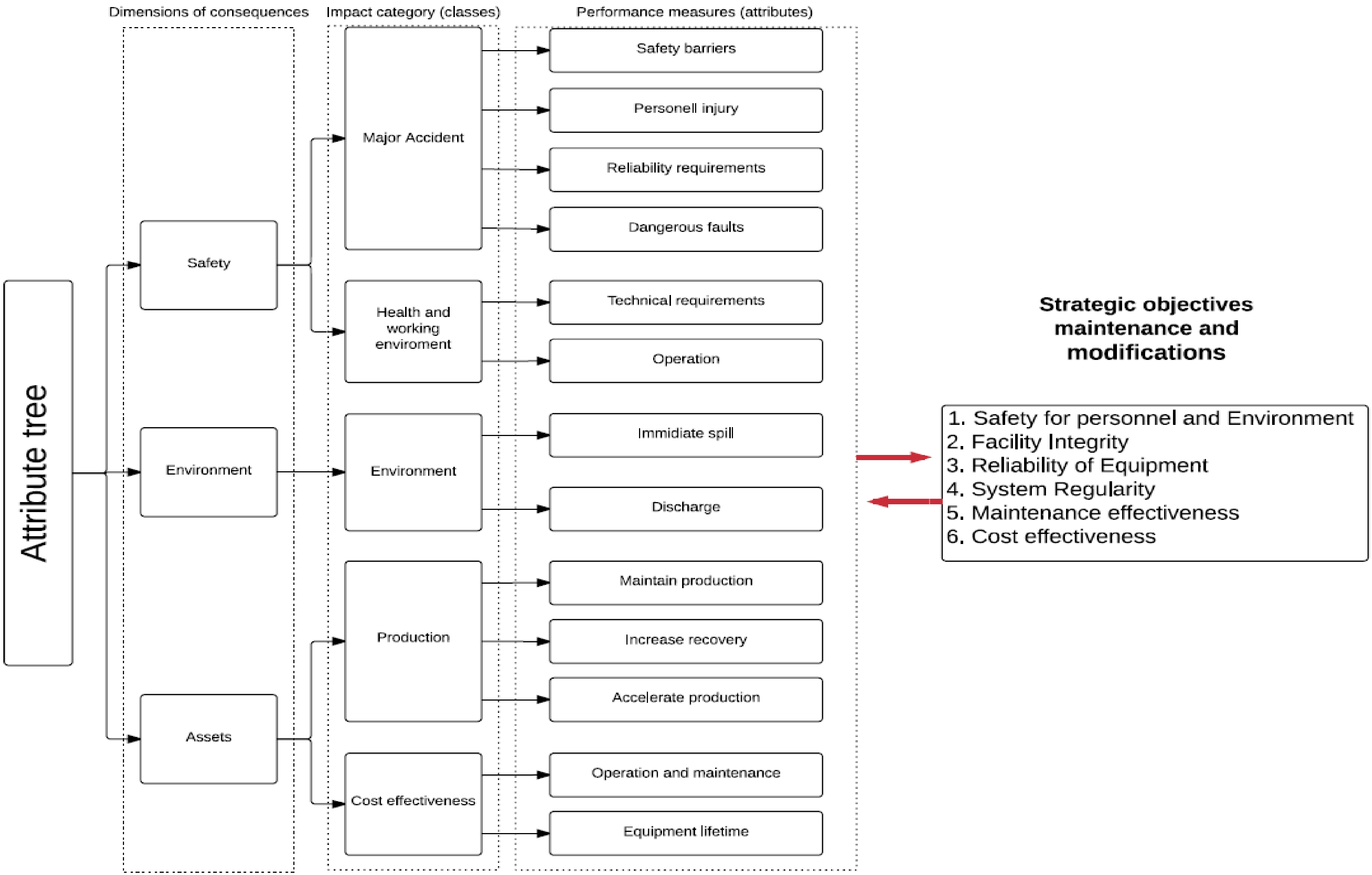
The main impact categories (classes) are not detailed statements and therefore do not lead to a direct evaluation. However, we may be interested to evaluate relative importance between classes, as these are general enough to make a statement regarding the relative importance.

C*lasses* are therefore divided into more elementary objectives, which are called performance measures (attributes). The attributes represent the specific goals affected by the decision. Within the environment category, example immediate spill and change in emission are two objectives that can be affected or achieved depending on the decision in question.

As mentioned in Chapter 3.3 the number of attributes should be kept to a manageable amount, from six to twenty. It would be possible to decompose e.g. discharge into even further categories (CO2, NOx, etc.) but this is considered to be too detailed for this process. The justification for not applying several attributes to describe the environmental impact is that it may introduce problems regarding input to the evaluation. Assets are not included as a single class, since assets can be structured further down.

On this basis, the following hierarchy of attributes are suggested by utilizing the desirable qualities first introduced in Table 2

It should be noted that these might not be representative in all situations.


Dimensions of consequences
Impact category (classes)
Performance measures (attributes)
Attribute tree
Safety
Environment
Assets
Major Accident
Health and working enviroment
Environment
Production
Cost effectiveness
Safety barriers
Personell injury
Reliability requirements
Dangerous faults
Technical requirements
Operation
Immidiate spill
Discharge
Maintain production
Increase recovery
Accelerate production
Operation and maintenance
Equipment lifetime
Strategic objectives maintenance and modifications
1. Safety for personnel and Environment
2. Facility Integrity
3. Reliability of Equipment
4. System Regularity
5. Maintenance effectiveness
6. Cost effectiveness

A description has been provided to ensure that the decision maker is aware whether the attribute in question should is of importance or not. In addition, the description should help the decision maker to weight the importance of the attribute. It is stressed that the purpose of the attributes is to evaluate maintenance and modification proposals, not covered by other (preventive and corrective) maintenance activities. Alternatively, when other types of maintenance are not adequate.

Table 6 - Description of attributes

Attribute	**Abbre viation**	**Description**
Safety barriers	SB	How do the identified proposal influence the functionality of the existing safety barriers or functions, or are there a possibility for improvements the in quality of existing performance barriers or functions?
Personnel injury	PI	Can the identified proposal change the present risk for personnel injury? Are injuries likely to occur? Can it eventually prevent future injuries?
Reliability requirements	RR	Are there any issues with the compliance with reliability requirements (SIL) or the components that achieve the compliance (sensors, actuators, logic, etc.) linked to the proposal that could lead to hazardous situations?
Dangerous faults	DF	Are there any dangerous situations, faults or near misses, observed in relation to this proposal? Related to dropped objects, etc.
Technical requirements	TR	Is the proposal related to technical working environment requirements? Can this potentially lead to any work related absence or diseases? Other working environment factors (noise, lighting, vibration, radiation or temperature) that can lead to a long-term disability should be included.
Operation	OP	Can the proposal influence the operational working environment? Functional requirements, working routines, location, and ergonomics should be considered. May lead to improved material handling, etc.
Immediate spill	IS	Can the identified proposal result in an immediate spill of oil or chemicals to the environment? Is it possible to reduce the amount of spilling and vaporisation present today?
Discharge	DC	Can a consequence of the identified proposal lead to long-term change in emissions, power consumption, waste etc.?
Maintain production	MP	Can the short-term production level be changed as a consequence of the proposal?
Increase recovery	IR	Can the recovery rate be changed as an outcome of the proposal?
Accelerate production	AP	Can the production be accelerated or deceleration as an outcome of the proposal?
Operational and maintenance cost	CE	Can a consequence of the proposal change operational- and maintenance costs?
Equipment lifetime	EL	Can the identified proposal change the expected life span of equipment?

Since the information usually are limited and to achieve a concise choice of attribute levels a fundamental range of criteria are proposed in Table 7. However, the naming of the different levels in the index varies in some degree depending on the consequence category of each attribute.

4.1.2 Establish performance criteria

There are three ways of assessing attributes levels ref. Chapter 3.3.1. The third approach, where scoring the value of options issued indirectly, by giving the decision maker a series of pairwise verbal assessments expressing a judgement of the performance have been evaluated as most suitable for the purpose. An argument for applying this approach is that it may lead to a broader understanding of the problem and being consistent over time when evaluating several different proposals (Department for Communities and Local Government, 2009).

The performance *index* allows the decision maker, to rank the available alternatives in order of preference. The equivalent attribute levels are then used in Equation 5 and Equation 6 as a starting point for the decision-making process.

By applying an alternative approach by constructing a range of attributes, this opens to include opportunities in the same scale as the risks. The alternative would be to build a separate range of attributes for risks and opportunities.

Table 7 – Performance criteria's

Safety and Environment									
w_i		**Safety barriers (SB)**	**Personnel injury (PI)**	**Dangerous faults (DF)**	**Reliability (RB)**	**Technical Requirements (TR)**	**Operation (OR)**	**Immediate spill (IS)**	**Discharge. (DC)**
3	**Large improvement**	Proven and acknowledged from governmental view	Proven and acknowledged from governmental view			Proven and acknowledged from governmental view	Proven and acknowledged from governmental view	Spill reduction >100 bbl. per year	The present levels of discharge will be reduced by 100%
2	**Medium improvement**	Proven and acknowledged within discipline	Proven and acknowledged within discipline			Proven and acknowledged within discipline	Proven and acknowledged within discipline	Spill reduction >10 bbl. per year	The present levels of discharge will be reduced by > 50%
1	**Small improvement**	Proved and acknowledged within the company	Proved and acknowledged within the company			Proved and acknowledged within the company	Proved and acknowledged within the company	Spill reduction >1 bbl. per	The present levels of discharge will be reduced by < 20%
0	**No effect**	No effect	No injury	No effect	No effect	No leave	No change	No change	No change
-1	**Minor effect/impairment**	Problem is only occurring under certain circumstances (testing etc.).	Injury (first aid/MCT)			Minor burdens	Works, but not fully commissioned.	Onsite response. Fully containable Spill < 1 bbl.	The present levels of discharge will be increased by < 1%
-2	**Moderate effect/impairment**	Problem that have to be regularly corrected	Single LTI without PPD			Burdens	Partly working, but not optimal.	Onsite response spill > 1 bbl.	The present levels of discharge will be increased by < 10%
-3	**Serious effect//impairment**	Part of safety function is out of use	Injury (LTI with PPD/Multiple LTI)	Dangerous situation have been reported	The function does not comply with reliability requirements,	Short-term sick leave	Difficult to perform	Third party assistance Spill > 500 bbl.	The present levels of discharge will be increased by < 20%
-4	**Major effect**	Safety function is out of use	Fatality or multiple LTI with PPD			Sick leave	Require exceptional perpetration and involvement of 3rd party.	National assistance Spill > 5000 bbl.	The present levels of discharge will be increased by < 50%
-5	**Catastrophic effect**	Impairment of several connected barrier functions or main safety function	Multiple fatalities or PTDs			Long term absence for several people	Impossible to execute	International assistance Spill > 100.000 bbl.	The present levels of discharge will be increased by 100%

Cost and Production						
w_i		**Production (PD)**	**Recovery (RY)**	**Accelerate production (AP)**	**Cost effectiveness (CE)**	**Equipment lifetime (EL)**
3	**Large improvement**	Avoid shutdown every 6 months	Increase the recovery by more than 10%	Accelerate the production by more than 10%	Reduction of cost by more than 1000 000 NOK per/year	No need for replacement ever
2	**Medium improvement**	Avoid shutdown every year	Increase the recovery by more than 5 %	Accelerate the production by more than 5%	Reduction of costs by more than 100 000 NOK per/year	Minor extension of lifetime, but have to be replaced within 10 years from planned replacement
1	**Small improvement**	Avoid shutdown every 5th year	Increase the recovery by more than 1%	Accelerate the production by less more than 1%	Reduction of costs by less than 10 000 per/year	Slight extension of lifetime, but have to be replaced within 5 years from planned replacement
0	**No effect**	No change	No change	No change	No change	No change
-1	**Minor effect/impairment**	Disruption of operation not recordable	Reduce the recovery by 1%	Retardation of production by more than 1%	Increase of costs by more than 10000 per/year	Decrease of lifetime, but have to be replaced within 15 years
-2	**Moderate effect/impairment**	Brief disruption (production loss less than 1 day)	Reduce the recovery by 5%	Retardation of production by more than 5%	Increase of costs by more than 100 000 NOK per/year	Decrease of lifetime, but have to be replaced within 10 years
-3	**Serious effect//impairment**	Partial shutdown (production loss less than a week)	Reduce the recovery by 10%	Retardation of production by more than 10%	Increase of cost by more than 1000 000 NOK per/year	Decrease of lifetime, but have to be replaced within 5 years
-4	**Major effect**	Major damage (production loss less than 1 month)	Reduce the recovery by 20%	Retardation of production by more than 20%	Increase of cost by more than 10 000 000 NOK per/year	Decrease of lifetime, and have to be replaced within 1 year
-5	**Catastrophic effect**	Total loss of operation for more than one month	Reduce the recovery by 40%	Retardation of production by more than 40%	Increase of cost by more than 100 000 000 NOK per/year	Urgent, have to be replaced within 6 months.

