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Practical use of cost-benefit analyses



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SUMMARY

The petroleum industry is Norway's most important trade, and has been an important contributor to the economic growth for the last 30 years. The industry has nonetheless also inflicted, and will continue to inflict the society with considerable consequences, affecting both humans and the environment. The cost-benefit analysis is a well known and widely used analysis in respect to risk-reduction. Its main purpose is to identify and quantify all the advantages and disadvantages from the different projects and to rank them according to their expected net present values. It is also a much disputed analysis, as some people find it unethical to transform every element of the analysis into a monetary value, including human life and environmental influence.

What we will try to visualise, is how some companies in the petroleum industry uses the cost-benefit analysis in respect to risk reduction, and how it is carried out with regard to legislations and the trends in the risk level. A theoretical interpretation of the cost-benefit analysis, and other risk analysis that are used as quality assessment, will be given first, to show the composition of the analysis.

Legislations and good offshore practice must be the underlying causes in every decision. Even though all the companies involved are international companies and therefore subject to both national and international legislations and demands, in this context the Norwegian legislations have been of importance.

When including the development in the risk level, the most important factor was to find out whether the risk level might affect the valuations and implementation in the cost-benefit analysis. But it rather showed a mutual influence between the risk level and the cost-benefit analyses' risk reducing measures. Even though the risk level affects the cost-benefit analysis, in the sense that there is still room for improvements, it is also visible that risk-reducing measures have had its effect on the risk level. There has been a visible reduction in accidents over the past few years, both in respect to personnel and to the environment.

PREFACE

This master's thesis represents the end of my master's degree in Risk management at the University of Stavanger, and has been an individual assignment. The subject of the thesis was formulated together with Gunnar Dybvig in the Petroleum Safety Authority (PSA).

I would like to express my thanks to several people. First I shall give a big thanks to Stein Erik Hilmersen in ExxonMobil and David Bayly in Total, who have given me a lot of valuable information throughout the whole process. I would also like to give my thanks to Kjell Sandve in ConocoPhillips, Hans Magne Olsen in Norske Shell and Espen Fyhn Nilsen in StatoilHydro for helpful information and useful suggestions.

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Stavanger 15.06.2009

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TERMINOLOGY

Definitions and terminology is taken from [Vinnem, Offshore risk assessment]

Acceptance criteria (for risk)	Criteria that are used to express a risk level that is considered acceptable for the activity in question, limited to the high level expression of risk.
ALARP	As Low As Reasonably Practicable. Expresses that the risk level is reduced – through a documented and systematic process – so far that no further measure may be identified, except those that have costs that are grossly disproportionate to the benefits.
Cost-benefit evaluation	Quantitative assessment and comparison of costs and benefits. In the present context often related to safety measures or environmental protection measures where the benefits are reduced safety or environmental hazard.
Environment safety	Safety relating to protection of the environment from accidental spills which may cause damage
Escape way	Routes of specially designated gangways from the platform, leading from hazardous area to muster areas, lifeboat stations, or shelter area.
Main safety function	Safety functions that need to be intact in order to ensure that personnel are not directly and immediately exposed, may reach a place of safety in an organised manner, either on the installation or through controlled evacuation.
Major accidents	Accidents where multiple (often 5 or more) fatalities may be caused, often resulting from a hydrocarbon leak or from a serious structural damage.
NORSOK	Norwegian offshore standardisation organisation

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Occupational accidents	Accidents relating to hazards that are associated with the workplace (falls, slips, crushing etc.), thus other hazards than hydrocarbon gas or oil under pressure. These accidents are normally related to a single individual.
Personnel safety	Safety for all personnel involved in the operation of a field.
Risk acceptance	Decision to accept a risk
Risk analysis	Systematic use of information of identify sources and to describe the risk
Risk assessment	Overall process of risk analysis and risk evaluation
Risk reduction	Actions taken to lessen the probability, negative consequences, or both, associated with risk
RNNS	A risk level project (Risiko Nivå på Norsk Sokkel)

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1. INTRODUCTION

1.1 BACKGROUND

The petroleum industry is Norway's most important trade, and has been an important contributor to the economic growth for the last 30 years. The industry has nonetheless also inflicted, and will continue to inflict, the society with considerably large consequences and costs related to accidents causing a threat to human lives, and environmental and material damages. To keep the activities safe, it is, among other things, important that the given regulations and demands are followed.

“Petroleum activities shall be safe and prudent, both in relation to an individual and an overall consideration of all the factors of importance to planning and implementation of petroleum activities as regards health, environment and safety. The distinctive character of the individual enterprises together with local and operational conditions shall also be taken into account. A high level of health, environment and safety shall be established, maintained and further developed.”

§8 Prudent petroleum activity, Framework HSE

To be able to keep the petroleum activities safe and prudent, it is important with a good HSE management, continuous risk-reduction and improvements. It is also important to be able to balance the benefits and the costs associated with the improvements and risk-reducing measures.

“In effectuating risk reduction the party responsible shall choose the technical, operational or organisational solutions which according to an individual as well as an overall evaluation of the potential harm and present and future use offer the best results, provided the associated costs are not significantly disproportionate to the risk reduction achieved.”

§9 Principles relating to risk reduction, Framework HSE

Risk reduction is necessary to achieve and maintain a good yield. The problem is that limited resources makes prioritisation between different measures essential to be able to achieve the best results as possible. This is why it is important to have good procedures when choosing between different alternative solutions. There are many methods for evaluation and judgment of the different risk-reducing measures, but there is considerable disagreements on how effective or practical they are. The cost-benefit analysis is such a tool, helping the decision maker to choose among different measures.

The cost-benefit analysis builds upon a comparison of all the advantages and disadvantages from a risk-reducing measure, and is a way to systemize the information. The analysis transforms every element into monetary values and makes it easy for the decision maker to compare different solutions. This valuation is also the analysis' biggest weakness, since not every element is easy to transform, like human lives or environmental damages.

1.2 PURPOSE

The purpose with this thesis is to give an understanding of, and to discuss, how some companies in the Norwegian petroleum industry uses the cost-benefit analysis in their decision making process with respect to HSE risks. This is the main problem of the thesis. To fix the limits, there have been formulated three guiding questions that shall be answered to cover the main problem:

1. Is there accordance between the theoretical description of the cost-benefit analysis and the way the analysis is carried out in practice?
2. Is the cost-benefit analysis carried out satisfactorily with regard to given laws and regulations?
3. Do the trends in the total risk level affect the valuations or the implementation of the cost-benefit analysis?

1.3 METHOD

To answer the guiding questions and the main problem of the thesis, there has been carried out a data collection and performed analyses of these data. To increase the quality of the thesis, different methods have been used to collect the information. The collection of data has been carried out through interviews, document analysis, and literature studies.

Five different oil companies have been contacted in relation to the thesis. There was prepared an interview guide with questions about task allocation, working of the analysis, and challenges with the analysis. The performance of the interviews and the communication with the different companies has varied between personal meetings, telephone conversations and communication through e-mail.

The document analysis is mainly based on internal documents about regulations and risk criteria, provided by some of the companies. Because of all the sensitive information, there will be no reference to the different companies. Also other documents with relevance for the practical use of the cost-benefit analysis in relation to HSE have been used, like St.meld. nr 7 (2000-2001), St.meld. nr 12 (2005-2006), St.meld. nr. 21 (2004-2005), NORSOK Z-013, NOU 1997: 27, NOU 1998: 16. Literature studies have been carried out to get the basic understanding of the cost-benefit analysis and as to draw a comparison to the practical use of the analysis.

1.4 DELIMITATIONS

This thesis shall give a presentation of the practical use of the cost-benefit analysis in the petroleum industry. Since cost-benefit analysis is a rather wide term, the focus will mainly be on the use of cost-benefit analysis within the HSE area. This way, most of the difficult aspects with the analysis will also be covered.

The thesis is also delimited in the way that the companies' use of the analysis will be compared and discussed according to the theoretical presentation of the analysis, the regulations related to the analysis and the risk level.

1.5 SCOPE

To give an overall picture of the cost-benefit analysis the thesis is divided into two parts, the first part concerns the underlying influences and the second part concerns the practical performance of the analysis. The first part includes chapter 2-4, and is a general presentation of risk analysis and a theoretical introduction of the cost-benefit analysis in chapter 2. It will also be a presentation of the basic calculations related to the cost-benefit analysis.

In chapter 3, there will be an introduction of the requirements the Petroleum Safety Authorities has to the Norwegian offshore industry. It will be given a presentation of the most relevant regulations related to the practical use of the cost-benefit analysis. Chapter 4 will be a short description of the risk level on the shelf, showing how the risk for both personnel and environment has changed over the past few years. An accident trend might show if there are any relations between the risk level and the elements included in the cost-benefit analysis.

The second part consist of chapter 5 and 6. In chapter 5, there will be a presentation of the practical use of the cost-benefit analysis. In this part we can see how the companies use the analysis and the challenges they might meet in the process. We will try to find which elements that are included in different cost-benefit evaluations and how they influence the analysis. In chapter 6 we will try to visualise and discuss how the practical use of the cost-benefit analysis is performed according to the theory, the Norwegian regulations and the safety level. And at the end, chapter 7 will present the results from the discussion in form of a conclusion.

2. RISK REDUCTION AND THE COST-BENEFIT ANALYSIS

This chapter gives a general presentation of risk analysis and then a theoretical presentation to how the cost-benefit analysis can be used in the process of reducing risk. It will also be a presentation of the basic calculations related to the cost-benefit analysis.

2.1 A GENERAL AND THEORETICAL PRESENTATION

The traditional cost-benefit analysis was developed for the evaluation of public policy issues. An approach designed to measure the benefits and costs of a public project, using a common scale – the country's currency. Later, the analysis has also been used in other contexts, in particular for evaluating projects in the oil sector. The same principles apply, using values reflecting the company's benefits and costs. [3]

An accident in the petroleum industry can lead to severe consequences outside the company, mainly for the society. Because of this, Norway has seen it as beneficial to have some control over the companies' safety performance. As stated in St.meld nr 7 (2001-2002), the government has a comprehensive HSE concept that embraces both major accidents and working accidents. And by including economic values, it shows the petroleum industry's importance to society. This importance is underlined in the HSE Regulations with requirements for continuous improvement of HSE.

According to St.meld nr 7 (2001-2002), the HSE concept contains:

- *Health*, from the health acts, covers health services, health-related emergency preparedness, transportation of sick and injured, sanitary conditions, drinking water supply, production and offering of eatables, and other conditions regarding health and hygiene. Health service covers both curative and preventive services. Hygiene includes industrial hygiene and other actions carried out to prevent illness or to improve the health conditions. This also includes conditions going beyond what usually is connected to the development of a safe working environment. Hygiene covers in this way all conditions containing individual or environmental health care.

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- *External environment*, from the pollution and waste acts, are to protect the external environment from pollution and growth of waste.
- *Working environment*, from the working environment act, is a collective term covering all elements in the working situation that may influence the workers physical and mental health and welfare. The term contains health safety, including physical, chemical, biological and ergonomic factors. It also contains mental influences and welfare conditions.
- *Safety*, from the petroleum activity act, has a broad meaning and covers safety for personnel, environment, the economic values which are represented by the devices and vessels, and operation availability.

Risk reduction is an essential part of maintaining a good HSE standard and to make sure that the safety level stays within a reasonable level. To achieve the best risk reducing results as possible, it is important that the decision maker has sufficient information about the risk level, present situation, different risk reducing measures, and the expected results from the proposed measures. There are several analyses which provide the decision maker with the required information, and the cost-benefit analysis is one of them.