4.1.3 Create a value function

As presented in Chapter 3.1 and Chapter 3.4, decision alternatives may not always have negative outcomes; some decision alternative can create opportunities as well.

From the performance criteria made in the previous chapter, each outcome has a value; the value is a number that is attached to the possible result of the attribute. The attribute levels are to be connect to the relative desirability (here measured on a scale from -5 to 3) to the attributes concerned. The value function (Equation 4) converts different levels for a set of attributes into an overall score. The value for option i represent the plausible maximal potential consequences the measure may mitigate. Scoring is used to tell something about the strength of measure of achievement, performance or consequence of the attribute with a value.

It is suggested that risk (Equation 5) and opportunities (Equation 6) are presented both independently and together by using absolute values for each criterion. The purpose of this is to make the decision maker more aware of the risks and opportunities for each decision object (modification proposal). It will be demonstrated how to perform this in the next section.

Chapter 3.3.4 express the combination of weights and scores further. Based on this the following value function is suggested.

Equation 4 - Proposed value function

$$v_i = \sum_{i=1}^{n} a_i(w_i) \cdot c_i$$

v_i	is the overall value of an alternative
w_i	is the value for criteria i
c_i	is the weight of a the importance of the class
a_i	is the weight of a the importance of the attributes within a class

For risk (lower part of the scale in table 6) the sum tells something about the plausible maximal potential consequences the measure may mitigate This may i.e. be -1 if a first aid injury is considered as the maximum plausible consequence that may be prevented by implementing the measure.

Equation 5 - Value function for "risk"

$$v_R = \sum_{i=1}^{n} |a_i(w_i)| \cdot (c_i)$$

For opportunities (upper part of the scale in table 6), the sum tells something about the plausible opportunities by implementing the measure. This may i.e. be 2 if the implementation may result in avoiding a regular shutdown every year.

Equation 6 - Value function for "opportunity"

$$v_O = \sum_{i=1}^{n} a_i(w_i) \cdot (c_i)$$

In other words this process may be described as *"multiply an option's score on a criterion by the importance weight of the criterion, do that for all the criteria, then sum the products to give the overall preference score for that option. Then repeat the process for the remaining options"* (Department for Communities and Local Government, 2009, p. 65).

An alteration is made to the value function first introduced in Chapter 3.3.2 to reflect the weighting if the attributes within each class. As mentioned, the purpose of having a separate weight within each class is to make a more transparent model allowing different stakeholders view, to influence the outcomes. Examples of applications are available both by Keenay (1992) and Accorsi, et al (1999).

However, if we were to weight 13 different criteria's, the weight of each criterion may not reflect the actual importance. It would also be very difficult to carry out if we were to use, e.g. the AHP method (ref Chapter 3.3.3).

Note

To calculate the value function, only absolute values should be used. We do not want to subtract the e.g. the risks from the opportunities and use this. The reason for this is may lead to loss of valuable input. It is also suggested to multiply the result by 10 to get a more scalable number, as small numbers may be difficult to separate from one another. It has not been identified the use of a "scaling" in other literature.

The examples provided in Chapter 4.1.5 are used to illustrate. R is risk, and O is opportunities

Example A $v = |-6{,}4|_R + 0{,}6_O = 7{,}2$

Example B $v = |-0{,}8|_R + 1{,}2_O + 0{,}8_O = 2{,}8$

Example C $v = 0{,}6_O = 0{,}6$

If not absolute values were used Example A and B would get respectively a score of 5,8 and 2,0. The underlying reason for doing this is the sum available when comparing the overall value for different proposals to one another. If the numbers were subtracted this could have introduced confusion, as opportunities are not favourable in the evaluation.

4.1.4 Define weighting for classes and attributes.

The weights for the trade-off between the different elements in an attribute tree could be made by simply making the decision maker appointing the weights. However, this does not seek deeper into the decision maker's preferences for certain outcomes (Accorsi, et al., 1999). Another problem is that the consistency between different preferences may also be a challenge. (Department for Communities and Local Government, 2009)

For an efficient decision process, different concerns have to be evaluated, as there often are several individuals or groups that are interested in influencing a decision. Hence, the decision maker may need to compare their own objectives and goals to other stakeholders. These goals may be shared, but weighted differently among the various stakeholders. The AHP process has been identified as a process inviting to prioritising between goals in an auditable and justifiable way. An example of different interested parties in this context may be within the organisation itself, Operations, Administration, HSEQ, etc. may be various parties having different prioritisation.

During a workshop, 15.04.15 there was conducted an exercise to derive weighting and prioritizing between the various consequence dimensions. Reference is made to the Analytical Hierarchy Process, described in Chapter 3.3. The prioritizing was performed by a pairwise comparison between the different objectives. This weighting was only carried out on the classes and do not represent the weighting within each class. For details regarding calculation, see Attachment A.

Table 8 - Weighting based on AHP procedure

Class\Focus	Org. Baseline	Mod. Baseline
Major Accident	**0,43**	**0,35**
Working Environment	**0,08**	**0,10**
Environment	**0,04**	**0,10**
Production	**0,24**	**0,25**
Cost efficiency	**0,20**	**0,20**
Total	**1,00**	**1,00**

From Table 8 we can see that with the Original Baseline Major accident and cost issues receive the most attention. Original Baseline weights are created as a direct outcome of the AHP process; the Modified Baseline weights have been established to even the weighting.

It is worth to mention that the weighting above represent a small group of individuals and are only related to a maintenance and modification context. This however does not cover field development, design or de-commissioning. It should also be questioned whether the values can be reproduced or not. However, this gives an indication of where the focus between e.g. safety and cost may be. The partial conclusion should be that the figures above should not be used as an answer.

It is further a suggested to implement a relative weighting index. The purpose of this is to reflect how different individuals (stakeholders) may express the weighting. As no universal way of weighting have been identified; this may be as fruitful as any else.

Table 9 - Weight from different stakeholders

Class\Focus	Flat	Original Baseline	Modified Baseline	Safety	Environment	Assets
Major Accident	0,20	0,43	0,35	0,40	0,20	0,20
Working Environment	0,20	0,08	0,10	0,20	0,10	0,10
Environment	0,20	0,04	0,10	0,20	0,40	0,10
Production	0,20	0,24	0,25	0,10	0,10	0,40
Cost efficiency	0,20	0,20	0,20	0,10	0,10	0,20
Total	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**

Flat – simply describes when all weights are equal
Original Baseline – the starting point of weights in a maintenance and modification context the weights are gathered from the AHP process
Modified Baseline – adjustment is made to even the weighting, as e.g. environment received subtle attention using the AHP process
Safety – high focus on safety, working environment and external environment. Cost and production have “less” attention.
Environment – high focus on solutions that favour the environment, cost, and production have “less” attention.
Assets – cost and production have a high focus, factors, as safety, working environment and the environment is “less” important.

By looking in Table 9, we can see that different stakeholders and individuals may have different prioritization. How this eventually will have an effect on the overall value, is interesting, this will, therefore, be used as a basis for the sensitivity analysis.

The following fixed weighting within of attributes is been proposed. Note that classes (vertical) have been appointed based on the AHP process ref. Chapter 3.3.3. The attributes within each class are weighted based on subjective judgements regarding their relative importance. A short discussion is provided below.

Table 10 - Weights within different classes

Major Accident		Working Environment		Environment		Production		Cost efficiency	
Safety barriers	0,40	**Technical requirement**	0,60	**Immediate spill**	0,60	**Maintain Production**	0,60	**Cost effectiveness**	0,6
Personnel injury	0,30	**Operation**	0,40	**Discharge**	0,40	**Accelerate production**	0,20	**Lifetime extension**	0,4
Dangerous fault	0,15					**Increase Recovery**	0,20		
Reliability	0,15								
Total	**1,00**		**1,00**		**1,00**		**1,00**		**1,00**

Safety barriers should have the highest weight, as this is the decisive element to prevent a potential hazard from escalating. Personnel risk is also important, but by having a strong focus on safety barriers, a higher number of injuries and fatalities may be prevented. Dangerous faults detected, and reliability requirements are weighted equally important.

Compliance with working environment requirements is considered slightly more important than functional requirements. As deviations from working environment requirements may lead to long-term disabilities

The immediate spills are considered as more important than emissions as this require drastic measures when they arise. This will also draw attention from other interest groups, and will as well require investigation of the event.

Maintaining a steady and predictable production is considered as the most important factor, acceleration and increase of recovery are exceeding the original plan and design.

It should be noted that these weights are open to interpretation and modification if there are anything that call for adjustments.

4.1.5 Assessing scores.

The purpose of this section is to provide practical examples. Attributes, weights and scores suggested in the previous section will be used. The columns describe input in Equation 4 and the rows describe attributes and consequences that may be affected by the modification proposal. A relative weighting index with a primary focus on *Safety* has been used in the evaluated of the examples below.

v_i	is the overall value of an alternative
w_i	is the value for criteria i
c_i	is the weight of a the importance of the class
a_i	is the weight of a the importance of the attributes within a class

Project A; Enhancing a production process to save maintenance time (CE), it is believed that this will extend the lifetime of the equipment due to tear and wear (LE). The maintenance activates is also considered as heavy, and operators have complained about back pain as large equipment is being moved manually (WE).

Table 11 - Example project A

	w_i	a_i	c_i	v_i	$v_i x10$
WE	-1	40%	20%	-0,08	-0,8
CE	2	60%	10%	0,12	1,2
LE	2	40%	10%	0,08	0,8

Project B; there has been trouble with the detection principles in the turbine chamber, resulting unfortunate trips as dirt cover the sensors. Hence, the detectors have to be inhibited (ST). A consequence of this is that detection not is available in periods. This is due to the inadequate technical solution. During every turbine stop a separate activity, have to be carried out to remove and clean the detectors (CE).