The cost-benefit analysis is a well known and a widely used tool to compare risk reducing measures. When performing a cost-benefit analysis, there are different methods and principles that are worth mentioning. There is the traditional cost-benefit analysis which operates with measurable sizes on one side, and a multi-attribute analysis which give separate assessments for every element [2].

The traditional cost-benefit analysis shall include all elements. This is also emphasised in NORSOK Z-013, which say that the cost-benefit analysis shall be interpreted in the widest way possible – there shall not be any surprising effects from the analysis, every thinkable effect shall be included. The method is not simple to carry out; every element included in the analysis shall be transformed into monetary values, summarised and discounted into the measure's net present value, even non-economic consequences such as expected loss of lives and damage to the environment. The main principle when

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transforming the elements is to find the company's willingness to pay to obtain risk reduction [3]. Risk reduction within the HSE areas involves transformation of many non-economic elements. There are also analyses which just calculate the expected net present values for some of the elements, and carry out separate analyses and assessment for the remaining elements [2].

A cost-effectiveness analysis can be performed to avoid the problem of transforming all elements to one unit. This involves a systematic valuation of the costs from different measures that has the same goal. In such analyses it is the efficiency that is calculated, which indicates calculation of expected cost per expected saved life. The costs are transformed into economic values with the purpose to find the project with the lowest costs.

A multi-attribute analysis is a decision support tool combining qualitative and quantitative evaluations. This means that there is no attempt to transform all the different attributes to a comparable unit, but it performs separate assessments for each element. Each element can get valued with scores or with calculated net present values [2].

All these methods are referred to as cost-benefit analysis, but it is the traditional cost-benefit analysis that is the official cost-benefit analysis [2]. To show the process of how to carry out a cost-benefit analysis, it is proper to use Terje Aven's model, Figure 2-1, which shows the main steps that should be included when performing a cost-benefit analysis.

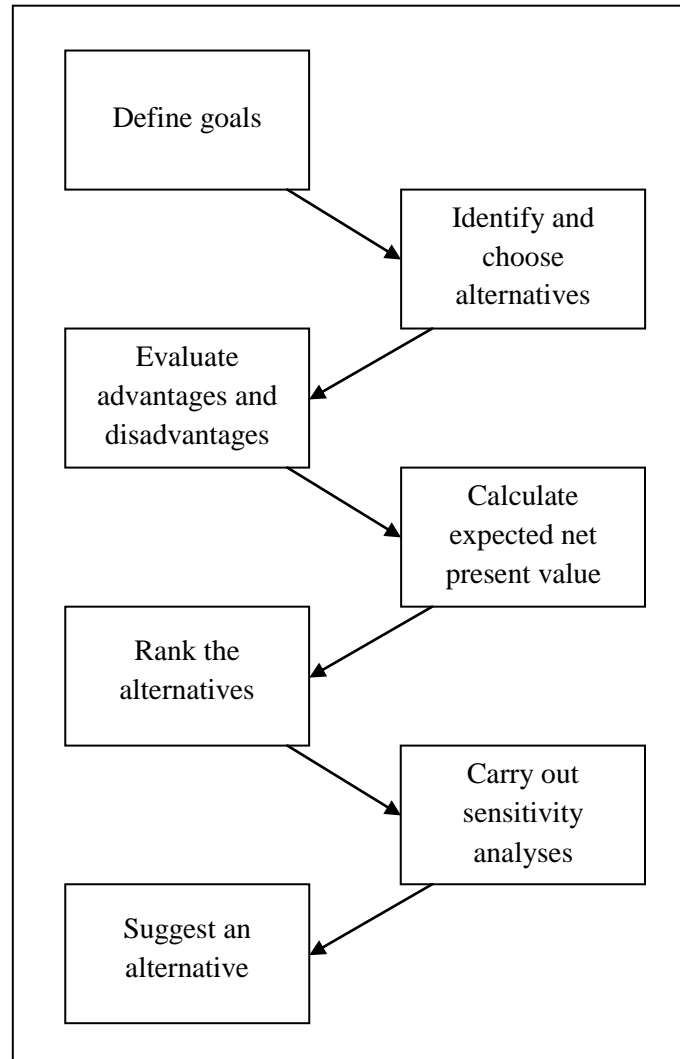


Figure 2-1: Schematic presentation of a cost-benefit analysis [2]

According to this figure, the different measures have to be identified and chosen based on defined goals and regulations, and then ranked according to their expected net present values. To see the results from the chosen measures and how the results depend on the conditions and assumptions, it is usual to perform sensitivity analyses. And then, based on these analysis and calculations, the best alternative shall be chosen. This is a simple, but good way to describe the process of the cost-benefit analysis.

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This process has a lot in common with the checklist described in NOU 1998: 16. The checklist consists of four steps:

- Problem description
- Specific description of all possible measures
- Specific description of all possible effects
- Follow-up and evaluation

A more detailed description of this checklist is given in Appendix A. By combining Aven's seven main steps and the points from the checklist, the cost-benefit analysis is pretty much depicted.

The process starts when it is detected that a risk level has surpassed or are in danger of surpassing an acceptable level. Every company in the petroleum industry shall have a set of risk acceptance criteria that indicates what risk level is considered to be acceptable or desirable, based on regulatory requirements or intra-company demands. Some examples of typical risk acceptance criteria used [3]:

- The FAR value should be less than 10 for all personnel on the installation, where the FAR value is defined as the expected number of fatalities per 100 million exposed hours.
- The individual probability that a person is killed in an accident during one year should not exceed 0.1%.

When using the risk acceptance criteria, we normally talk about limits for acceptable and unacceptable risks. The upper limit indicates a pre-determined quantitative risk acceptance criterion. If the risk level surpasses this limit, risk analysis should be carried out to identify which risk-reducing measures that are required [3]. If the risk level is below the lower limit the risk is acceptable and there is no need for any improvements, unless it is out of self-interest. The area in between these two limits is the ALARP area ("As Low As Reasonably Practicable").

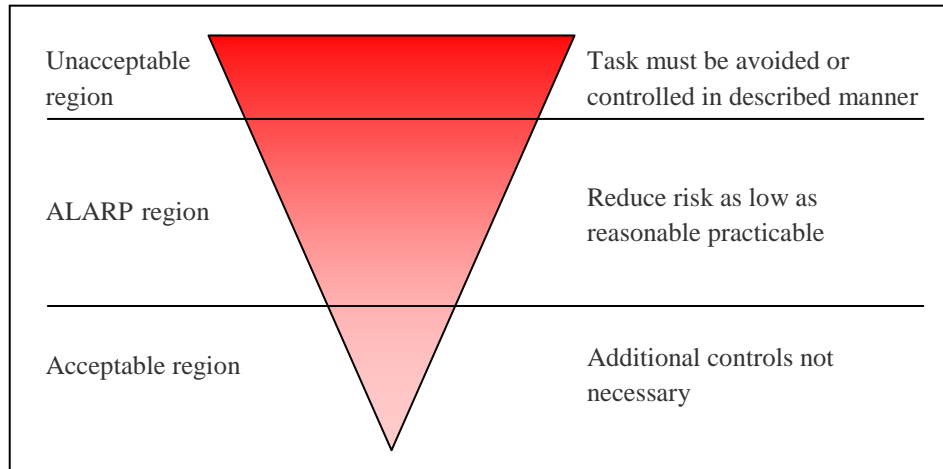


Figure 2-2: Risk acceptance criteria and ALARP [10]

The ALARP principle signifies that as far as it is reasonably practicable, one should try to remove or reduce dangerous conditions identified through the risk analysis and judgment process. The principle implies “reverse burden of proof” [1]:

“Identified risk-reducing improvements should be implemented, unless it can be demonstrated that the benefits are grossly disproportionate to the costs and operational restrictions.”

The cost-benefit analysis is an important tool in the process of reducing the risk level to become ALARP. It is also used to calculate how “grossly disproportionate” the costs are compared to the benefits. [1]

When evaluating the risk level and which risk reducing measures that should be implemented, it is important to evaluate every possible incident that might occur and every possible consequence that might come from the incident occurring. In other words, evaluation of risk should include:

- Identification of hazards and threats (causing unwanted incidents)
- Survey of possible losses caused by the identified hazards and threats

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SINTEF has a good illustration of a schematic overview over identified threats and losses covering:

- **Values** which needs to be attended to
- **Hazards and threats** to the values
- **Loss categories** – specifications of the losses and consequences from the threats

The illustration in the SINTEF rapport is in Norwegian, but it is depicted here in English and with some adjustments to make it more adequate for this type of risk evaluation.

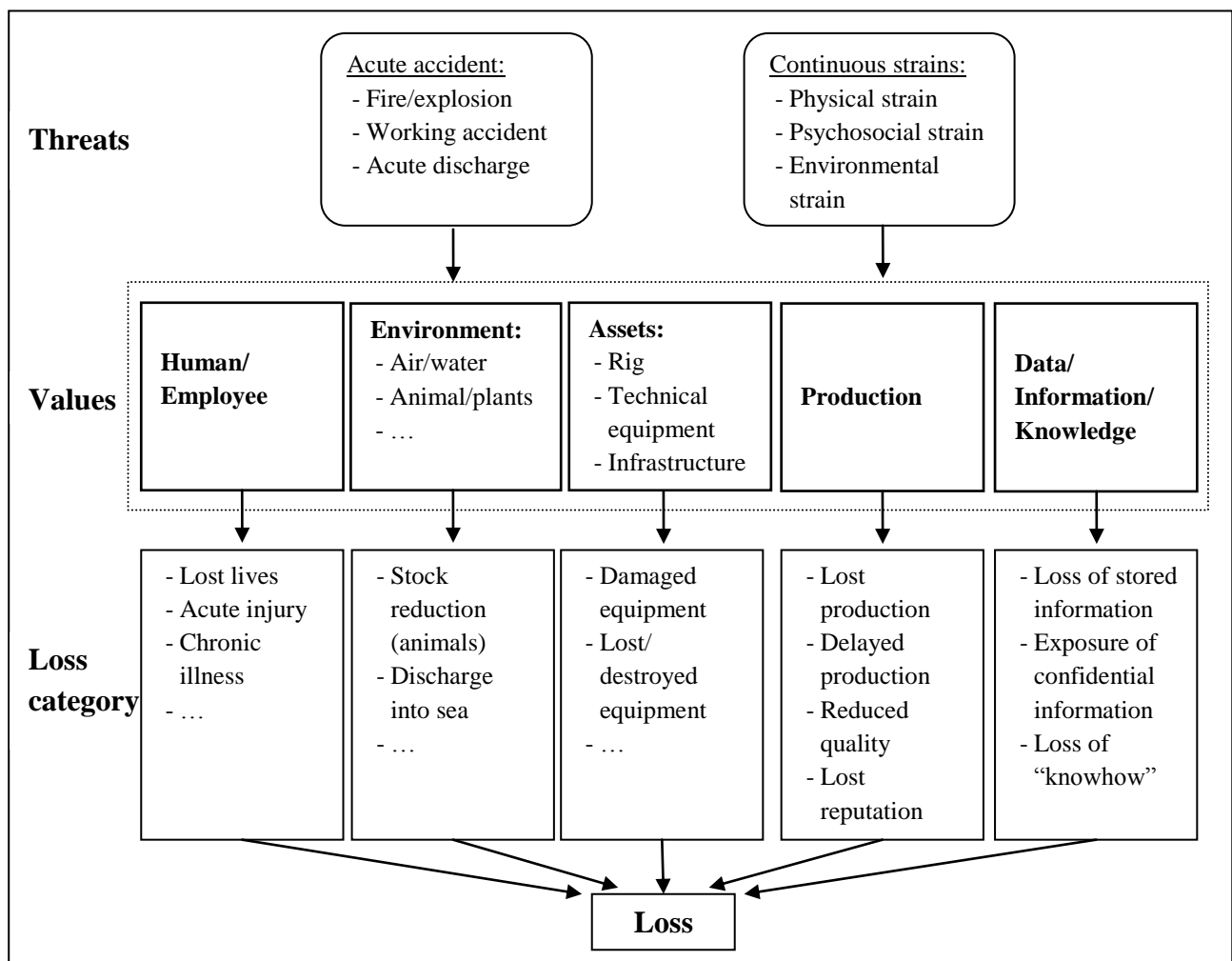


Figure 2-3: Illustration of values, threats and loss categories [10]

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Acute accidents and continuous strains may have considerable negative effects on the employees, the environment, assets, production, and data. However, the expected consequences or losses may vary, depending on the affected values, and the probability and scope of the threat.

One way to differentiate between the consequences and their likelihood is to use a risk matrix. An example of a risk matrix is given in Appendix B. The risk matrix can give a perspicuous overview over the risk picture, but since it uses relatively rough categories, it might be difficult to differentiate between different risks [1]. It might be easy to illustrate the risk acceptance criterion when it is shown through a risk matrix, but the matrix is not detailed enough to use as decision basis when risk reducing measures are to be chosen.

Quantitative risk analyses (QRA), on the other hand, are often used in the process of evaluating which risk reducing measures to implement, since it contributes to give a technical decision basis. By including the QRA results in the cost-benefit analysis one can find out whether or not a proposed risk reduction measure would be reasonably practicable [4]. The basic use of QRA is actually to demonstrate the safety level – that e.g. the risk level for personnel is as low as reasonably practicable and that no hazards have been overlooked. [14]

As mentioned earlier, a complete cost-benefit analysis transform all elements into monetary values and then calculate the expected net present value, $E[NPV]$. This makes it possible to weigh all the effects toward each other and also to make it a consistent procedure for making decisions.

The different cost- and benefit effects of a project do not normally appear at the same time. This indicates the need for a method that makes it possible to compare and sum up all the effects from the project. When computing the NPV of a project, we take into account time and the discounting cash flow. The relevant project's cash flow is specified, and the time value of money is taken into account by discounting the future cash flows by the appropriate rate of return. [3]

(1)

$$NPV = \sum_{t=0}^T \frac{X_t}{(1 + r_t)^t}$$

- X_t = Cash flow at time t
 T = Time period considered
 r = Required rate of return (discount rate at time t)

The NPV-method indicates that the project's yearly beneficial profit is discounted to the time of the investment. One reason is that the value of a NOK today is worth more than a NOK tomorrow. NPV is the base year's net value of all the costs and benefits of the project. The project is profitable if the E[NPV] is bigger than or equal to zero.

Another way to value a project is with life cycle perspective [5]. This might be written in a mathematical expression:

(2)

$$LCC = \sum_{n=1}^N 1,0p^{-n} \left[\sum_{j=1}^3 \Delta C_{nj} * V_j(C) - RC_n - IC_n \right] > 0$$

- LCC = Life cycle costs (net present value) from a particular risk reducing measure from year 0 until year N
 N = Last year of the projects lifetime
 $1,0p^{-n}$ = Discount factor for year n , based upon the interest rate p %
 ΔC_{nj} = Difference in expected accidental consequences in year n , with risk dimension j
 $j = 1$ dimension: risk to personnel
 $j = 2$ dimension: risk to environment
 $j = 3$ dimension: risk to assets
 $V_j(C)$ = Valuation of risk dimension j as a function of the accidental consequence C

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- RC_n = Running costs (operation, maintenance, etc.) in year n
 IC_n = Investment costs in year n

Running costs and investment costs represent the calculated costs used in the comparison with the benefits. The running costs are yearly (mainly direct) costs which should be discounted in relation to a fixed interest. Both running costs and investment costs should be treated as gradually increasing costs for the given risk-reducing project. These costs are determinative and should be estimated according to usual rules for cost estimation. [5]

The calculation of the benefits may be written like this:

(3)

$$\Delta C_{nj} = \sum_{i=1}^I [f_{nij}^i * C_{nij}^i - f_{nij}^{rrm} * C_{nij}^{rrm}]$$

- C_{nj} = The difference in expected accidental consequences in year n , risk dimension j for I (amount of) accidents
 f_{nij} = Accidental frequencies in year n , scenario i , risk dimension j (“ i ” is the initial state, and “ rrm ” is the state after the risk-reducing measures)
 C_{nij} = Accidental consequences in year n , scenario i , risk dimension j

There are three main risk dimensions we usually look into when calculating the benefits, these are:

- Risk to personnel
- Risk to environment
- Risk to assets

2.1.1 RISK TO PERSONNEL

Reduction in risk for personnel means an estimation of differences in all or some of the following:

- Total deaths per accident

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- Conditional probability per accident
- Frequency of accidents causing death

PLL (Potential loss of life) or FPPY (Fatalities Per Platform Year), is the statistical expected amount of personnel killed in an accident, per year [14]. This value is directly dependent on the amount of personnel exposed to the risk. PLL has the advantage that if the number of exposed personnel is reduced with one, this will be reflected in the fatality measure.

The PLL value can be expressed as:

(4)

$$PLL = \sum_n \sum_j (f_{nj} * c_{nj})$$

f_{nj} = Annual frequency of accident scenario n with personnel consequence j

c_{nj} = Expected number of fatalities of accident scenario n with personnel consequence j

FAR (Fatal Accident Rate) values are common units of measure when we talk about “loss of lives”. It shows the statistical expected number of fatalities per 100 million (10^8) exposed hours [14].

(5)

$$FAR = \frac{PLL * 10^8}{Exposed\ hours}$$

The FAR value does not differentiate between the accidents’ type or scope, nor is it dependent on the amount of employees because it is defined per exposed hour. The FAR values are on the other hand often related to different categories of activities or groups of personnel, since activity or personnel related values often is more informative than a average FAR value for all employees. A high FAR value indicates dangerous activity.

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The downside is that if the exposure over the year is low because of few people exposed, the total risk will also be low.

Individual risk (IR) or average individual risk (AIR) is used to calculate the probability that a single person will die in an accident during a year. A problem with IR is that it is unsuitable to measure the effect from a risk-reducing measure. [14]

(6)

$$AIR = \frac{PLL}{Exposed\ individuals}$$

Group or societal risk may be presented by an F/N diagram, expressing the frequency of accidents with N fatalities or more [2].

When determining the value of the benefits for personnel there are two alternative possibilities:

- Estimate the cost of a statistical life
- Estimate the willingness to pay to prevent a statistical death

Regardless of which of the alternatives chosen, it is complicated to set the values since there cannot be given any exact definition or quantification [5]. When we talk about a statistical death (or life) we talk about the future and the probability of a death – no one has died yet, and we do not know who will.

“It's not the worth of human life I shall discuss, but of «life-saving», of preventing death. And it's not a particular death, but a statistical death”

Schelling (1968)

The value of a statistical life is defined as the value society or a company is willing to pay to reduce the number of expected deaths with one. A statistical life means that there exists a probability for losing a life without knowing who is dying [1]. It is appropriate to use

statistical lives in situations where we are not able, or do not want, to calculate with actual deaths.

There are major differences when it comes to estimating the value of a statistical life. In Norway and the western world the value often lays between 2-100 MNOK, and the Ministry of Finance has suggested a value of approximately 15 MNOK [3]. The estimated value of the social loss of “production capacity” from a typical offshore worker is set to be 6-7 MNOK [5].

A company’s willingness to pay for a risk-reducing project can be measured based on market price (hedonic method) or surveys (conditional valuation). The use of hedonic methods is mainly based on wage differentials in jobs with different probability for death, but it has a series of problems attached when it comes to data and choice of method. The advantage of conditional valuation, when finding the value of a statistical life or the value of the environment, is that interviews may be directly attached to the type of risk that is to be valued, and at the same time it is possible to analyse the representative selection [6].

2.1.2 RISK TO ENVIRONMENT

The environment risk from offshore installations is dominated by the large spills from blowouts, pipeline leaks or storage leaks. Reduction in the environmental risk means an estimation of differences in all or some of the following [5]:

- Size on waste per accident
- Conditional probability per waste
- Frequency of accidents which may lead to waste

Valuation of environmental risk may include many different aspects:

- Cleaning up costs
- Costs of oil loss
- Compensation for fishery and farming industry, society etc, for loss of salary because of environmental damages

Practical use of cost-benefit analyses

These aspects are all tangible in the way that economic values are relatively easy to define. Still there are many intangible aspects, like loss of reputation, as to be seen as an environmentally irresponsible organisation etc.

The “willingness to pay”- approach is also a good way to evaluate the damage on the environment. There seems to be many people that are willing to pay large amounts to prevent damage on the environment, even if the positive effects of a project are far from certain [5].

2.1.3 RISK TO ASSETS

The asset risk is comprised of possible damage to equipment and structures, as well as the resulting disruption of production [5]. Reduction in risk for material values means an estimation of differences in all or some of the following:

- Scope of damage per accident
- Duration of shutdown per accident
- Conditional probability for damage on equipment
- Frequency of accidents leading to damage on assets

The calculation of differences in risk for material values is done on differences concerning costs from:

- Production delay
- Damage on equipment and constructions
- Temporary solutions

Damage on assets is the easiest elements to calculate and is usually constituted by the following components:

- Costs for replacement of constructions and equipment caused by material damage
- Value of production loss/production delay

The consequences of production loss and production delay are different for oil and gas. Gas deliveries are usually completely lost if the production is shut down, while oil

production can be postponed and restarted later. Delay in the oil production is dependent on the circumstances, and on the production level. This means that the valuation of the production loss is different according to when the accident appears.

In addition to the production shutdown, special emphasis must be placed on realistic estimates of the least serious accidents such as un-ignited gas leaks or un-ignited short duration blowouts. It is usual that even un-ignited hydrocarbon leaks lead to long time production shutdowns, because of investigations or because the need of improvements detected by an incident. In the assessment of production loss, the actual impact on gas delivery to the costumers should also be evaluated. For gas export it is often required a calculation of relevant buffers such as storage, “line pack”, and compensation. [5]

The need for sensitivity analyses when taking decision about risk and safety shall always be considered [5]. Especially in combination with cost-benefit analysis is it necessary to carry out sensitivity analyses, to see the effects from the different measures. This can apply to e.g. the value of a statistical life or the discount rate [2]. The sensitivity analyses represent the ruggedness in the results [5].

2.2 CHALLENGES WITH THE USE OF THE COST-BENEFIT ANALYSIS

The use of cost-benefit analyses in relation to risk management leads to several challenges. This is among other things attached to:

- Identification and valuation of the benefit of investing in HSE measures
- Valuation of costs and benefits, and by this the wish to reduce the risk, can vary between a company and socio-economic perspective
- When is there a disproportion between a measure’s benefits and its costs?
- What is the “right” time perspective when defining the benefit value of a HSE measure?