Table 12- Example project B

	w_i	a_i	c_i	v_i	$v_i x10$
ST	-4	20%	40%	(0,64)	-6,4
CE	1	20%	60%	0,06	0,6

Project C - The production from well X is limited as equipment Y is a bottleneck. Improving this may facilitate for a higher recovery from that well (RY).

Table 13 - Example project C

	w_i	a_i	c_i	v_i	$v_i x10$
RY	3	20%	10%	0,06	0,6

Now as attributes, scoring and weighting have been set up, the model may be applied. To use this as an aid to decision-making, we are interested in knowing three things.

What is the sum of the value function for risks associated with each the proposal? What is the sum of the of the value function opportunity related to the proposal? What is the total sum of the value function for both risks and opportunities associated with the proposal?

Table 14 - Score based on project A, B and C

	Sum opportunity	Sum risk	Sum total
A	2	0,8	2,8
B	0,6	6,4	7,0
C	0,6	0,0	0,6

As we see from Table 14, project A receives the largest sum for the opportunity and project B receive the largest sum for risk. The total sum is highest for project B.

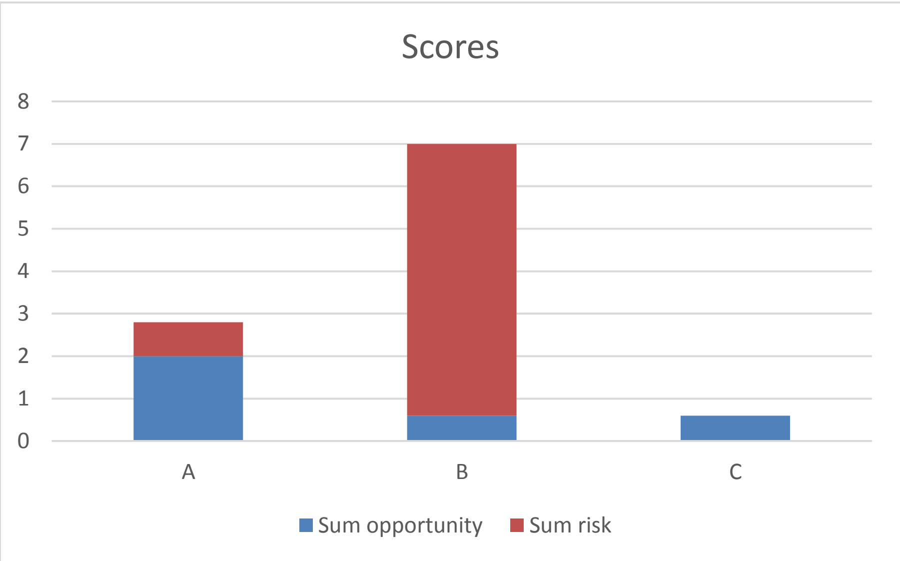


Figure 21 - Comparison between A, B and C in diagram

By applying a *safety* based weighting, modification proposal B, get highest preference value. Proposal A gets the highest score related to opportunities. Alternative C gets a low score since *production* not is weighted.

4.2 Case

The purpose of this chapter is to perform a case study on a selection of modification proposals. This will be divided into three parts

1. Apply the model to real modification proposals. This will show if there are proposals that potentially are not covered by the proposed structure.
2. Perform sensitivity analysis to see whether the weighting of different interest groups impacts the on the overall desirability.
3. Identify any potential adjustments to the model.

The idea is to investigate whether the MAUT is applicable for evaluation of modification proposals. The easiest way is, therefore, to use real (in this case old) modification proposals to see how the model applies. By utilizing both accepted and rejected proposal, it is possible to see if the desirability would have changed because of implementing the model. Some limitations have been made;

- Only the modification proposals forwarded in the period 01.07.12-01.07.13 (1 year) have chosen for further studies.
- The proposals go beyond corrective and preventive maintenance.
- A subjective scoring of the importance of relevant attributes has been performed; these numbers may not represent the desirability for other decision makers/expert team.
- Weights for each class and within each class are gathered from Chapter 4.1.4
- A sensitivity of the scores for each criteria's has not been performed

To avoid sensitive information that may expose EPN, not all relevant info is included regarding the modification proposals. The table below describes respectively, reference, purpose and status of each modification proposal. *Reference* column is used as an abbreviation for each project to keep track over how the desirability changes. *Purpose* provides a short description of what is desired to achieve. Moreover, *status* describes whether the measure has been implemented or not.

Table 15 - Modification proposals used in case study

Ref	Purpose	Status
A	Reduce temperature in potable water.	Approved
B	Lifting arrangement for sea water lifting pumps is unsatisfactory	Approved
C	Redesign of lifeboat lifting lugs, as complete testing not is possible on existing lifting lug	Approved
D	Optimisation of system logic system on 46, as pumps trips and cause extensive maintenance.	Approved
E	Venting of deep-water sensors, to ensure correct alignment of the platform and prevent wrong readings.	Approved

F	Modification of anti-surge panels, to avoid clogging.	Approved
G	Turning of level glasses on separators and scrubbers, to facilitate better working environment	Approved
H	Hooks for utility cabinet, to avoid trip hazard's and facilitate for better working environment	Approved
I	Level measurement system, to optimise detection principles and speed up time to stable system after shutdown	Approved
J	Permanent spill Oil handling system	Approved
K	Permanent H2S removal system for gas	Approved
L	Automatic hypochlorite injection t drinking water	Approved
M	Modification of MEG centrifuges to increase static pressure to salt tank	Approved
N	Prevent clogging scrubber	Approved
P	Change heavy doors in Living Quarter	Approved
Q	Optimize routing on helideck popup piping	Approved
R	Removal of oil fumes for compressor	Approved
S	Improve diesel drainage from firewater pump.	Rejected
T	Permanent access to roof for maintenance of local HVAC	Rejected
U	Local wall inside telecom/instrument office	Rejected
V	Dirty smoke(cigarette) container	Rejected
W	Generate overpressure in fire pump module	Approved
X	Install detection of MEG spill	Approved
Y	Installation of automatic grease-luber	Approved

An overview of the values used for the applicable criteria's that are used in the calculations are included in Attachment B.

Table 9 illustrate how different weighting of classes affects the output of the multi-attribute analysis. Different colours are used to show how the value changes depending on the applied weight. The columns represent the different weights for various stakeholders defined in chapter 4.1.4, and the rows represent modification proposals project described above. Dark blue indicate high value and dark red indicate low value. R is the sum of risk (negative consequences); O is the sum of opportunities and S is the total sum of the absolute value of R+S.

Table 16 - Results from value function

	Flat			Baseline.org			Baseline.mod			Safety			Environment			Assets		
	R	O	S	R	O	S	R	O	S	R	O	S	R	O	S	R	O	S
A	-2,4	3,6	6,0	-1,0	2,9	3,8	-1,2	3,0	4,2	-2,4	2,4	4,8	-1,2	1,8	3,0	-1,2	3,0	4,2
B	-6,0	2,4	8,4	-4,5	2,4	6,9	-4,5	2,4	6,9	-7,2	1,2	8,4	-3,6	1,2	4,8	-3,6	2,4	6
C	-6,7	0	6,7	-7,9	0,0	7,9	-7,2	0,0	7,2	-8,7	0,0	8,7	-4,6	0,0	4,6	-4,6	0,0	6,1
D	-2,1	1,2	3,3	-2,4	1,2	3,6	-2,2	1,2	3,4	-3,0	0,6	3,6	-1,5	0,6	2,1	-1,5	1,2	2,7
E	-4,0	0	4,0	-2,3	0,0	2,3	-2,6	0,0	2,6	-3,4	0,0	3,4	-2,0	0,0	2	-2,0	0,0	2,6
F	-1,0	3,6	4,6	-1,2	1,4	2,6	-1,3	1,8	3,1	-0,5	3,6	4,1	-0,5	1,8	2,3	-0,5	1,8	3,8
G	0,0	2,4	2,4	0,0	1,0	1,0	0,0	1,2	1,2	0,0	2,4	2,4	0,0	1,2	1,2	0,0	1,2	1,2
H	-2,0	0	2	-2,2	0,0	2,2	-2,0	0,0	2	-2,8	0,0	2,8	-1,4	0,0	1,4	-1,4	0,0	1,4
I	0,0	2,1	2,1	0,0	4,0	4,0	0,0	3,4	3,4	0,0	3,5	3,5	0,0	1,9	1,9	0,0	2,6	2,6
J	-1,4	2,4	3,8	-3,0	0,7	3,7	-2,5	1,2	3,7	-2,8	2,4	5,2	-1,4	3,0	4,4	-1,4	1,2	2,6
K	-3,6	3,6	7,2	-1,4	3,6	5,0	-1,8	3,6	5,4	-3,6	1,8	5,4	-1,8	1,8	3,6	-1,8	3,6	5,4
L	0,0	5,6	5,6	0,0	3,0	3,0	0,0	3,4	3,4	0,0	5,0	5	0,0	2,8	2,8	0,0	3,4	3,4
M	-5,2	0	5,2	-3,5	0,0	3,5	-3,8	0,0	3,8	-4,0	0,0	4	-2,6	0,0	2,6	-2,6	0,0	3,8
N	-2,8	4	6,8	-1,1	3,0	4,2	-1,4	3,2	4,6	-2,8	2,8	5,6	-1,4	2,0	3,4	-1,4	3,2	4,6
P	-4,4	0	4,4	-3,2	0,0	3,2	-3,2	0,0	3,2	-5,2	0,0	5,2	-2,6	0,0	2,6	-2,6	0,0	2,6
Q	-7,3	0	7,3	-10,1	0,0	10,1	-9,0	0,0	9	-9,4	0,0	9,4	-5,3	0,0	5,3	-5,3	0,0	6,5
R	-3,6	2,4	6	-1,4	0,5	1,9	-1,8	1,2	3	-3,6	2,4	6	-1,8	4,8	6,6	-1,8	1,2	3
S	-2,4	0	2,4	-1,7	0,0	1,7	-1,8	0,0	1,8	-1,8	0,0	1,8	-1,2	0,0	1,2	-1,2	0,0	1,8
T	-2,4	0	2,4	-1,7	0,0	1,7	-1,8	0,0	1,8	-1,8	0,0	1,8	-1,2	0,0	1,2	-1,2	0,0	1,8
U	0,0	1,2	1,2	0,0	0,5	0,5	0,0	0,6	0,6	0,0	1,2	1,2	0,0	0,6	0,6	0,0	0,6	0,6
V	0,0	0	0	0,0	0,0	0,0	0,0	0,0	0	0,0	0,0	0	0,0	0,0	0	0,0	0,0	0
W	-3,3	0	3,3	-7,1	0,0	7,1	-5,8	0,0	5,8	-6,6	0,0	6,6	-3,3	0,0	3,3	-3,3	0,0	3,3
X	-3,6	0	3,6	-0,7	0,0	0,7	-1,8	0,0	1,8	-3,6	0,0	3,6	-7,2	0,0	7,2	-7,2	0,0	1,8
Y	-4,4	1,2	5,6	-1,8	1,2	3,0	-2,2	1,2	3,4	-4,4	0,6	5	-2,2	0,6	2,8	-2,2	1,2	3,4

Blue represent highest values, and gradual shading down to red, where red represent the lowest value. The rows represent the different projects, and the columns represent weighting and respectively score for R, O and S.

From Table 16, it is possible to see that different proposals get different values depending on which weights they receive. We can see from the table that flat weighting generate higher values on the selected proposals than others do. Of the 24 projects, 14 of these get the highest score using a flat weighting. On the other end, we see that environmental weighting get the lowest score in 20 of the 24 modification proposals.