Practical use of cost-benefit analyses

Even if many economists would refer to the cost-benefit analysis as a substantial and practical tool to guide the decision-maker, it is important to keep in mind that the analysis does not provide hard recommendations. The analysis must be reviewed and evaluated, as we cannot replace difficult ethical and political deliberations with a mathematical one-dimensional formula, integrating complex value judgements. [2]

In theory, every element and project is transformed into monetary values. If the expected net present value of the project is positive the project is economically efficient. The problem is that many of the elements in the project cannot be transformed based on market prices. There will be elements like environmental effects, health strains, psychosocial working conditions and the risk of losing a human life. The HSE area has many elements that are difficult to transform into an economic value.

The cost-benefit analyses have limitations and are based on a number of assumptions and presumptions, and their use is based not only on scientific knowledge, but also on value judgements involving ethical, strategic and political concerns. The analyses provide support for decision processes outside the direct application of the analyses. It is necessary to see beyond the expected values [3].

The socio-economic consequences of serious accidents are considerable. For those affected by a fatal accident the consequences are serious and contain more than what appears in a socio-economic evaluation – the value of a life can not only be expressed in money [11].

3. NORWEGIAN REGULATIONS

This chapter is based on the requirements the Petroleum Safety Authorities has to the Norwegian offshore industry. To find out whether the cost-benefit analysis is carried out with regard to the given laws and regulations, this chapter will be used as a basis for the comparison. It will only be given a presentation of the most relevant regulations related to the practical use of the cost-benefit analysis. All the information for this chapter is taken from [16].

The regulation of HSE in the petroleum industry is based upon five regulations which are derived from the legislation. These are:

- *The Framework regulations*: Regulations relating to health, environment and safety in the petroleum activities
- *The Management regulations*: Regulations relating to management in the petroleum activities
- *The Information duty regulations*: Regulations relating to material and information in the petroleum activities
- *The Facilities regulations*: Regulations relating to design and outfitting of facilities etc. in the petroleum activities
- *The Activities regulations*: Regulations relating to conduct of activities in the petroleum activities

Among these are the Framework regulations, the Management regulations and the Facilities regulations the most relevant requirements with respect to the cost-benefit analysis, and therefore these are the regulations that will be included in the following.

3.1 THE FRAMEWORK REGULATIONS

The regulations in chapter III in the Framework regulations is of special interest and among these the most important are section 8 and 9.

Section 8: Prudent petroleum activities

“Petroleum activities shall be safe and prudent, both in relation to an individual and an overall consideration of all the factors of importance to planning and implementation of petroleum activities as regards health, environment and safety. The distinctive character of the individual enterprises together with local and operational conditions shall also be taken into account.

A high level of health, environment and safety shall be established, maintained and further developed.”

Section 9: Principles relating to risk reduction

Section 9 covers most issues concerning risk reduction. This includes requirements for legislation, internal requirements and acceptance criteria, the BAT principle, precautionary principle, and substitution:

“Harm or danger of harm to people, the environment or to financial assets shall be prevented or limited in accordance with the legislation relating to health, the environment and safety, including internal requirements and acceptance criteria. Over and above this level the risk shall be further reduced to the extent possible. Assessments on the basis of this provision shall be made in all phases of the petroleum activities.

In effectuating risk reduction the party responsible shall choose the technical, operational or organisational solutions which according to an individual as well as an overall evaluation of the potential harm and present and future use offer the best results, provided the associated costs are not significantly disproportionate to the risk reduction achieved.

If there is insufficient knowledge about the effects that use of the technical, operational or organisational solutions may have on health, environment and safety, solutions that will reduce this uncertainty shall be chosen.

Factors which may cause harm, or nuisance to people, the environment or to financial assets in the petroleum activities shall be replaced by factors which in an overall evaluation have less potential for harm, or nuisance.”

3.2 THE MANAGEMENT REGULATIONS

There are several sections in the Management regulations that are of importance. The most important are the regulations on the risk acceptance criteria and on the risk analyses.

Section 6: Acceptance criteria for major accident risk and environmental risk

According to section 6, acceptance criteria shall be used in assessing results from the quantitative risk analyses. The acceptance criteria shall be set for:

- a) *the personnel on the facility as a whole, and for groups of personnel which are particularly risk exposed,*
- b) *the loss of main safety functions,*
- c) *pollution from the facility,*
- d) *damage done to third party.*

Section 13: General requirements to analyses

The analyses should, by using recognised models, methods and techniques and the best available data, provide the necessary decision basis in order to attend to health, environment and safety.

The purpose, conditions, assumptions and delimitations, which the analyses are based on, shall be clear. And updates should be carried out when alterations in the conditions, assumptions and delimitations individually or as a whole affect the results of the analyses, or when other new knowledge of significance to the results of the analyses exists.

Section 14: Analyses of major accidental risk

“Quantitative risk analyses and other necessary analyses shall be carried out to identify contributors to major accident risk, including:

- a) the risk connected with planned drilling and well activities, and show which effect these activities have on the total risk on the facility,*
- b) the effect of modifications and the carrying out of modifications on the total risk,*
- c) the risk connected with transportation of personnel between the continental shelf and shore and between facilities.”*

Section 15: Quantitative risk analyses and emergency preparedness analyses

“Quantitative risk analyses which provide a balanced and as comprehensive picture as possible of the risk shall be carried out”.

This means that the external and internal incidents that the facility or transportation system is most vulnerable to should be identified.

The risk analyses shall:

- a) identify situations of hazard and accident, select initiating incidents and map the causes of the incidents,*
- b) carry out modelling of accident sequences and consequences so that, among other things, possible dependencies between physical barriers can be revealed, and so that the requirements that must be set in respect of the performance of the barriers, can be calculated,*
- c) classify important safety systems,*
- d) show that the main safety functions are adequately provided for,*
- e) identify dimensioning accidental loads,*
- f) provide the basis for selecting the defined situations of hazard and accident.*

Necessary sensitivity calculations and evaluations of uncertainties shall be carried out, and the effect of risk reducing measures should be calculated as far as possible.

Practical use of cost-benefit analyses

Section 16: Environmentally oriented risk and emergency preparedness analyses

The analyses shall be carried out for acute pollution and for operational discharges from the facility. The analyses shall comprise the categories

- Near to source
- Open sea
- Coast and shore zone
- Vulnerability

The analyses must be comparable, and environmentally oriented emergency preparedness analyses shall be carried out in respect to the facility. Results from characterisation of oil and chemicals, and actual efficiency figures for emergency preparedness material shall be part of the analysis basis.

Important information for carrying out these risk analyses include:

- the physical, chemical and eco-toxicological properties of the pollution,
- the characteristics of the pollution,
- transport and spread,
- weathering,
- vulnerability of eco systems,
- meteorological data,
- environmental prioritisation map for vulnerable resources.

Section 17: Analyses of the working environment

It shall be carried out analyses which will ensure a sound working environment and provide decision support in the technical, operational and organisational solutions. In situations where mistakes may lead to hazardous situations and accidents and to exposure and physical or mental strain, the analyses shall contribute to:

- Improving of the health, well being and security of the employees
- Preventing personal injury, deaths and work related disease

In order to ensure a proper working environment, the various analyses should complement each other so that they cover both situations of hazard and accident as well as exposure to working environment factors.

3.3 THE FACILITIES REGULATIONS

Among the facilities regulations it is section 6, about main safety functions, which is of greatest importance.

Section 6: Main safety functions

Main safety functions are supposed to ensure the safety for personnel and limit pollution.

In case of an accident, the following main safety functions shall be maintained:

- a) *preventing escalation of accident situations so that personnel outside the immediate vicinity of the scene of accident are not injured,*
- b) *maintaining the main load carrying capacity in load bearing structures until the facility has been evacuated,*
- c) *protecting rooms of significance to combating accidental events, so that they are operative until the facility has been evacuated,*
- d) *protecting the facility's safe areas so that they remain intact until the facility has been evacuated,*
- e) *maintaining at least one evacuation route from every area where personnel may be staying until evacuation to the facility's safe areas and rescue of personnel has been completed.*

4. RISK LEVEL ON THE SHELF

In this chapter there will be given a short description of the risk level on the shelf, showing how the risk for both personnel and environment has changed during the recent years. An accident trend might show if there are any relations between the risk level and the elements included in the cost-benefit analysis. The information for chapter 4.1 is mainly got from [9] and for chapter 4.2 is mainly based on [17].

4.1 RISK LEVEL FOR PERSONNEL

In 2000, PSA initiated the “RNNP”, a risk level project, to see the development in the risk level on the Norwegian shelf. The main focus in the project is personnel risk, and this is shown by including major accidents, work accidents and selected working environment factors. The four main causes for potential lost lives, which also can have an impact on the environment is process leaks, occupational risk, ship collision and riser/pipeline leaks.

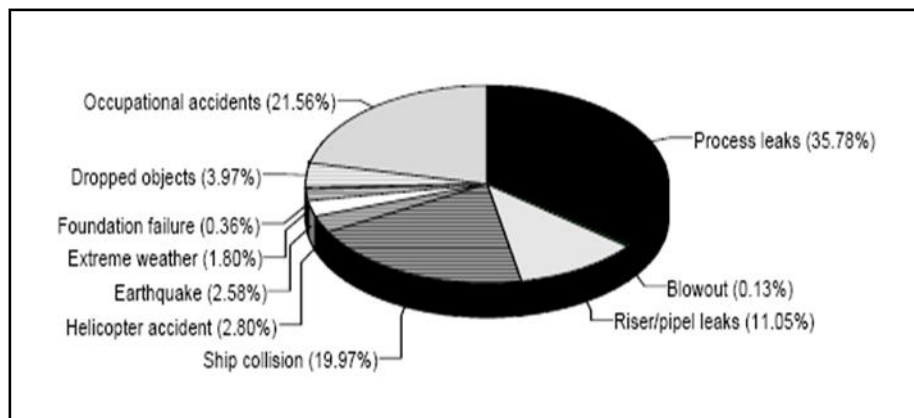


Figure 4-1: Contribution to PLL [18]

Since 2002 there has been a marked reduction in the number of hydrocarbon leaks with a leak rate of more than 0.1 kilo per second. 2007's 10 leaks constitute a clear reduction from 2006 (15 leaks of more than 0.1 kg/s), and is statistically lower than the average for the period 2001-2006. There has also been a reduction in incidents related to drilling and wells. The monitoring of ship traffic on the shelf is constantly improving. Ships on a collision course have had a slight but steady decline since 2002.