By sorting the table above from high to low in all columns, it is possible to see how it affects the overall desirability of the 5 projects with the highest scores for each weighting category. This could, of course, be extended to top 10, but 5 is evaluated suitable for the amount of data used.

Risk reduction potential

Table 17 - Risk values

Priority\Class	Flat	Org. Baseline	Mod. Baseline	Safety	Environment	Assets
1	**Q**	**Q**	**Q**	**Q**	X	X
2	**C**	**C**	**C**	**C**	**Q**	**Q**
3	**B**	W	W	B	**C**	**C**
4	M	**B**	**B**	W	**B**	**B**
5	Y	M	M	P	W	W

We can see from the table above that the model is quite consistent despite on different weighting of each class. Especially project Q, B, and C are included for all the different stakeholder preferences. It is worth to notice that there is no change between the Original Baseline and Modified Baseline.

Opportunity potential

Table 18 - Opportunity values

Class\Focus	Flat	Org. Baseline	Mod. Baseline	Safety	Environment	Assets
1	**L**	I	K	**L**	R	K
2	**N**	K	I	F	J	**L**
3	K	**N**	**L**	I	**L**	**N**
4	A	**L**	**N**	**N**	**N**	A
5	F	A	A	A	I	I

We see here as well from the table above that the model is quite consistent despite on different weighting of each class. Especially project L and N are included in all the different classes.

Total score

Table 19 - Total values

Class\Focus	Flat	Org. Baseline	Mod. Baseline	Safety	Environment	Cost
1	**B**	**Q**	**Q**	**Q**	X	**Q**
2	**Q**	**C**	**C**	**C**	R	**C**
3	K	**W**	**B**	**B**	**Q**	**B**
4	N	B	W	W	**B**	K
5	**C**	K	K	R	**C**	N

The most interesting table may be to look at the preference in the table with total scores. We can see that project B, Q, and C all are in the top five independent on the weighting. Project B, Q, and C also scored high on the opportunity. To visualise the partial consistency between the weighting Figure 16 – How different weighting (sensitivity analysis) may change the overall desirability using MAUT Figure 16 show how the development of scores depending on the weighting used.

The modification proposals that were declined (S, T, U and V) have received a slight different colour.

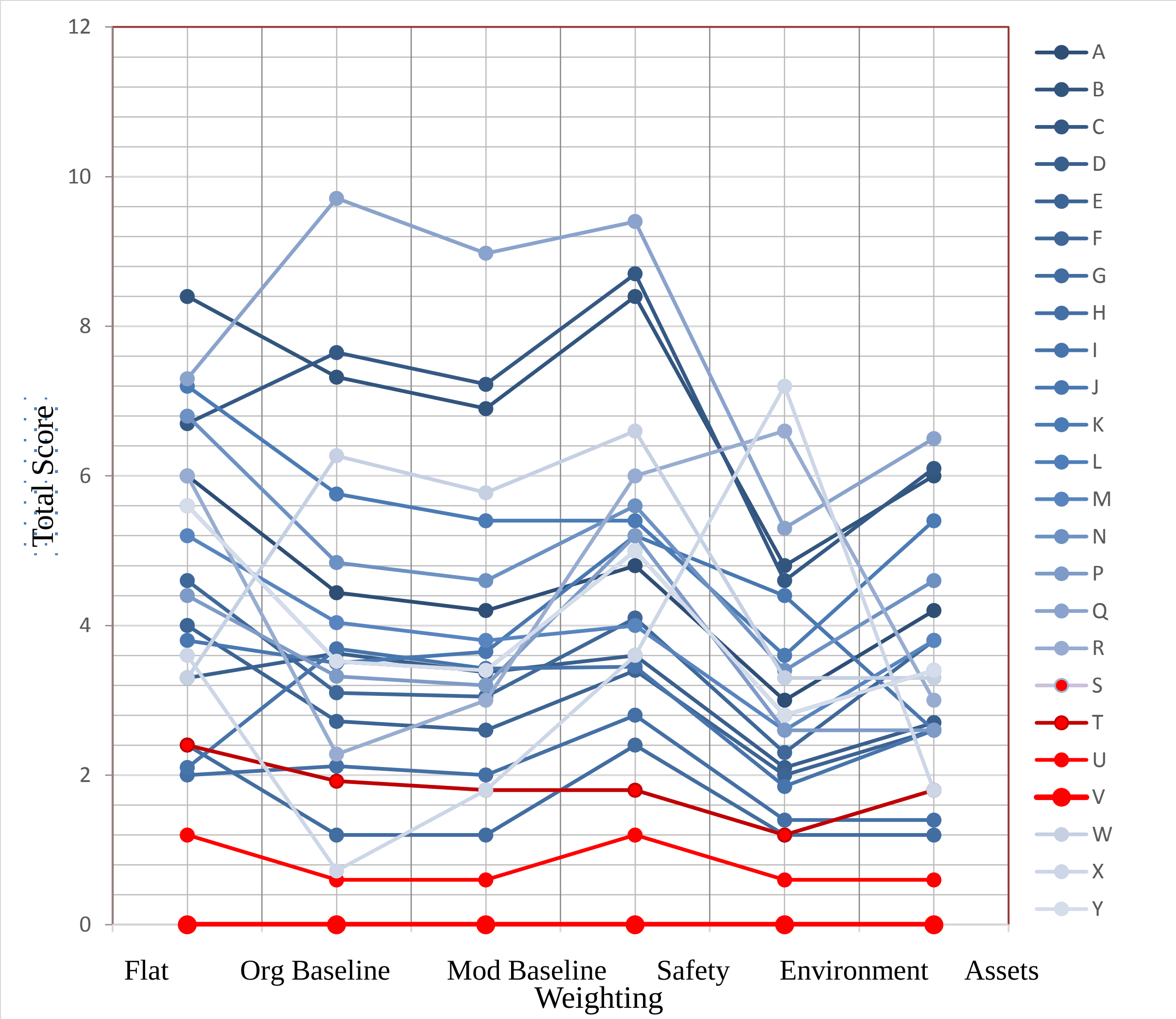


Figure 22- Scoring depending on relative weighting

Figure 22 search to visualise that the total value of the different proposals are somewhat consistent depending on the weighting used.

Y-axis represents projects (A-Y) ascending score, each project gets a point on this scale. X-axis describes the different weighting affecting results. Project S, T, U and V is coloured red. Project S and T received the same overall evaluation; hence, they follow the same line.

Line graph has been used as this shows how the sums of each project are changing depending on the weighting they receive.

4.3 Recommendations and adjustments.

In Chapter 4, a recommendation on how different modification proposals can be evaluated is presented. However, it is necessary to see how the evaluations can be applied as a part of the decision-making process.

The purpose of this section is to describe how the use of MAUT can be implemented in a decision situation. This chapter is structured as follows; by first giving some suggestions regarding the enrolment of proposals, second by giving a recommendation of how and when to perform multi-attribute evaluations and third, on how to select modification proposals between one another. The last section some general recommendations based on the findings and experience from this thesis. Figure 23 illustrate how different literature have been applied the decision problem.

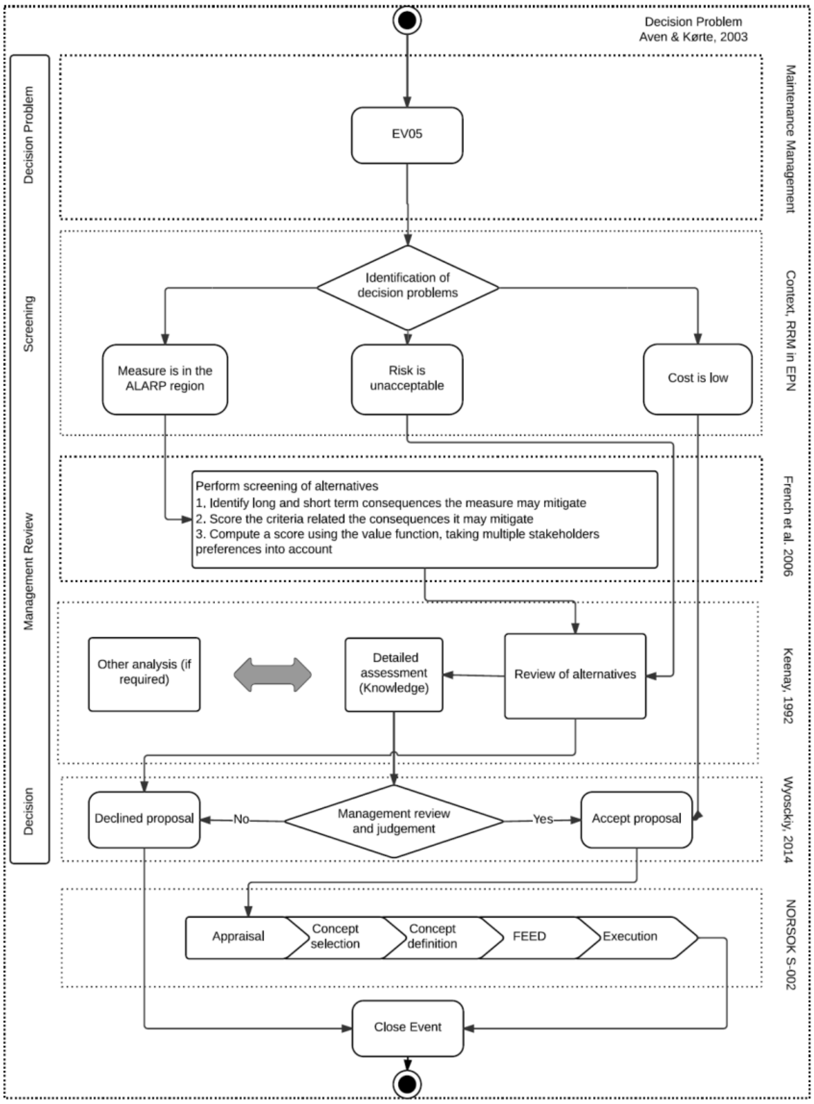


Figure 23 - Process and relevant literature

This figure does not invite to an overall process such that all roles are reflected. A proposal for a revised process is included at the end of Chapter 4.3

4.3.1 Enrolment of modification proposals

When a proposal for a technical change (EV05) is initiated, one of the first considerations should be regarding the input to the proposal. It is essential for the decision maker to have adequate decision basis. However, the first requirement for the process to work is that it should be a clear division on what is classified as modification and what is classified as a maintenance activity. A suggesting is that *only modification proposal involving a function change or considerable reconstruction* should be classified as an EV05. Which is somewhat in accordance with the definition provided (Norsk Standard, 2010) first introduced in chapter 1.1.

A clear description of the requirements for function change with the defined project drivers has to be prepared. The description should contain information on what is problem or challenge. Description of the root cause should be evaluated before the proposed solution is submitted. It should assess whether the need for a technical change has occurred because of that the function is not operated or maintained in accordance with the design.

- Reference to "Functional Location" (Tag) / System
- Description of the actual problem and the cause of the problem
- Proposed solution with any options
- Past experience (failure, history, events etc.).
- References to relevant requirements
- Risks of implementation

The information required above can be based on

- Documentation and technical information
- Dispensations (internally and against regulatory requirements)
- Other technical deviations
- Operators or other technical leaders.

The modification proposal should be evaluated before it is forwarded for evaluation in the technical change board.

4.3.2 Evaluate modification proposals

When all the required information is gathered, the following points is to be questioned by the Technical Change Board;

1. Is the risk unacceptable high? Then direct implementation is required
2. Is the cost "low"? Direct implementation is advised.
3. Is the risk in the ALARP region?

It is assumed that the Technical Change Board consist of representative personnel from different organizational units.

If the proposal is within the ALARP region, it is suggested to proceed with the multi-attribute analysis, based on the background data. The procedure have been defined as

1. Identify relevant long and short term consequences
2. Score the criteria (w_i) based on the maximum mitigation potential or consequence potential if no change is performed as presented in Table 7. If the decision maker belief that the mitigation potential correspond to value -3 by 30 percent, and -2 by 40 and -1 by 30 percent, -3 should be selected.
3. Compute scores using weighting from e.g. Table 9 (c_i) and Table 10 (a_i) by manual calculations, Excel sheet, COMOS or other software.

A proposal on how to such a tool could be developed have been made as a small part of this thesis. It is not a very attractive solution; however, it suits the purpose and limitations of this thesis.

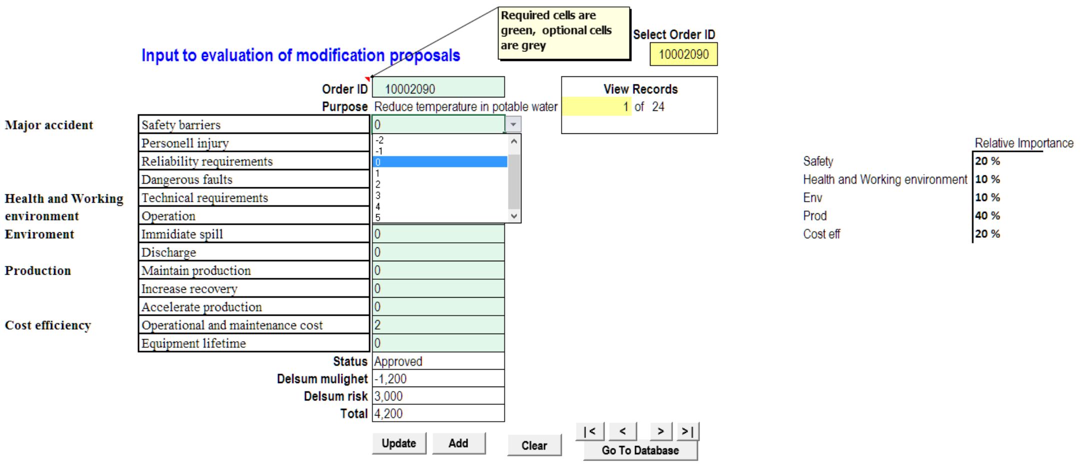


Figure 24 - Use of evaluation in EXCEL

By using the Excel file in Attachment D, it is possible to add, change, score and weight different classes and the weights within each class in a straightforward manner. It is also possible to prepare a description and add an event number for each proposal.

4.3.3 How to select between different modification proposals.

When several modification proposals in ALARP region has been identified, evaluated and prepared, a review should be performed by the Technical Change Board to evaluate which proposals that are to be given priority.

It is suggested to hold frequently meetings ex. Bi-Weekly or Monthly, so that the proposals can accumulate and then see which proposals should be subjected to further justification. It should be possible to evaluate both new proposals (generated from last meeting) and existing proposals to see how new proposals meet existing modification proposals not initiated. The reason for this is that existing proposals may have a higher score/desirability than new proposals. A general reference to Chapter 3.4 is given to how decision problems should be handled in an ALARP environment.

If further analysis is required, this should be performed and used in the managerial review and judgement. An example of this may be to receive estimates on the implementation cost, ENPV, or similar and then compare them to it to burdens and benefits of the project. An example of this is provided in Figure 25.

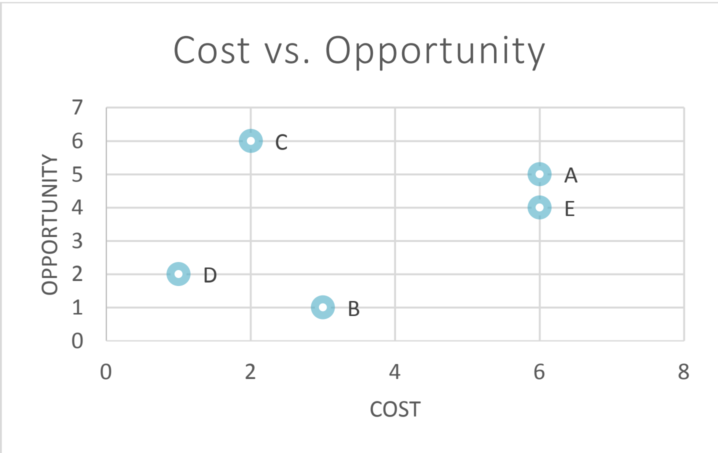


Figure 25 - Comparison between cost and opportunities

The figure above illustrates how project A, B, C, D and E score to each other based on cost and opportunity.

It has been evaluated as undesirable to implement pre-defined criteria in regards to whether a project should be implemented or not. This could be a “measure” of whether the project is considered as efficient or inefficient, e.g., “all projects with a score above 10 are efficient”. This does to some degree conflict with the theory regarding the use of expected values and acceptance criteria presented in Chapter 3.2.

Managerial review and judgement should take into consideration assumptions and limitations the analysis does not cover. Background information related to gross disproportion and performance presented in Chapter 3.2 should be discussed.

Considerations to the following factors should be included (Aven & Kørte, 2003)

- The decision alternatives being analysed
- The performance of the measures analysed
- That the results of the analysis represent individual judgements, to a large extent conducted by stakeholders and specialists.
- The challenge of assessing values for cost, benefits, and uncertainties
- The fact that the analysis results apply to a model

These considerations are important as the model only consider a few possible outcomes or events, depending on the data applied. It should also be decided whether other types of analysis should be provided.

Based on the finding the decision maker performs a review and judgement of the relevant data makes a decision other factors such risk perception and reputation should be evaluated when relevant. Further, an evaluation of all available alternatives, type of project (in accordance with portfolio management), complexity and success criteria's together with the boundary conditions of the decision problem should be made.

Depending on the size and complexity, a study should be initiated to ensure a solid technical solution. It should be checked in every phase of the project that the assumptions and basis for the project are still valid.

This evaluation cannot cover all proposals; some proposals may have deeper reasons to be carried out. However, the model may give a recommendation for which proposals that should be subjected to further evaluation based on the score it gets from the applied model.

4.3.4 Other recommendations

Quality assurance of the input to the evaluations are essential, as subjective evaluations can lead to manipulation of results as uncertainty regarding the consequences is reflected in a low manner.

The process first described in Chapter 2.1 has been adjusted to reflect the focus on knowledge, and creating alternatives, including providing analysis as input to the decision process.

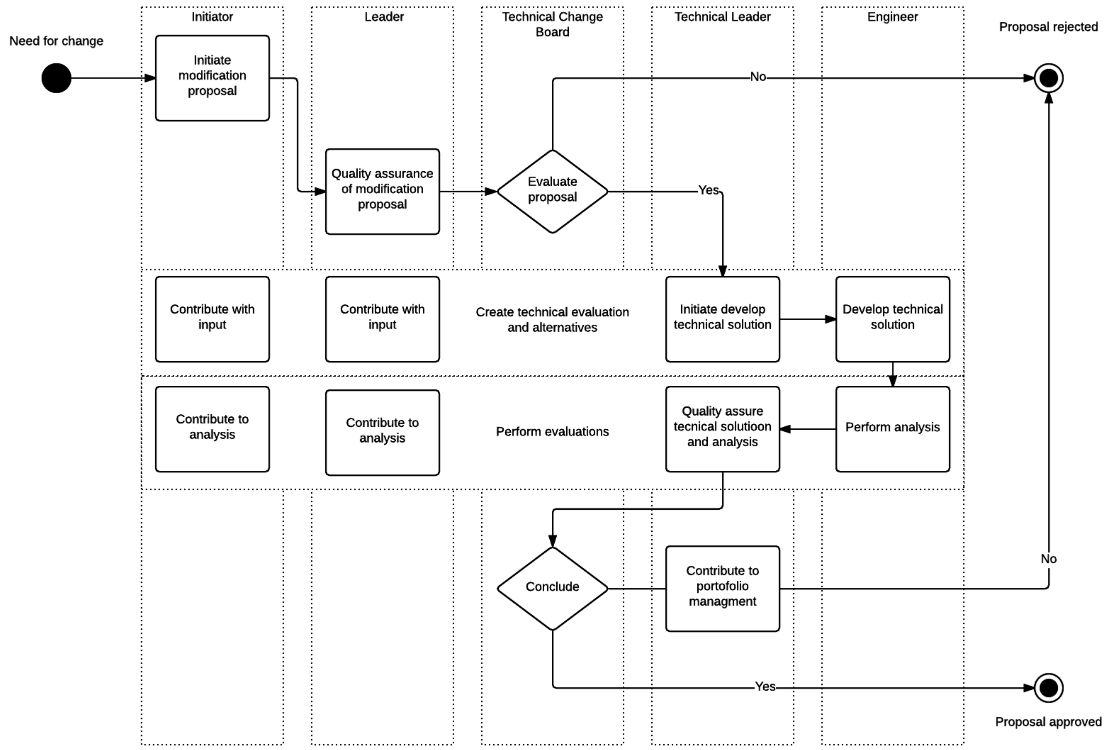


Figure 26 - Proposal for evaluation process

The suggested evaluation process still allow for that the identified modification proposal should include enough details so the evaluation process can be done correctly, however a more detailed requirement is suggested ref Chapter 4.3.1.

The next step is identical; the leader shall still evaluate the quality of the proposal. However, it is proposed that the proposal should be forwarded to the Technical Change Board rather than discipline engineer. The reason for this is that it may lead to better resource management, as the resources are controlled in a more sufficient manner (following portfolio management ref Chapter 3.1.4.). If the Technical Change Board evaluates the proposal as of importance, the proposal should be appointed to a technical leader for further justification. This may involve forwarding it to an engineer for further assessment, analysis can be supplemented if required. An example of what this may require is included in Attachment C. Further the proposal is then sent back to Technical Change Board for a final evaluation. Depending on the outcome and all the factors considered above the proposal is; rejected, sent to in-house engineering or contractor.

If the cost is considered as low, the measure can be sent to the technical leader for implementation rather than the development of the technical solution. If the risk is considered as unacceptable, the measure should still be evaluated to ensure a good technical solution.

An alternative could be to perform the MAUT in all stages to see the risk perceptions of the different individuals.

During the aging of the facility, some of these proposals can be interpreted as signs of weakness. The model as a whole does not address conditions of the specific barriers or elements that the measure may improve. However by incorporate the measures into a framework for a Barrier Management System, an overview can be made whether the situation addressed is affecting proactive and reactive barriers.