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From 2005 to 2008 there has been a significant improvement in the HSE areas. There had not been a fatality on a platform since 2002, until May 2009, when a scaffold builder fell down and died during the dismantling of a scaffold on Oseberg B. Compared with the average for the period 2000-2006, the total indicator that reflects the major accident risk shows a statistically significant reduction over the past years, both in production and mobile facilities. This is also the case for frequency of serious personal injuries [16]

Activity		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Administration and production	Work hours	5 686 709	5 915 265	6 256 441	6 774 628	7 300 114	8 026 293	7 915 058	8 915 814	9 193 310	9 313 287
	Injuries	82	63	65	63	48	32	41	48	37	43
	Injury/mill. hours	14,4	10,7	10,4	9,3	6,6	4	5,2	5,4	4	4,6
Drilling and well operations	Work hours	4 418 068	4 696 224	5 168 486	5 506 589	5 827 361	6 248 973	6 273 504	6 391 301	6 556 149	6 643 729
	Injuries	117	124	111	103	90	54	59	53	67	84
	Injury/mill. hours	26,5	26,4	21,5	18,7	15,4	8,6	9,4	8,3	10,2	12,6
Catering	Work hours	2 286 628	2 265 778	2 044 806	2 189 842	2 262 509	2 177 108	2 167 895	2 281 117	2 182 479	2 213 297
	Injuries	54	54	53	32	28	19	24	28	16	21
	Injury/mill. hours	23,6	23,8	25,9	14,6	12,4	8,7	11,1	12,3	7,3	9,5
Construction and maintenance	Work hours	9 579 291	10 764 923	10 293 676	10 204 786	11 490 368	10 167 463	9 893 529	10 288 651	11 096 764	10 958 779
	Injuries	330	382	320	248	238	196	182	180	198	165
	Injury/mill. hours	34,4	35,5	31,1	24,3	20,7	19,3	18,4	17,5	17,8	15,1
Total	Work hours	21 970 696	23 642 189	23 763 410	24 675 845	26 880 351	26 619 837	26 249 986	27 876 883	29 028 702	29 129 092
	Injuries	583	623	549	446	404	301	306	309	318	313
	Injury/mill. hours	26,5	26,4	23,1	18,1	15	11,3	11,7	11,1	11	10,7

Table 4-1: Injuries on permanently placed facilities [16]

The table shows that there has been a solid decrease in the number of injuries from 1999 until 2008. Although, during the last five years the risk level has been very variable, and there is no significant improvements. It is also interesting to notice that during these ten years, the working hours have, on a total basis, increased analogous with the decrease in injuries.

It is important for the petroleum industry to keep a high level of HSE management. Professional operators with a high care level and a good set of rules contribute to a low number of accidents, few serious injuries on personnel and a low probability of fatal accidents. Another contributor to the low accident rate is the long-term focus on development of new knowledge about risk, and the transference of this knowledge to preventive action. Even though the risk level is decreasing, there is still room for improvements. The petroleum industry still has the potential to cause huge negative

consequences and costs. This might be compared with the words of the Chinese philosopher Confucius:

“The superior man, when resting in safety, does not forget that danger may come. When in a state of security he does not forget the possibility of ruin. When all is orderly, he does not forget that disorder may come. Thus his person is not endangered, and his States and all their clans are preserved.”

Confucius, Chinese philosopher (551 – 479 BC)

As Confucius states, we have to continue to improve and develop to be able to cope with the risks that might occur. This philosophy is a good description of the attitude expected from the petroleum industry today.

4.2 ENVIRONMENTAL RISK LEVEL

The Norwegian petroleum industry has a “zero discharge”- goal, meaning no hazardous waste should be discharged into the sea. Using this as a precautionary goal will contribute to a reduction of the discharge of oil and hazardous waste that leads to unacceptable health or environmental damages. This goes for all offshore activity, both drilling and well operations, production, and discharge from pipe lines. A precautionary evaluation is required when discharging oil and hazardous waste, and the company must perform a risk assessment in addition to the application of discharging chemicals into sea.

Oil spills are caused by acute (illegal and uncontrolled) and operational discharge from offshore installations, ships and land based installations. The consequences of acute discharge depend on the amount and type of oil, season, location, wind and the amount of collected spill [13].

There is limited knowledge about the long term effects the operational discharge has on the environment, but it has been proved that the oil and gas activities puts pressure on the seabed environment near offshore installations, particularly as a result of discharge. In

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1991 discharge from oil-contaminated drill cuttings became prohibited, but it will take many years before the environment is restored to its original condition.

During the past few years, emissions of hazardous chemicals from the oil and gas industry have been reduced, and now it only accounts for about one per cent of Norway's total emissions. However, the oil and gas industry is still one of the largest sources of greenhouse gas emission and acidifying emission.

Even though discharge from cuttings and drilling fluid have been stopped, it has all ready altered species around offshore installations. It will take many years before the seabed returns to its original state. Produced water has been reduced the last years, even though the quantity of discharged water has risen [17].

There have been few major oil spills on the Norwegian continental shelf since the Ekofisk Bravo blow-out in 1977. Statsfjord A had an accident in 2008 where a 2" plug loosened and allowed considerable volumes of crude oil to leak out. This oil leak led to a significant amount of hydrocarbon gas evaporation, resulting in an explosive atmosphere. Even though the probability of these kinds of accidents are low, they do occur.

Oil and gas activities also count for a substantial proportion of Norway's emissions to air. In 2007, the industry generated 29 per cent of the country's CO₂ emissions, 28 percent of its NO_x (nitrogen oxide) emissions and about 40 percent of its NMVOC (non-methane volatile organic compound) emissions.

It is not possible for the oil and gas industry to operate efficiently without using large quantities of chemicals. As a rule, emissions increase with the age of a field.

Practical use of cost-benefit analyses

There has been an overall reduction in releases of hazardous substances in the period 1998 – 2007.

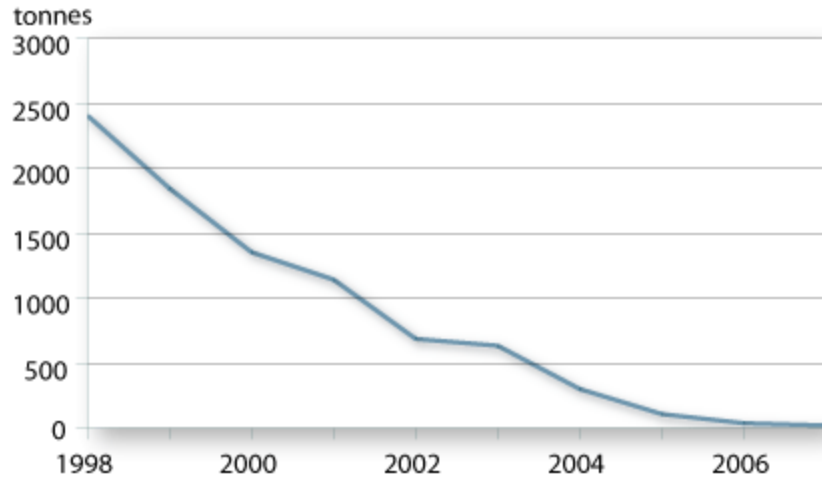


Figure 4-2: Emissions of hazardous chemicals from oil and gas industry [17]

Varying quantities of water is always produced along with oil, and has to be separated from the oil. The quantity of “produced water” generally increases substantially with the age of the oil field. The fields on the Norwegian continental shelf are now producing roughly equal amounts of water and oil.

The water can either be injected into the formation or treated. In 2003, about 14 percent of the produced water was injected. In other words, most of the water is discharged into the sea. Although it is treated first, it still contains traces of oil and chemicals. In addition, some oil is discharged with displacement water [17].

5. PRACTICAL USE OF COST-BENEFIT ANALYSES

In this chapter the practical use of the cost-benefit analysis will be presented. The information in this chapter is acquired through contact with five different companies (interview questions are attached in Appendix C), and with some supplementary information from [5]. Here we will learn how some companies use the analysis and the challenges they might meet in the process.

Several of the informants have stated:

“In the petroleum industry, cost-benefit evaluations are used in almost every decision in the company, but the cost-benefit analysis is mainly used in the process of implementing new risk reducing measures.”

The risk reduction is in focus, and mainly the risk-reducing measures within HSE.

5.1 ALLOCATION OF TASKS

To get a basic understanding of the process, the allocation of tasks is included – a short presentation of who is involved in the different parts of the analysis.

When a risk level is above the acceptance criteria, the customary procedure is to form a team of experienced personnel, to analyse a change, a problem or a situation that has led to the need of risk reduction. The team may consist of consultants and engineers from onshore, offshore, safety delegate and technical safety. Their assignment is to propose a set of possible risk reducing measures which will be evaluated based on their compliance with regulations, good offshore practice, low costs etc. The financial department is often involved in the process of transforming the proposed measures into economic values and to calculate the expected net present values for the different measures. When it comes to taking decisions, the responsible leaders are also included (platform leader, project leader etc).

Quantitative updates are often carried out by contractors or a group of specialist consultants who “*make out the foundation of the cost-benefit analysis, e.g. the effect on risk*”. The “effect on risk” is also mentioned as an evaluation of the benefits. DNV, Safetec and Scandpower are the most used consultants in this context. The reports from the consultants are used to identify mitigating measures to achieve ALARP.

When the risk concern elements are difficult to value, or when the effect from the risk reduction is hard to estimate, specialists from e.g. HSEQ are often involved in the risk analysis. Sometimes they go even further from the created team to obtain useful information, like one informant stated:

“When the risk reduction concern the working environment, one of the most central elements will be the personnel’s point of views and their evaluation of what is most important.”

Dependent of the identified risk level, different levels in the management has to be involved, e.g.:

Low risk – Production and maintenance Manager on the current field

Medium risk – Works Superintendent Norway

High risk – Chief Executive Norway

5.2 RISK REDUCING MEASURES

As previously mentioned, the main reason to carry out a cost-benefit analysis is in relation to risk reduction. To define the scope of this risk reduction the companies uses a risk matrix. The matrix gives a simple but clear overview over the present situation and how huge improvements that are needed to become ALARP.

The main elements in the risk matrix are, as shown in the risk matrix example in Appendix B; personnel, environment, asset and reputation. There are companies that include less, and other companies that include more elements. Only the elements they find important will be included.

Personnel safety must always have first priority when choosing between different risk reducing measures. One of the informants said that:

“We make use of PEAR (people, environment, asset, reputation) as priority basis and the order indicates that humans always shall be prioritised before economic concerns”

Usually combination of the cost-benefit analysis and QRA will be used. The results of the QRA can normally determine whether or not a proposed risk reducing measure would be reasonably practicable.

5.2.1 MAJOR ACCIDENTS

Major accidents may affect personnel, environment and asset. The scope of possible damage caused by major accidents should be limited to the highest extent possible. The evaluation of risk-reducing measures to minimise the risk of major accidents usually come as part of an overall risk analysis. A QRA will normally be undertaken to determine the overall risk level, and afterwards, risk-reducing measures are identified for further reduction of the risk to personnel and the environment.

In relation to cost-benefit analyses, both the probability of an event occurring and reduction of the event's effects, is of great importance in the analysis. Although, the order the are being sought to is also of importance. It is as one of the informants said that:

“Risk reducing measures to reduce the probability of an event occurring should be sought before those measures that reduce the effect of an accident.”

Risk-reducing measures that often are identified in combination with cost-benefit assessments for major accidents include:

- passive fire protection
- additional fire walls and fire barriers
- duplication of equipment to provide levels of redundancy
- alternative materials and design arrangements for pipe work, etc

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When the frequency of occurrence in each event is estimated, the consequences of these events are often modelled by use of empirical correlation or computer simulations to calculate the severity of each event. Then they are compared with harm criteria for personnel, equipment and the environment to generate the possible damage created by each hazardous event.

The combination of the frequency and the results from the consequence severity are used to calculate the risk for a particular scenario. The risk from all scenarios may then be combined to produce the risk for the whole installation.

Uncertainty is an important element when evaluating the cost-benefit assessments for major accidents. Therefore:

“Sensitivity analyses are often undertaken to evaluate the risk reducing potential for full or partial implementation of the measures and the uncertainty of cost estimates assessed”

In addition the experienced risk, comfort and well-being, and media and government attention elements can be assessed in combination with cost-benefit assessments for major accidents.

The main elements will have a risk reduction expressed as a reduction in:

- FAR for a group or an area
- Probability of damage of the main safety functions
 - o Escape ways
 - o Temporary refuge
 - o Evacuation means
 - o Structure
 - o Escalation barriers
 - o Central Control room
- Environmental or economic risk

Furthermore, the input risk (e.g. for personnel doing modifications or technical improvements on the platform), and costs (non-recurring, fixed and variable costs) are included.

5.2.2 WORKING ENVIRONMENT AND HUMAN LIFE

As mentioned in 5.1, employees will sometimes be involved in the risk-reduction processes concerning the working environment. It might be difficult to assess the risk-reducing measures for the working environment in quantitative terms, and therefore a qualitative approach might also be needed. As the employees are the ones exposed to the “everyday risk” it is sensible that they are included in the process of identifying the risk reducing measures especially in the qualitative approach.

Personnel safety has first priority, as mentioned at the beginning of the chapter, and it is important that all risk reducing measures are chosen in respect to personnel safety. Risk matrixes are often used to categorise the consequences from an accident, and to illustrate the risk level. In this context one of the informants stated:

“It is strongly underlined that this is not how we value e.g. a human life, but it is attached to risk reducing measures. It is also underlined that there shall not be any kind of auto mechanism in these types of decisions.”

Another informant said that:

“We do not set a price on a human life, but estimate the cost of a potential life saved”

It is also written in one of the companies’ manuals that:

“When the health and safety benefits are described, using estimates of the “value of human life” should be avoided...” and “... does not permit the use of statistical monetary values of a human life in ALARP judgement.”

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It is obvious that “valuation of a human life” is no preferred term. In stead, the measures used to estimate the employees safety or risk is; IR (equation 6), FAR (equation 5), and PLL (equation 4).

The average individual risk of death for any group of offshore workers, including the most exposed groups, shall be as low as reasonably practicable. The average individual risk seems to lie at $IR < 1 * 10^{-3}$

Estimation of individual risk for offshore personnel includes:

- The average individual risk shall be calculated on a yearly basis as the average for personnel in any specific group
- The risk due to helicopter transport between the shore and the offshore installation shall be included in the estimation of the average individual risk
- Occupational risk shall also be included in the estimation of average individual risk

It was mentioned that a common way to express risk reduction for personnel is a reduction in FAR.

“FAR is calculated both for groups with specific tasks and for the average crew member on board, average over the duration of a whole offshore period.”

However, not one of the companies mentioned any particular criteria in respect to FAR.

One of the informants mentioned PLL in combination with risk reduction for groups. It was also mentioned that PLL is the statistical number of lives lost.

5.2.3 ENVIRONMENT

Environmental aspects often have the same approach as the working environment when estimating benefits. This is because of the difficulties both areas have when carrying out estimations. The problem for environmental assessments is that there are no single parameters such as a life saved which can be used as a measure of the benefit.

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Another problem mentioned by one of the informant:

“The risk-reducing measure may have both positive and negative effects depending upon the aspect being considered e.g. fish, mammals, shoreline, energy usage etc.”

Some companies use the environmental risk analysis, MIRA, as a basis when considering the environmental impact. This approach involves setting a criterion for the percentage of time the environment can be impaired and then setting criteria for different types of activity.

The petroleum industry is responsible for one fourth of Norway's total waste of greenhouse gasses. Discharge of oil and chemicals from shipping and petroleum industry may damage the organisms and ecosystems in the sea, sea bottom and in the shoreline. To give the oil companies an incentive to reduce their emissions and discharge, the authorities have required the offshore petroleum industry to buy a quota for maximum level of pollutants to settle for the yearly waste. This quota and other environmental costs are all included in the valuation of the risk-reducing measures which affect the environment.

The risk of damage to the environment as a result from activities undertaken by the companies, must be within reasonable limits. If the limits are surpassed the risk must be reduced to a level as low as reasonably practicable. The risk categories can be shown based on consequences on the environment and the estimated frequency:

Practical use of cost-benefit analyses

Risk category	Consequences	Estimated frequency
1.	Noticeable environmental impact: <ul style="list-style-type: none"> - Some effect on mammals, birds, or fish - Between 1 km and 10 km of shoreline affected - Time to recover: less than 2 years 	More than 10^{-2} per year
2.	Significant to major environmental impact: <ul style="list-style-type: none"> - Effect on the environment in the area that could threaten or in worst case, reduce the diversity of flora and fauna - Between 10 km and 100 km of shoreline affected - Areas of scientific interest or in worst case, areas of great ecological value affected - Time to recover: between 2 and 10 years 	More than 10^{-3} per year
3.	Major environmental impact: <ul style="list-style-type: none"> - Diversity of flora and fauna reduced - More than 100 km of shoreline affected - Areas of great ecological value significantly affected - Time to recover: more than 10 years 	More than 10^{-4} per year

Table 5-1: Acceptance criteria for risk to environment [8]

These categories are derived from the Association of Norwegian Oil Companies (OLF) and are, to a greater or lesser degree, the categories and frequencies used by the companies. Table 5-1 can be referred to as installation-specific risk. Other acceptance criteria for environmental consequences can be for field-specific risk and operation-specific risk.

The risk maintenance and the risk reduction must be in compliance with the appropriate regulations, standards, and industrial good practice.

5.2.4 REPUTATION

Risk of reputation will always be considered during the assessment process, but not all companies include reputation as an element in the cost-benefit analysis. Some of the companies chose to include reputation or public impact as a part of the risk matrix, with guidelines for costs versus scale of media coverage. The human and social consequences of a fatality and other unwanted incidents that can appear, makes it necessary to have a strong and continues focus on health, environment and safety within every part of the company.

The company's competitiveness in contracts and competition for competent employees might depend on the company's reputation. One mistake or one fatality might be enough to loose a contract.

These matters are included in the qualitative evaluations as part of the initial consideration of the identified risk-reducing measures. Reputation and media coverage are considered in relation to good offshore practise, i.e. what do other companies do? And, is this good offshore practice which is accepted as the correct way in the oil and gas industry?

5.3 DECISION PROCESS

It is not possible to say exactly how much weight the cost-benefit analysis has in a decision, but one can say that it is never 0% and never 100%. The decisions are often based upon the "real benefit", or the expected benefits, that will be obtained. The decision process will also be driven by the total cost of the risk-reducing measure and the length of time over which the benefit is taken. The identified risk will weigh heavily in a decision process – if the identified risk is high – it will take very special circumstances for the risk reducing measure not to be implemented. The size of the investment and complexity will rather increase the need for structured decisions.

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Uncertainty is an important element and sensitivity studies are often undertaken to evaluate the uncertainty of the cost estimates assessed and whether the risk-reducing measures has potential for full or partial implementation. Sensitivity analyses present the ruggedness in the results.

Cost-benefit analyses are used to determine appropriate action and to test whether the risk-reducing measures are in gross disproportion in relation to the risk acceptance criteria. With this at hand, the decision makers decide whether the measures shall be implemented or rejected, and whether the risk can be considered as ALARP.

An example of a check list the decision maker might follow in the decision process:

- Is all national and international legislation met?
- Are all company requirements met?
- Are the determined risk levels in line with that of comparable concepts/ solutions?
- If some requirements or practices are not met, can it be demonstrated that this does not give rise to an increased level of risk?
- If quantitative targets are defined, are these met with sufficient margins in order to enable any possible later increase in risk to be acceptable without the need for extensive changes?
- Is Best Available Technology (BAT) used?
- Have the solution been chosen with inherent safety standards in mind?
- Are there any unsolved problems, or areas of concern, with respect to the risk to personnel and/or working and external environment, or areas where these aspects are in conflict?
- Are there any unsolved problems in relation to serious environmental spills?
- Is the concept robust with respect to safety, environmental and asset risks?
- Have the results of the latest R&D or other new experiences been considered?

One of the initial criteria when considering risk-reducing measures is whether the measure is necessary in order to comply with legislation and good offshore practice. All of the companies involved are international companies, and therefore they have got to

follow both Norwegian and international requirements. In addition to the current Norwegian regulations (PSA regulations) the companies follow other European or British regulations and some follow the American Petroleum Institute (API) regulations. For good offshore practice, the NORSOK standards are most often used.

For qualitative analysis the accidental frequency may affect the probability in the risk matrix and may also affect the quantitative results. External effects have little effect on the valuation and evaluation of the cost-benefit valuations and the decision process.

5.4 THE RESULTS

The results from the risk-reducing measures can be shown through event reports and QRA, or there are also global data tools that can be used to trace results. One example of such a data tool is Impact. Impact trace actions back to responsible persons or departments. Actions that are not closed according to plan will be noted to the management.

Every incident or effect from an implemented risk-reducing measure shall be included in the cost-benefit analysis and therefore there should not be any surprising effects from measures. One problem that is sometimes encountered is that a risk-reducing measure may be positive in one dimension but negative in another. For example minimising the amount of dismantling work for an installation may have a very positive effect on safety, but may also have a very negative effect on the natural environment. Some form of rating system can be used when assessing the different effects of risk-reducing measures. Such a system however needs to be rather open as it is not usually possible to compare littering or air emission against possible injury to a person.

It is also necessary to make a plan to follow up the analysis. This should include an evaluation of the conclusions made from the analysis, recommendations and plans for implementation of the risk-reducing measures.

5.5 THE COMPANIES' EXPERIENCES WITH THE ANALYSIS

The overall experiences with the cost-benefit analysis seem to generally be quite good, as there seems to be few problems attached to the use of the analysis. On the other hand there are a couple of challenges that have been expressed by the different companies, and they are listed as six points here.

The first challenges mentioned was that:

“Many of the risk-reducing measures could show a very high cost for statistical lives saved, and, on a pure cost-benefit basis, the measures should not be implemented. Although many of the measures represented good practice and could be implemented at a cost which was not excessive.”

The second challenge is the uncertainty in the quantitative risk analyses and the models used. A lot of uncertainty is involved when decisions are based upon calculations. If the models are not exact, then consequently, the true benefit in terms of potential lives saved will also be uncertain. This will then question the reliability of the decisions taken.

The third challenge is that some of the positive and negative effects – like media coverage, environmental impact and development in the working environment – are difficult to transform into an economic value:

“Potential positive or negative media coverage will definitely get reflected in a cost-benefit analysis. The challenge is to give it an economic value.”

The fourth challenge is the uncertainty around calculating the results. When the risk reducing measure are chosen, which measure gives the most reliable results?:

“Do we use P90-value, expected value or other?”

For the fifth challenge, it is also related on the results, but tends to be more aimed at the difficulty to measure the results and the lack of knowledge about what the real result will be. Will the implemented risk reducing measure have other effects than the ones identified when carrying out the analysis? And will the identified effects really emerge?

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This is not always easy to say, especially since some of the results e.g. for environmental impact will take several years to emerge.

The sixth and final challenge is that many decisions and prioritisations will be subject to discussions and disagreement. This is because different groups, for instance management, employee, special interest organisations and government, have different ethical principles and will therefore prioritise differently. There will also always be different opinions among the participants within a risk analysis group about the necessity of the different measures etc. This is the main reason for why the analysis is developed in teams.

6. DISCUSSION OF THE PRACTICAL USE OF THE ANALYSIS

This chapter consists of a discussion of how the practical use of the cost-benefit analysis is performed according to the theory, the Norwegian regulations and the safety level.