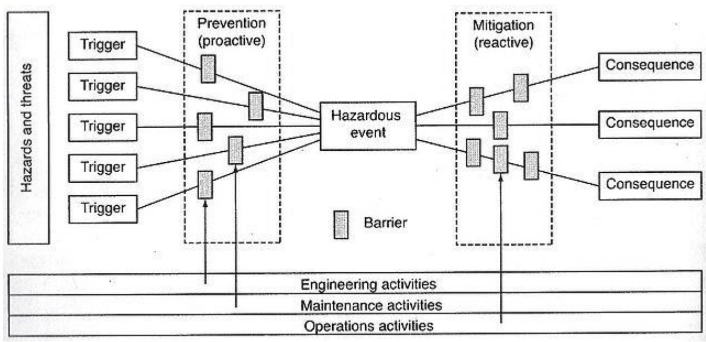


Figure 27 - A bow-tie diagram of risk management (Rausand, 2011 p.120)

As mentioned in Chapter 3.1.1 AIM can be used to control barriers and functions to ensure safeguarding of life and the environment.

Another benefit of collecting information regarding weak point is that it may contribute when updating the Total Risk Emergency and Preparedness Assessment (TREPA), as these are based on several assumptions, which may be difficult to handle in a practical context.

5 Discussion

5.1 Regulations and standards.

A large number of requirements affect ALARP decision making. Many of these are related to internal requirements and philosophies. Some of the requirements also include compliance with standards and authority requirements.

One of the main problems identified by the enforcement of the ALARP principle is the achievement of the requirements prescribed in e.g. NORSOK Z-013. High focus on meeting these requirements may lead the focus away from creating good decision alternatives, as presented in Chapter 3.2. It is stressed that some requirements are required to simplify the planning process; examples of these may be when designing safety systems and safety functions (Aven, et al., 2006).

Nevertheless, some requirements, like e.g. the use of BAT (Best Available Techniques) (NORSOK, 2001), evaluations in decision-making, may conclude that the alternative with the lowest environmental impact should be chosen, even though there may be significant factors (reliability, complexity, etc.) the analysis do not cover. It is therefore highlighted that different outcomes should be reflected as a part of decision-making.

By constructing a model that enable the decision maker to evaluate whether the modification proposal in question are related to specific outcomes, it will help to facilitate better alternatives as several areas are taken into consideration. Linking attributes to specific consequences are therefore evaluated as important, as this may cover several aspects traditional methods do not cover.

Another interesting finding in this context is related to the work performed by Vinnem et al., (2006), that concludes that the operators may have problem implementing the ALARP process as a part of their framework for RRM and decision-making. From this research, it was discovered that several of the operators on the NCS had limited the ALARP principle to quantitative analysis, i.e. only cost benefits analysis. The regulations provide very few specific requirements for decision-making. It follows that the risk reduction process at least should ensure compliance with legislation, including company requirements and risk acceptance criteria. Challenges associated with decision-making should, achieve a broad process and inverted "burden of proof" as a basis and be released from qualitative risk as the primary supporting basis (Aven & Kørte, 2003).

This may indicate an absence of a tool or process, which generally could lead to better consistency in decision-making. As a part of this thesis it was initially planned to carry out a survey to see how different operators (both drilling and production) carried out such assessments for their facilities, this turned out to be a very sensitive area, hence no useful results were returned. A total of three drilling and three operators on the NCS were contacted.

5.2 Literature review

As presented, a wide range of decision theory exists. The theory introduced by Neumann & Morgenstein (1953), in Chapter 3.2, provides statements on how a decisions-maker should behave rationally, however the use of these axioms are questioned in the approach of risk acceptance criteria and ALARP (Abrahamsen & Aven, 2008). Further Aven & Kørte (2003), argues in the discussion of expected utility theory that the only way risk and decision analysis can be rational to assist decision-making, is when the decision maker is consistent with preferences amongst consequences and in his assumptions about uncertainties. Furthermore, if these requirements are fulfilled; expected utility theory may be attractive as it provides recommendations based on a logical, mathematically coherent basis (Aven & Kørte, 2003).

They further question whether such analysis provides sufficient information to decision makers, which is adequate as a basis for the decision in question. Moreover, that decisions makers require more information than these approaches provide (Aven & Kørte, 2003), as e.g. CBA do not take into consideration that the information may be based on weak knowledge. A challenge using CBA as decision aid is that various individual preferences are reflected in a low amount (Aven & Kørte, 2003). These individual preferences may be answered using the MAUT as it invites to the discussion of individual preferences (French, et al., 2007). An identified problem in general is with regards to the transformation of the values to comparable sizes e.g. cost, environment, or safety.

The MAUT offer simplification in the assumptions and recommendations in a practical context. The evaluation may reflect a clear value, based on the input (which may include assumptions and evaluations). However, in effect, the result of the value from MAUT evaluation may be difficult to relate in a decision context (Aven & Kørte, 2003). One of the benefits addressed by using MAUT is that the model may be designed such that the decision-makers preferences can be represented in a sufficient way, taking several stakeholders value into account. The AHP process presented provides a justifiable way that may help to prioritize different stakeholders concerns (Accorsi, et al., 1999). This actually forces the decision maker to think in a clear way about its preferences (Bedford & Cooke, 1999).

The main argument in this thesis for using MAUT is that it is quite easy to understand and to use. MAUT does to a large extent take subjective judgements into consideration, as it allows the different stakeholder to use their own weights in a decision problem, which despite weighting differently may lead to the same conclusions. The reason for this is that it may help different stakeholders realise how close far away they are or in disagreements, and what divides them. (Department for Communities and Local Government, 2009)

It should be questioned how the MAUT approach disproportionality and the four justifications for the gross disproportion as presented in Chapter 3.2. It is an suggested, that MAUT require these points to be evaluated as a part of the method. Benefits and burdens are expected to be judged after scoring the different attributes, which make the decision maker being able to evaluate these factors outside the model itself. Uncertainty have to be taken into consideration as the approach requires subjective evaluations and acknowledgement of these, implicit meaning that judgements are performed beyond expected values. The MAUT do not capture an effect on “baseline” risk itself, however if comparing several alternatives within e.g. a system to another it may be possible to see how the alternative performs. This may be linked to the last justification of gross disproportion, which is related to selection of the most efficient solutions in complex systems regardless to understatements to participants.

Both the CBA and MAUT are frameworks helping, to structure degrees of beliefs about outcomes and subjective values of these. Before the decisions are taken, the review and judgment phase should therefore, take into account limitations that the model cannot cover (Aven & Kørte, 2003). Therefore, several aspects are also covered by decision theory; this will be covered in the next section.

The significance of knowledge in a decision context is stressed as crucial for all participants in decision making, as risk and uncertainty are more than, history, probabilities and expected values (Norsk Olje og Gass, 2014). Basic understanding of risk management in project phases and required input quality has to be highlighted, as well as the relationship between internal and external stakeholders. The purpose of this is to see which “forces” that can influence the result.

There are significant amounts of decision theory available; the starting point for this thesis was to develop a tool that could be used for decision-making. Covering all angels seemed reasonable at first, but after grasping the amount of available literature, it was realized that it would not be possible to include all available methods. However, the work of French, et.al (2007), appeared attractive based the achievement of certain objectives, which is the starting point for modifications, to achieve higher performance in one or several areas. Another problem identified at an early stage is that the input values for e.g. cost are uncertain in an appraisal phase. It is believed that by simplifying the use of risk and decision analysis, better risk management can be achieved simultaneously with cost efficiency, as continuous improvement is an important contribution to safety.

It was not desirable to use the discount rates and utility functions as presented by the work of Bedford et.al (2005), as this would complicate the decision itself, as various positions within EPN are required to provide input to the evaluation of modification proposals. The starting point lead to the framework on how to structure objectives and attributes provided by Keenay, (1992). With this as a basis, additional literature was used to build a model that could be used for MAUT in decision-making.

If there were more time, it would be possible to see how different alternatives of Multi Criteria Analysis could be used on several decision objects, and how different methods of treatment would affect the required input and output. The partial conclusion is that the available literature indicates that the use of MAUT can be considered as useful in a decision context. The method should be used in the perspective of an overall judgement rather than being used as a mechanical approach in the selection of the best alternative (Aven & Kørte, 2003).

5.3 Recommendations

A recommendation for how selection criteria and a model for evaluation proposals have been suggested. There are several of the aspects of the recommendation that to be discussed, as there may be some ambiguity to the proposal. The first point of discussion will be the proposed evaluation criteria's.

The use of several attributes within a class may introduce uncertainty regarding the importance and impact of the results. As some classes have fewer attributes than others, this may introduce some concerns regarding the importance of every attribute. E.g., Major Accident has more attributes (four) than Environment (two). However, all classes are weighed mutually and are divided into classes with the different attributes weighed with each other. The values may help solving the question regarding trade off, and whether some criteria's receive higher built-in values than others.

It is argued that criteria's that are suggested are clear and logical, as they reflect the desirable fundamental properties in Table 2. It was through a review with EPN considered that they were applicable to the decision context, however, as these are individual interpretations others may challenge them as it may be difficult for the users to understand the underlying assumptions (Aven & Kørte, 2003), therefore communication and understanding of each criterion is a significant factor in the use of these.

This use of weighting may result in that some operational goals may not be of a specific "interest" or value by the decision maker. An example of this is the one described for an increase of in Chapter 4.2. Here it was used a relative *safety* weighting that had the effect that the value of *production increase* was insignificant compared to other alternatives. However, as described earlier, by adjusting the weight to draw attention to respectively production, the proposal would get a higher score. A partial conclusion may be that the decision-maker need to have an opinion regarding the importance of the different viewpoints related to a decision. It should also be questioned whether the proposed tool give preferential treatment to capacity increase or investment projects as a whole. This type of projects would maybe be captured by other instances, rather than maintenance and modification proposals. It is further concluded that the changes in weighting and preferences may change the desirability of a proposal.

The use of AHP process to appoint weighting have been challenging as, 1) there do not seem to exist any answer on how people should prioritize between different objectives and, 2) the introduction of several weights for different categories are also may seem suspect as the decision makers may not understand the implications of the numbers they assign (Aven & Kørte, 2003). Further, the following concerns to using the AHP have been identified as relevant for this thesis method (Department for Communities and Local Government, 2009).

1) Linking between the scale and definitions are there arbitrariness in the interpretation of the different scales and definitions, how do individuals perceive this? Which may be difficult as

only subjective evaluation of the importance is performed, e.g. how do different individuals interpret that alternative A is nine times as important as B?
2) Electing weights before criteria's are set, which is related to that the decision maker have to make statements of relative importance without being aware what is compared.
3) AHP is not empirically testable; changes in preferences over time may change the assumptions of the method.

All the points mentioned above may be challenging as MAUT relies on the assumptions that the decision maker is stable, consistent in judgements and that preferences do not change (Aven & Kørte, 2003). This may be difficult in practice, when we can expect some turnover in the involved personnel and up to three different shifts offshore, as the different personnel may interpret the scales within each attribute differently.

Using attributes on a scale from -5 to 3 in the evaluation model seems like an attractive mathematical concept as it invites the decision make to perform pairwise concrete comparisons to prioritize the different alternatives. By using this method, it is also possible to appoint precise definitions for each value. At an early stage in the thesis the evaluation scale from 0-1 (or 0-100) were identified. It seemed somewhat difficult to create values in the 0-100 range regarding the importance of attributes when comparing them to one another. The use of attribute levels introduced by, Keenay (1992), show that it is easy to set maximum and minimum desirable levels for the evaluation of the performance of each attribute. Scores are developed from the performance of alternatives with respect to an individual criterion and aggregated into an overall score. These minimum and maximum acceptable levels could be adjusted to implement the 0-1 or (0-100) range. Another feature of scaling is that it can be adjusted to place emphasis on certain outcomes such as individual and group risk. If there were more time, this would be done in the thesis, to see whether this influenced the result. Note; AHP process may approach the Multi Criteria Analysis by itself (Zanakis, et al., 1999).

Use of pessimistic and optimistic values in the selection of values should be evaluated, as this is essential for the evaluation of modification proposals. The use of MAUT in this setting requires evaluating the consequences of as is situation, or/and if no modification is performed, this may be considered for both point-in-time risk and potential future changes. Some individuals would immediate maximize the expected outcomes of any identified measure; meanwhile some underrate the impact of the identified measure. It is believed that trough communication and frequent use there might be a shared understanding of the consequences related to the different identified modification proposals.

This is the point where uncertainty is taken into consideration by using pessimistic values for the negative consequences and optimistic values for opportunities. The though is that uncertainty is associated with future consequences and the multiple objectives those consequences may realize (Keenay, 1992). It might be possible to establish a 'confidence' criterion, but options are then assessed for their relative risk, however, the key players who wish to define risk, are required to use preference scores rather than probabilities.

The approach suggested does not require the decision maker to establish a probability or a confidence interval of the outcome. This approach is a conservative, as it not seeks to the decision makers uncertainty regarding the expected result of the mitigating measure, hence revolve the definition of risk provided by PSA. The main reason the MAUT have been simplified such a way, is that the decision require simplification in the process. Usually, probabilities are a measure of the amount of uncertainty about the occurrence of an event (French, et al., 2007). However, at this stage in the decision, a simplification is required as there is personnel do have limited knowledge of the possible future consequences. Focuses on the identification of possible hazardous outcomes rather than prescribing the belief in these by probabilities seem like a reasonable thought. Then uncertainty and disproportion is handled by the managerial review rather than a part of the value itself. Hence, the precautionary principle is somewhat reflected in that the most severe consequences are anticipated.

The recommendation does to some degree build on the expected utility theory axioms presented in Chapter 3.2, as it assumes that the decision maker always can decide between different alternatives. It also follows the *transitivity* axiom that assumes that an individual also decides consistently. In this coherence, it carries that the decision makers do not change it preferences for a decision problem over time and that similar, future decision problems will be treated equally. It also requires that the decision maker appoint sufficient resources such that the different proposals can be executed. It is beyond the scope of this thesis to suggest an optimal investment level. Still, the highest expected utility should not necessarily be chosen.

As mentioned at the beginning of this chapter, the mathematical concepts of using MAUT approach have not been evaluated, and may be questioned. A comparison of different methods of implementation of Multi Criteria Analysis, conclude that it may have an impact of the prioritization of the alternatives (Zanakis, et al., 1999). The use of such model does not tell us whether the ALARP principle is met. However, by discussing and prioritizing the measures located in the ALARP region (Figure 17), this may lead to taking decisions that have an overall higher impact on the safety level. Compared to e.g. the CBA or CEA these methods do not scale the performance of different alternatives compared to each other. Based on this the following success criteria for using such a model can have been identified;

- Understanding and knowledge of the problem addressed
- Rational and consistent judgments have to be performed
- Decisions should be made as a group, or be checked, to ensure consensus.
- Disproportion should be handled afterwards as a part of the management review
- It is assumed that the decision maker is rational when electing resources

Comparing the benefits to the burdens of using such a model do result in that the benefits are high, as the selection of different attributes engages in the discussion of the criteria to support a decision. By the use of budget and portfolio management, this may also ensure a constant improvement in safety level within all disciplines depending and utilizing the available resources. The burdens by using such a model are that the value produced does not have any significant meaning before comparing several alternatives to one another.

5.4 Evaluation of modification proposals

The process proposed in Figure 26; do share many of the same points as Aven & Vinnem, (2004). The decision maker should start by performing a crude analysis of burdens and benefits addressing various attributes, from this the crude analysis, will eliminate some alternatives and may include new ones. The implementation of the Multi-Attribute analysis itself is suggested to be conducted in the first part of the evaluation to see how different proposals scored one another. The multi-attribute analysis is then used to screen out the various alternatives for further evaluation.

Further, it will be necessary to identify and define decision problems, opportunities, and alternatives. The third step is to perform a more detailed analysis if required; this may be in, e.g., high investment projects where there may be incentives to postpone a project, or as the last part of the plausible justifications for the "gross disproportion" implementation of ALARP, where the decision maker may try avoiding a RRM. This help narrowing down the favourable alternatives through a formal process. Managerial review and judgement should take into consideration assumptions and limitations the analysis does not cover. Therefore, it is important that the outcome of an analysis is reviewed and evaluated, as certain factors not can be replaced by a one-dimensional formula, together with complex judgements. This does not mean that CBA or CEA should be avoided, but that that the decision process itself should ignore such problems and focus on the judgement itself (Aven & Kørte, 2003).

Based on the findings the decision maker performs a review and judgement of the relevant data makes a decision other factors such as risk perception and reputation should be evaluated whenever relevant. Opportunities and risks should be compared to one another, along with the knowledge not captured by the values addressed. Which capture the essence of decision-making – to understand the decision problem.

During each stage of the development of the technical solution, it should be assured that the underlying assumptions and conditions not are changed.

The approach suggested does at some extent reflect the RRM principles presented in Chapter 2.1.2 where it is stated that,

a) A risk reducing measure should be implemented without further assessment of benefits and burdens if compliance with relevant requirements not are achieved.
b) Perform a coarse qualitative analysis of the benefits and burdens of the risk reducing measure. If the costs are not judged to be large, the measure is to be implemented. Significant disproportion has not been demonstrated.
c) More detailed analysis if the costs are considered large

However, the first point on this scale would be direct implementation, it may seem easy, and not rational that the evaluation should be performed on such internal requirements, the technical solution should be evaluated regardless of its importance. The second and latter item of the risk reduction process this could normally be approach by the MAUT, as the approach suggested conducting a crude analysis of the burdens and benefits. The more detailed analysis would be performed after further investigation or development of the concept as indicated in Figure 26.

Another question appearing is whether proposals that do not contribute to a reduction in the probability of accidental events should be handled using this process and compared to ALARP decision-making. As a part of the thesis, all kinds of proposals have been equally weighted, regardless of their impact, as opportunities are considered as well as risks. An idea could be to “categories” the urgency of the proposal i.e. on a scale from *nice-to-have*, to *internal requirements,* to *statutory requirements* and *risk reducing measures that need to be implemented* to avoid shutdown or similar consequences. However, this is beyond the Scope of this thesis, but could easily be incorporated to e.g. Figure 17, that show the ALARP «triangle». It should also be mentioned that by applying the two “regions” of ALARP principle no proposals would be to small or insignificant to for the within the boundaries of the model.

An interesting finding from the case study was that there is some ambiguity regarding what should be classified as a modification proposal or not. It seemed to be difficult to separate between different types of maintenance, replacement, modifications, and investments. An alternative could be to classify these further.

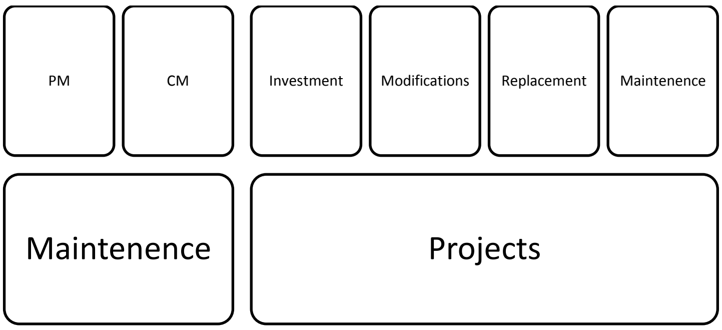


Figure 28 - Segregation between different types of project

From Figure 28 maintenance and replacement can be linked directly to the Barrier Management and Integrity Asset Management while modification and investments may be related to improvements and other achievements or long-term goals. It is worth mentioning that the suggested model not were part of the initial scope of this thesis, however it have imposed itself forward, as the suggested model may not be applicable for evaluation of all the categories mentioned above. This may be linked to portfolio management as described in Chapter 3.1.4. Risk evaluation performed as part of the decision basis for barrier management must be planned and executed, so is detailed enough and appropriate to the analyse (PSA, 2013). The suggested process proposed does to a large extent take a contribution and knowledge from other parties and stakeholders into account.

Implementation of the MAUT is not considered as a challenge; see Figure 24 for an example of practical implementation. This can also be found in Attachment D.

5.5 Case study

One of the most interesting findings regarding the sensitivity evaluation of the multi-attribute theory is that it is less sensitive to changes weighting and, therefore, seems to be insensitive when considering different stakeholders perspectives. This show that input data matter and that sensitivity analysis help reveal the tolerance of results to the various stakeholders perspectives.

From Figure 22 it is possible to see that the projects that not were approved (S, T, U, and V) in the portfolio (2013-2014) got a relative low score compared to the other alternatives. This could lead to a corresponding broad discussion whether the model reflects the decisions actually conducted, however, this is not done as the evaluations made of the proposals are broadly made as a personal assessment. It is worth mentioning that in the period of the modification proposals, a system, which categorised preference of proposals, were not available, hence the evaluation were made on a clear managerial basis.

The assessment of the importance of each project does contribute to a significant uncertainty in these results. The uncertainty is related to how the different modification proposals are scored. It should also be asked whether the "know-about" regarding acceptance influenced the results. However, a point is proven, that the attractiveness of modification proposals can be screened evaluated based on limited information and knowledge. As mentioned in the previous section, uncertainty has to be evaluated after the scores are evaluated. An identified problem by this is that the decision maker does not evaluate attributes as relevant for the proposal.

The difference between the sum of risk and opportunity have not been interpreted any further, as this to a large extent would be more applicable to each decision situation to consider the trade-off between pros and cons as indicated in Figure 22. The decision maker should, therefore, handle this during the managerial judgment and review. An important question is how the extent of different modification proposals affects the model if e.g. a project is considered as large will this lead to a high score, as it attracts many attributes? Not necessarily, as smaller projects may be as efficient as large ones.

Another point worth mentioning is that none of the projects represent large "investments projects". The model does neither reflect the cost in such a way and has not been checked as a part of the thesis. Nevertheless, it would be interesting to see if the use of e.g. man-hours responded to the scoring of the project.

The last "concern" regarding is whether the use of the performance criteria used in chapter Table 7 are evaluated correct, as it opens to that some projects may be evaluated as an opportunity rather than a risk or vice versa. Depending on the evaluation, the model will anyway give a contribution to the overall score.

It should also be noted that the case study was performed on the modification proposals on the GJØA facility. GJØA is relatively young compared to its design life and, therefore, the method might have spread differently on another facility (or older facility), which other challenges or underlying assumptions.

6 Conclusions and further work

6.1 Conclusion

The thesis has suggested a tool for decision support in the selection of modification proposals. During a search for alternative methods, the MAUT has been identified as a conspicuous method that invites to an open, transparent and clear evaluation. MAUT may also reply to some of the questions regarding disproportionality, and the individual risk that in contrast to the CBA and CEA may avoid the use of indistinct values.

Development of decision alternatives is primarily driven by the boundary conditions of the decision problem, settled by experts and management. The boundary conditions include stakeholders' values, organisational goals, standards, and preferences, as well as governmental and societal concerns. By reflecting these in the creation of the different criteria, a versatile model can be created.

By using strategic values to the organisation, as well as maintenance strategy it was possible to construct and build a model, which reflected the desirable outcomes of the decisions to be made.