6.1 PRACTICAL USE OF THE ANALYSIS WITH BASIS IN THE THEORY

Comparing a theoretical presentation with a practical performance is complicated. To compare the components mentioned by the companies with components mentioned in the theory would not work. It would make the practical use of the cost-benefit analysis very similar to the theoretical presentation. The use of the elements is what makes the difference, and find out whether the companies use the elements in the same way they are proposed in theory.

Aven's schematic presentation of a cost-benefit analysis, Figure 2-1, is a starting point to get an understanding of how a cost-benefit analysis is performed.

Define goals

The need for a cost-benefit analysis depends on the change, problem or situation that has, or has a high probability, of occurring. Therefore, the presentation of the present situation is crucial when defining the goals for the cost-benefit analysis. A risk matrix might be used to illustrate the severity of the present situation, and simply show how much the frequency or probability of the event have got to be reduced to become acceptable.

Risk matrixes are widely used by the companies, as it is a simple way of showing where the modifications are needed. The problem with the risk matrix is that it uses very rough calculations, and therefore it is sometimes difficult to use correctly. One must keep in mind that the risk matrix is just a tool to render the risk, and not a tool for analysis. By using the risk matrix in the goal definition, the problem of confusing it with an analysis tool may be reduced. In this way it works as an input tool as to what the following risk analyses should include.

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The determination of an acceptable risk level varies between the different risk areas. Each risk matrix is related to only one type of event, and that event affects personnel, environment and asset in different ways. Each of the risk levels has to be considered in the following determination of possible risk-reducing measures.

Identify and choose alternatives

The definition of the goals is the foundation stone for the identification of alternative measures – the necessary risk reduction for each area makes out the scope of the analysis. The companies often undertake a QRA to identify the aspects which have the greatest mitigating effect on the risk level. According to the theory, a QRA gives a technical decision basis to the choice of method. The reason to carry out a QRA in combination with a cost-benefit analysis is to get input that can help determine whether a proposed risk-reducing measure would be reasonably practicable, and thereby which of the alternative measures is worth taking further.

The identification of alternative measures must include every area that might get affected by the identified risk, not just the area where the event is expected to appear. This might show the need for passive fire protection or other barriers that might prevent an escalation of the initiating event. If the event should appear despite the risk-reducing measures, the barriers would make sure that the consequences get as low as possible.

SINTEF has a model, Figure 2-3, which illustrate possible loss categories. The consequences or losses may vary, depending on which values affected and the scope of the threat, but the illustration gives a good overview over losses that might occur and therefore could be combined with the analysis.

Evaluate advantages and disadvantages

Every advantage and disadvantage of the proposed risk-reducing measures should be evaluated and included in the analysis. Even though a risk-reducing measure may be positive in one dimension, it might be negative in another.

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One example of a risk-reducing measure is to prevent a gas leak. This involves changing old valves in the pipelines. The production must be stopped while the valves are changed, which will cause reduced production of gas and thereby reduced sale and income.

Compared to the consequence of a gas leak, the expenses of the change will be minor. A gas leak can lead to:

- an automatic shutdown, which might last until the investigation of the accident is finished
- evacuation of the employees
- increased discharge to air
- replacement of equipment
- an explosion, which could have led to fatalities, considerable destruction of the platform, massive discharge etc.

Even if the risk-reducing measure might have disadvantages, the consequences from an accident will most likely be worse. The advantages and disadvantages should be described as far as possible. There is no room for surprising effects.

One problem is that even though the analysis group has included every thinkable effect, it is still possible that other effects might arise. One can give a pretty good estimation of what will happen, but never a guarantee. It can be used a form of rating system when assessing the different effects of risk-reducing measures. Such a system however needs to be rather open as it is not usually possible to compare littering or emission to air towards a possible injury to a person.

Calculate expected net present value

The essence of the cost-benefit analysis is to calculate the expected net present value for all the proposed risk-reducing measures – if the project's $E[\text{NPV}]$ is higher than or equal to zero, the project is profitable. Every identified advantage and disadvantage is quantified or transformed into monetary values. Since the different costs (disadvantages) and benefits (advantages) of the measure do not normally appear at the same time. The

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costs and benefits are discounted to the time of the investment or to the start of the project. The reason for doing this is to be able to compare the effects of the project.

Some companies use Life Cycle Costs (LCC) in combination with the cost-benefit analysis, as does NORSOK Z-013. In LCC, only the costs are taken into account. The benefits are included in the sense of risk reduction as a result from the costs. As it does not include gain or income, this will not give a satisfactory picture of the measures' results. There is more to a risk-reducing measure than just cost and an x percentage reduction in the risk level.

Some of the elements in the risk-reducing measure are difficult to value, like a human life or the effects on the environment. To value a human life is said to be unethical, and it seems like every company avoid using the term "value of a human life". It is even said by one of the companies' manual that "it is not permitted to use statistical monetary values of human life in ALARP judgement". This differs from the theory which repeatedly says that the value of a statistical life is the company's willingness to pay to reduce the expected number of fatalities. To prove reduced risk for personnel, one normally use reduction in FAR, PLL or/and AIR, to show the probability for an accident leading to death of personnel is reduced. Reduced risk to environment is shown by reduced frequency per year.

Rank the alternatives

If the $E[NPV]$ of a risk-reducing measure is positive, the project is profitable and worth taking further. The different risk-reducing measures may be good at different areas. One might be best based on safety and another is best based on reduction of costs. A rating system for each preferred characteristic give an indication of the most suitable measures. Also the qualitative description of which effects the different measures might cause, is included when ranking the alternatives.

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Carry out sensitivity analyses

Uncertainty is an important element. Sensitivity studies are therefore often undertaken to evaluate the uncertainty of the cost estimates assessed and to evaluate whether the risk-reducing measures have a potential for full or partial implementation. Sensitivity and uncertainty analysis should also be considered on the QRA results, to provide an understanding of the effect key assumptions have on risk calculations. Sensitivity analyses present the ruggedness in the results.

Suggest an alternative

It is important that the proposed alternatives stay within a reasonable cost level, is ALARP, covers all the HSE aspects and can provide real benefits. HSE is an important contributor to the safety to both personnel and the environment,

ALARP and risk acceptance criteria are repeatedly mentioned in both theory and by the companies. All measures proposed are to make the risk level acceptable or as low as reasonably practicable. The cost-benefit analysis is a tool in the process of reaching ALARP or the acceptable area. This is done by calculating how “grossly disproportionate” the costs are compared to the benefits.

When choosing amongst the suggested alternatives, one must first single out the best, and probably the most expensive, alternatives. Then one look at the second best alternatives; can it be good enough? Is it worth investing more money to achieve a lower risk level? Every company say that personnel safety comes before everything, but what is safe enough? Is the idea to eliminate or mitigate the risk? There are many factors that might influence the choice of risk-reducing measures, but most important is to provide real benefits, and reduces the identified risks as low as reasonably practicable.

One thing not included in Aven’s presentation of the cost-benefit analysis is the underlying causes affecting the analysis. When the companies carry out a cost-benefit analysis, they do it because the risk is above an acceptable level. These risk acceptance criteria should, according to the theory, be based on regulatory requirements and inter-

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company demands. And according to the companies, every proposed risk-reducing measure should be evaluated based on their compliance with regulations and good offshore practise. Best available technology and research and development are to be the basis for the suggested alternative measure to ensure efficient risk reduction. All in all, the underlying causes are the basis for every decision made in respect to the cost-benefit analysis. This will be further discussed in the following chapter, as the legislations consider most of the underlying causes for risk analysis and risk reduction.

To claim that the practical use of the cost-benefit analysis is similar to the theory based on this presentation is not sufficient. Several points are not mentioned in Aven's presentation which has a considerable effect on the difference in the comparison of the practice and the theory. Therefore an expansion of Aven's schematic presentation, to also include elements from the checklist in NOU 1998: 27 and information gained from the companies will be a better basis for a comparison. Aven's presentations include the main steps in how to gradually carry out the analysis. The checklist and the information from the companies give examples of what should be included under each step of the analysis, and the underlying causes for what is included.

A suggestion to such a model is given below.

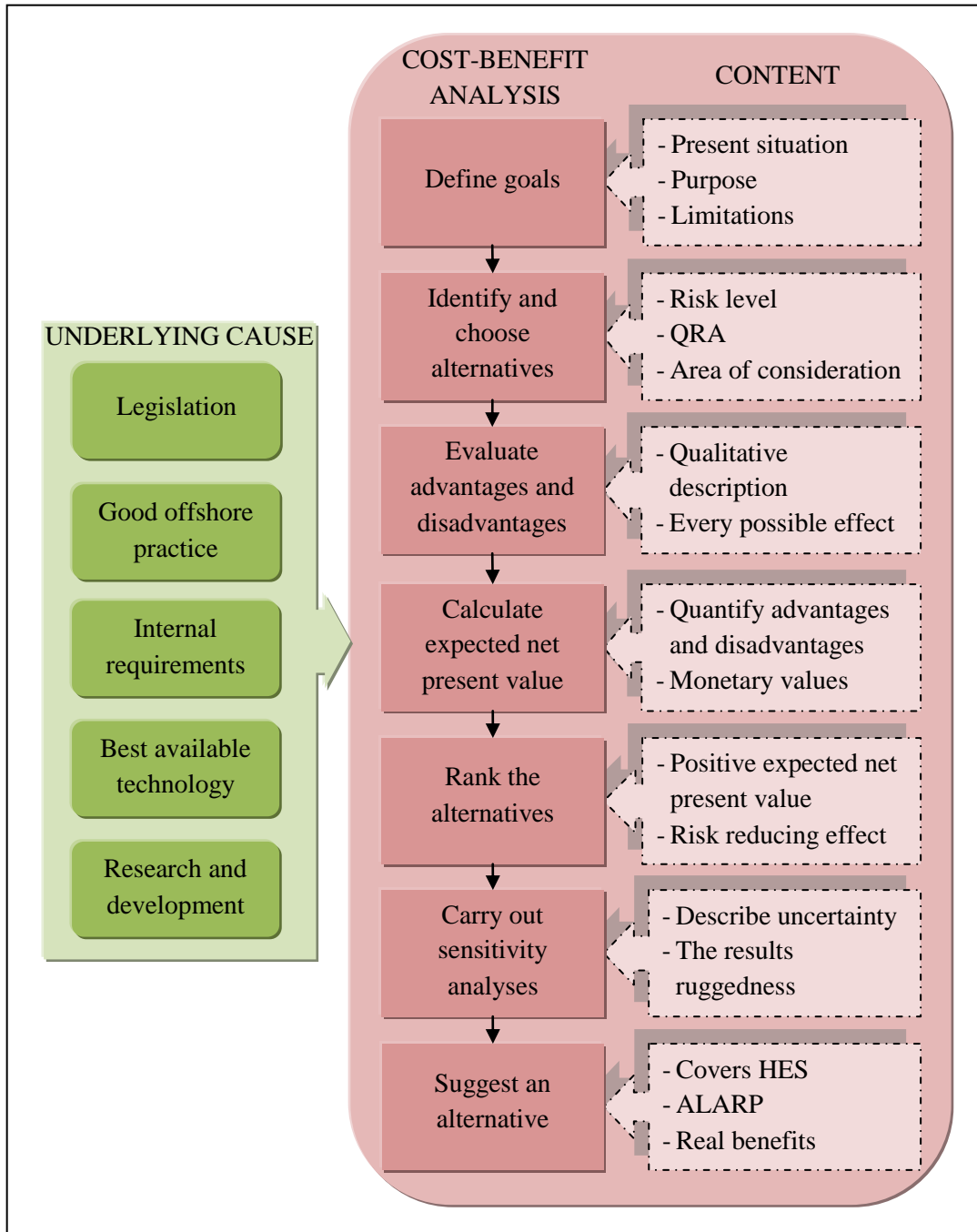


Figure 6-1: Cost-benefit analysis with underlying causes and content

The companies have come across several challenges in their use of the cost-benefit analysis. Some of the challenges are that a result, based only on a pure cost-benefit analysis, not is reliable enough. The calculations and models might not always be exact, and this will question the reliability of the decisions taken. This implies that a qualitative

evaluation is necessary for the analysis to be a good decision basis. And according to chapter 2.1, this still fits the description of a traditional cost-benefit analysis. Most of the elements get valued, while the other elements, that are found difficult to value, are given a separate analysis. This makes the analysis more reliable and easy to carry out, since all elements are covered in their most suitable manner.