It has been suggested using a multi-criteria value function, which makes it possible to see how the evaluation of different criteria can be combined into one overall value. The overall value can be used to compare both opportunities and risks on suggested modification proposals to one another. The idea is that the values express the performance of the identified measure based on which potential consequences it may mitigate.

To ensure that risk-based decisions go beyond expected values, a framework has been suggested focusing on gaining knowledge and creating alternatives, as it is argued that decisions makers require more information than the MAUT provides by itself.

Through a case study, it has been indicated that the MAUT is less sensitive to changes in weighting from different stakeholders. It has also been demonstrated that it is useful as it may comprehend uncertainty by choosing the highest plausible consequences. Another finding from this is that it may not seem rational to collect all types of technical changes under one category, as some are related to retaining barrier performance, and some are related to continuous improvement and investment projects.

The overall conclusion is that the MAUT may be considered useful as decision support in a modification context. MAUT should be included in the overall judgement rather than being used as a mechanical approach in the selection of the best alternative in a decision context. It requires the decision maker to have an opinion regarding the importance of the different stakeholders, which capture the key essence of the decision making to make informed decisions.

6.2 Further work

EPN

- Practical implementation of the suggested framework, trough procedures, and other required instances.
- Implementation through a Barrier Management System.
- Look further into classifying and segregating different types of modification projects.

General

- Comparison how e.g. CBA, CUA, and Multi-Attribute Theory may approach the same problem.
- Study on how uncertainty is implemented through Multi-Attribute Theory in a practical manner.

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Figures

Tables

Equations

ATTACHMENT A – AHP Calculation

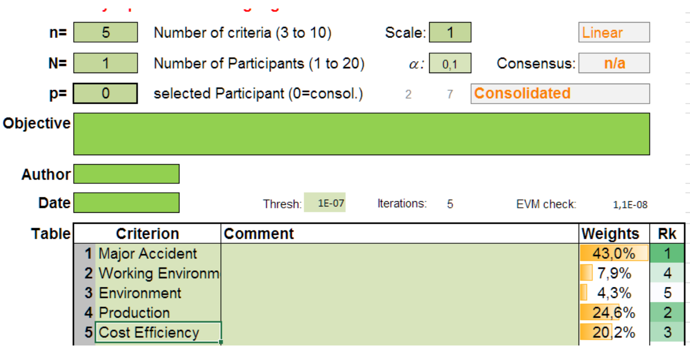
Based on five pairwise comparisons, the participants were required to respond to a pairwise comparison question asking the relative importance of the five. The nine-point scale described in chapter 3.3.4 was used to perform the verbal comparisons. If the judgement is that *B* is more important than *A*, then the reciprocal of the relevant index value has been assigned.

For example, if *Major Accident* were felt to be very strongly more important as a criterion for the decision than *Environment*, then the value 1/7 would be assigned to *Environment* relative to *Major Accident*, the reason for this is that the decision maker is assumed consistent in making judgements. Based on this a 5x5 matrix were establishing to evaluate the relative importance of five criteria's.

Table A.1 – The AHP process

	Major accident	Working Environment	Environment	Production	Cost Efficiency
Major accident	1	5	7	2	3
Working Environment	1/5	1	3	1/5	1/3
Environment	1/7	1/3	1	1/5	1/5
Production	1/2	5	5	1	1
Cost Efficiency	1/3	3	5	1	1

The individual weights were calculated based on the eigenvalue of each criterion. Based on the input the AHP priority calculator[2] found on the following website was used, and values were calculated. http://bpmsg.com/academic/ahp.php

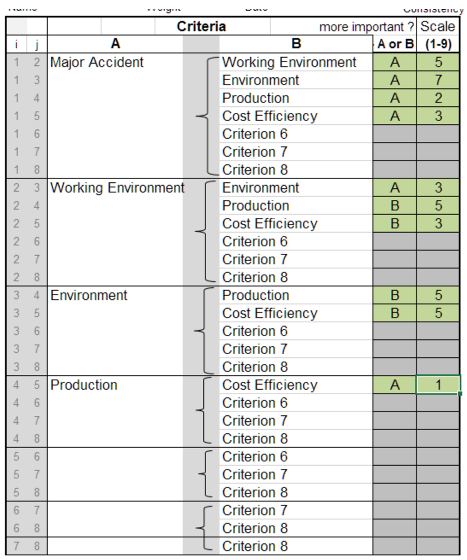


n= 5 Number of criteria (3 to 10) Scale: 1 Linear
N= 1 Number of Participants (1 to 20) α: 0,1 Consensus: n/a
p= 0 selected Participant (0=consol.) 2 7 Consolidated
Objective
Author
Date Thresh: 1E-07 Iterations: 5 EVM check: 1,1E-08

Table	Criterion	Comment	Weights	Rk
1	Major Accident		43,0%	1
2	Working Environm		7,9%	4
3	Environment		4,3%	5
4	Production		24,6%	2
5	Cost Efficiency		20,2%	3

Figure A.1 – Results from calculation

The values presented in Table A.1 are the input values for each comparison. The values presented in are the results (weights), which are presented in chapter 4.3.3.



i	j	Criteria A	Criteria B	more important ? A or B	Scale (1-9)
1	2	Major Accident	Working Environment	A	5
1	3		Environment	A	7
1	4		Production	A	2
1	5		Cost Efficiency	A	3
1	6		Criterion 6		
1	7		Criterion 7		
1	8		Criterion 8		
2	3	Working Environment	Environment	A	3
2	4		Production	B	5
2	5		Cost Efficiency	B	3
2	6		Criterion 6		
2	7		Criterion 7		
2	8		Criterion 8		
3	4	Environment	Production	B	5
3	5		Cost Efficiency	B	5
3	6		Criterion 6		
3	7		Criterion 7		
3	8		Criterion 8		
4	5	Production	Cost Efficiency	A	1
4	6		Criterion 6		
4	7		Criterion 7		
4	8		Criterion 8		
5	6		Criterion 6		
5	7		Criterion 7		
5	8		Criterion 8		
6	7		Criterion 7		
6	8		Criterion 8		
7	8		Criterion 8		

Figure A.2 Input values

[2] Goepel, K. D., 2014. *BPMSG AHP Online System.* [Online] Available at: http://bpmsg.com/academic/ahp.php[Accessed 05 31 2015].

ATTACHMENT B – Evaluations of modification proposals

The following two pages show which factors that have contributed to the results in Chapter 4.2

Table B.1 show how the different modification proposals have been scored based on the applicable attributes and potential mitigating consequences. The rows represent each project, and the columns represent the different attributes and score   Table B.1 – Values assigned

Project	Name/description	Safety barriers	Personnel injury	requirements (Y/N)	Reliability	Technical Requirements	Operation	Immediate Spill	Discharge	Production	Recovery	Accelerate Production	Cost Effectiveness	Lifetime extension
A	Reduce temperature in potable water	0	0	0	0	1	-3	0	0	0	0	0	2	0
B	Lifting arrangement for sea water lifting pumps is unsatisfactory	0	-2	0	0	-2	-3	0	0	0	0	0	2	0
C	Redesign of lifeboat lifting lugs, as complete testing not is possible on existing lifting lug	-2	0	0	-3	0	-2	0	0	-1	0	0	0	-2
D	Optimisation of system logic on system 46, as pumps trips and cause extensive maintenance.	0	0	-3	0	-1	0	0	0	0	0	0	1	0
E	Venting of deep water sensors, to ensure correct alignment of the platform and prevent wrong readings	0	0	0	0	-1	-2	0	0	0	0	0	-1	0
F	Modification of anti-surge panels, to avoid clogging	0	0	0	0	1	0	0	0	-1	0	0	0	3
G	Turning of level glasses on separators and scrubbers, to facilitate better working environment	0	0	0	0	2	0	0	0	0	0	0	0	0
H	Hooks for utility cabinet, to avoid trip hazard’s and facilitate for better working environment	-1	0	0	0	-1	0	0	0	0	0	0	0	0
I	Level measurement system, to optimise detection principles and speed up time to stable system after shutdown	2	0	0	0	0	0	0	0	0	0	1	0	0

J	Permanent spill oil handling system	-1	-1	0	0	1	0	1	0	0	0	0	0	0
K	Permanent H2S removal system for gas	0	0	0	0	-1	0	0	0	0	0	0	3	-3
L	Automatic hypochlorite injection to drinking water	0	0	0	0	1	1	0	0	0	0	0	1	3
M	Modification of MEG centrifuges to increase static pressure to salt tank	0	0	0	0	-1	0	0	0	0	0	0	-2	-2
N	Prevent clogging scrubber	0	0	0	0	-1	-2	0	0	0	0	0	2	2
P	Change heavy doors in Living Quarter	-1	0	0	0	-3	0	0	0	0	0	0	0	0
Q	Optimize routing on helideck popup piping	-3	0	0	-3	0	0	0	0	0	0	0	-2	-2
R	Removal of oil fumes for compressor	0	0	0	0	-3	0	2	0	0	0	0	0	0
S	Improve diesel drainage from firewater pump.	0	0	0	0	-1	0	0	0	0	0	0	-1	0
T	Permanent access to roof for maintenance of local HVAC	0	0	0	0	-1	0	0	0	0	0	0	-1	0
U	Local wall inside telecom/instrument office	0	0	0	0	1	0	0	0	0	0	0	0	0
V	Dirty smoke(cigarette) container	0	0	0	0	0	0	0	0	0	0	0	0	0
W	Generate overpressure in fire pump module	-3	0	0	-3	0	0	0	0	0	0	0	0	0
X	Detection of MEG spill	0	0	0	0	0	0	-3	0	0	0	0	0	0
Y	Installation of automatic grease-luber	0	0	0	0	-3	-1	0	0	0	0	0	1	0

ATTACHMENT C – Checklist for evaluation of modification proposals

Table C.1 Checklist for evaluation of modification proposals

1	Scope of Work
1.A	Is the background for the modification proposal satisfactory?
1.B	Are there any assumptions related to the background that have to be highlighted?
2	Technical and operational requirements
2.A	Is there identified any special operational requirements, conditions or risks that have to taken into consideration?
2.B	Are there any deviations from existing requirements? And are these documented?
2.C	Are there any reported problems from vendor etc., related to the identified problem?
2.D	Does the identified problem affect existing barrier functions?
3	Possible concepts
3.A	Is at least one possible solution concept identified, and is one of the suggested solution concepts recommended?
3.B	Does the recommended solution concept solve the underlying problem?
3.C	Is the proposed solution “good enough”?
3.D	Are there other assumptions that not are addressed?
4	Design basis
4.A	Is the design basis and available documentation adequate?
4.B	Is relevant documentation available?
5	Risks and Opportunities
5.A	Are risks and opportunities related to the execution of the project highlighted?
5.B	Are risk and opportunities likely to change during the execution of the project?
6	Are there interface to other project on the same or affected system?
6.A	Is it evaluated how the proposal shall be executed? Study, Minot mod or Direct execution?
6.B	How does the project align with project portfolio and available resources?
6.C	Should the proposal be executed?

ATTACHMENT D – Excel sheet

The attached Excel File provides a suggestion on how the modification proposals can be collected in a common database.

The basis is collected from http://www.contextures.com/exceldataentryupdateform.html[3], the Visual Basic code has been modified to include several data entries and numerical input.

It has not been achieved to prepare a comparison function between different proposals.

[3] Contextures Inc., 2015. *Excel Data Entry and Update Form.* [Online] Available at: http://www.contextures.com/exceldataentryupdateform.html [Accessed 05 31 2015].