Another challenge is the calculation of media coverage, environmental impact and other elements in the analysis that are not easy to transform into an economic value. These are elements that always will be a part of the analysis, but there will never be any correct way to calculate them.

There are also challenges with the difficulties to measure the result. The lack of knowledge about the real results, demand more experienced knowledge from the analysis team. The aim is to include every thinkable effect from the measure, but as one cannot guarantee the future there are always possibilities that something unexpected might occur. This is the nature of estimated assessment.

6.2 PRACTICAL USE IN PROPORTION TO THE LEGISLATIONS

All the companies involved are international companies, and are therefore subject to both national and international legislation. In this context, only the Norwegian regulations are used. Among the regulations from PSA there are three sets of regulations that are of interest in respect to the practical use of cost-benefit analyses: the Framework regulations, the Management regulations and the Facilities regulations. As mentioned in the previous chapter, the legislation should be the underlying cause for every decision made when suggesting and choosing risk-reducing measures. If other criteria are to be used they have to be documented to be as good as, or better than, the criteria in the regulations.

6.2.1 *THE FACILITIES REGULATIONS*

Section 8: Prudent petroleum activities

Section 8 in the Framework regulations can be used as the superior goal for the cost-benefit analyses – prudent petroleum activity. All the decisions in a cost-benefit analysis are done for making the petroleum activities more safe and prudent. To be able to achieve this goal, HSE management and a high focus on accident and risk reduction is essential. How to reach the goal of prudent petroleum activity is not given. It depends on the risk assessments and on which factors that are considered relevant by the different companies. The companies involved have expressed that an effort must be made during the cost-benefit assessment to consider all possible factors that might affect the analysis and all the possible effects that might arise from the measure.

Section 9: Principles relating to risk reduction

Principles relating to risk reduction require compliance with legislation for health, environment and safety, internal requirements, and acceptance criteria. These factors are all extensively in use, and are included in the checklist over “elements covered” during the decision process. Every company has its own sets of risk levels which they find acceptable to expose their employees, the environment and the asset to. Risk should be reduced to the extent possible. This is a well known and widely used demand to keep the risk level as low as reasonably practicable.

To use and access the best technology possible is of great importance for the companies when they perform risk-reducing measures. This is mainly mentioned in relation to environmental risk. Reduction of environmental risk is largely dependent on research and development, and to be able to reduce discharges to the extent possible one needs the best available technology to get the best results.

New technology is often combined with uncertainty, because of the lack of knowledge and how it might improve the current situation. Knowledge is therefore a precautionary principle – by increasing knowledge about the technological developments the uncertainties are reduced. The companies do not mention this in particular, but as they are

preoccupied with the latest R&D and the use of BAT, increasing knowledge will always be a part of a company's development.

6.2.2 *THE MANAGEMENT REGULATIONS*

There are several requirements that are of importance in relation to the cost-benefit analysis. Among them are the risk acceptance criteria and the chapter of risk analyses.

Section 6: Acceptance criteria for major accident risk and environmental risk

The acceptance criteria for major accident risk and environmental risk set in section 6, are the same as the ones mentioned by the companies, except damage done to third party. Damage to third party has not been a subject in this relation, and therefore there is no basis for comparison.

The average acceptance criteria set by the companies:

- Risk to personnel: $IR < 1 * 10^{-3}$ per year
- Risk to losses of main safety functions: $< 5 * 10^{-4}$ per year
- Risk of pollution: estimated frequency per year varies between $1 * 10^{-2}$ and $1 * 10^{-4}$

The estimated frequency of pollution, as mentioned above, is an installation-specific risk where the acceptance criterion varies with the impact on the environment. The variation in the estimated frequency varies from noticeable to major environmental impact. There is also field-specific risk and operation-specific risk when assessing the pollution effect on the environment.

Section 13: General requirements to analyses

The cost-benefit analysis is used to determine appropriate actions to reduce identified risks. However, how a big part of the decision basis built on the cost-benefit analysis is not easy to find. It can never be 0% and never 100%. The identified risk in itself will weigh heavily in a decision process. If the identified risk is high, it will take very special circumstances for the risk-reducing measure not to be implemented. In addition to the

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cost-benefit analysis it is common to get input from a QRA and use sensitivity analyses to evaluate the uncertainty of the cost estimates.

Documentation of how, when and why to carry out an analysis, is of great importance. This is required in section 13 in the Management regulations. As a guidance of what to include in the documentation, many companies use NORSOK Z-013 as a source. The same demands are used for the cost-benefit analysis as well as for the quantitative analyses. The reason for carrying out a cost-benefit analysis is supposed to be clear. Because e.g. when carrying out cost-benefit analyses for the working environment the employees are often included in the process. To make sure the results is correct, it is important to make the purpose for the analysis unmistakable. A complete and comprehensive presentation of the results should be made to enhance knowledge and understanding for future assessments.

All decisions have got to involve, and be signed by a responsible leader. Both the quantitative and the qualitative analyses should be approved and signed before they are implemented. Even identified measures that are not to be implemented has to be signed by onshore and offshore management, and by safety delegate. This gives the responsible leaders and the management a good overview over identified measures, and which of the measures that is, or will be, implemented and which measures that will not.

Section 14: Analyses of major accidental risk

The evaluation of risk-reducing measures to minimise the risk of major accidents usually comes as part of a total risk analysis. This includes both qualitative and quantitative analyses. Normally a QRA will be undertaken to determine the overall risk level and then risk-reducing measures are identified in order to reduce the risk to personnel and the environment further. This is demanded in section 9 in the Framework regulations. The QRA is used to identify the aspects which have the greatest effect on the risk levels and the risk-reducing measures.

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Section 15: Quantitative risk analyses and emergency preparedness analyses

As mentioned above, the QRA is used to identify the aspects which have the greatest effect on risk-reducing measures. To reduce the probability of an event occurring, the measures that reduce the effect of an accident should be sought. Measures that often are identified for cost-benefit assessments include: passive fire protection, additional fire walls and fire barriers, duplication of equipment to provide levels of redundancy, alternative materials and design arrangements for pipe work etc.

Empirical correlation or computer simulations are used to model and calculate the consequences and severity for each risk initiating event. These models are next used to generate an overview over the possible damage created by the events. Combined with an estimation of the frequency of the events, it gives an illustration of the risk for each particular scenario. The total risk for the installation is a combination of the risk for all scenarios.

Section 16: Environmentally oriented risk and emergency preparedness analyses

It is commonly known amongst the companies that environmental risk associated with offshore operations must be as low as reasonably practicable, and must be based on the best available technology. Some companies mentioned that they use a variation of the MIRA approach as a basis to consider the environmental impact. MIRA gives a common approach and framework as to carry out environmentally oriented risk analyses. These analyses will be comparable between fields and between companies.

It is common to estimate the frequency of environmental impact by $x * 10^{-x}$, and the companies also mentioned that they often divide the acceptance criteria for the environmental risk into field-specific risk, installation-specific risk, and operation-specific risk. This makes the analysis comparable and easily interpretative. That there is no single parameter as to measure the benefits of a risk reducing measure in the environment, but a collection of different parameters. This might complicate the calculations in the cost-benefit analysis and the comparison of the results between the companies.

Section 17: Analyses of the working environment

When the cost-benefit analyses concern risk-reducing measures for the working environment, some companies often involve the employees in the process, as they know “*where the shoe pinches*”. This way the employees choose the elements included in the cost-benefit analysis and also how the elements are weighted. Effects of risk-reducing measures concerning working environment tends to be difficult to assess in quantitative terms, therefore a qualitative approach is also necessary to the aspects. Other companies use contractors, like DNV and Safetec, to carry out quantitative updates and to identify reducing measures to achieve ALARP.

The average individual risk of death for any group of offshore workers, including the most exposed group, must be as low as reasonably practicable, and is not supposed to have a frequency of more than $IR < 1 * 10^{-3}$. This is the common criteria expressed by the companies. It is also common to use changes in FAR to express risk reduction. None of the companies mentioned any particular criteria in respect to FAR.

6.2.3 *THE FACILITIES REGULATIONS*

Section 6: Main safety functions

Main safety functions should ensure the safety for personnel and limit pollution. The main safety functions mentioned by the companies were:

- Escape ways
- Temporary refuge
- Evacuation means
- Structure
- Escalations barriers
- Central control room

The impairment frequency is calculated for each of the main safety functions. This might e.g. be a frequency of $1 * 10^{-4}$ per year for each accident affecting one of the main safety functions, or a frequency of $5 * 10^{-4}$ per year for the total amount of accidents affecting one or more of the main safety functions.

In addition to the numerical presentation of the impairment frequency, the risk analysis includes the area which the impairment scenarios occur and the mechanism of the impairment. The aim is to provide a better basis for judging effects of alternative risk-reducing measures.

6.3 PRACTICAL USE IN PROPORTION TO THE RISK LEVEL

The cost-benefit analysis is a tool in the process of reducing an identified high risk, and its goal is to find a measure that reduces the risk level with $x\%$. The analysis is supposed to identify every possible effect that might appear as a result of implementing the risk-reducing measure. There is no room for any unexpected surprises as a result of the implementation. After the implementation; how can one be certain that the risk-reducing measure had the estimated effects?; and what if a risk-reducing measure was implemented and the accident still happen. Would this indicate the analysis failed? Since, it is not possible to guarantee elimination of an identified risk, then no. Remember that the result from the cost-benefit analysis is a measure that is most likely to reduce the risk to an acceptable level. There is never a guarantee.

One of the problems associated with the cost-benefit analysis is; there is no easy way to measure the effects from a risk reduction. One does not know whether an accident that does not occur during the time period considered, was prevented by the measures or whether it just did not happen.

Over the past years there has been a visible reduction in accidents affecting personnel. Hydrocarbon leaks, incidents related to drilling and wells, and ships on a collision course have had a slight, but steady, decline since 2002. From 2005 to 2008 there was a significant improvement in the HSE area. Injuries related to the work activity on a platform have, on a total basis, been reduced from 26,5 injuries per million working hours in 1999 to 10,7 injuries per million working hours in 2008. This imply that implemented risk-reducing measures have had its effects.

Emission of hazardous chemical from the petroleum industry has been reduced over the past few years. Even though the oil and gas industry now only counts for about one percent of the total emissions in Norway, this industry is still the largest source of greenhouse gas emissions and the second largest source of acidifying emissions. There is still room for considerable improvements.

Knowledge about the long term effects the discharge has on the environment is limited, and this can make the process of choosing the right risk-reducing measure difficult. It is proven that oil and gas activities have put pressure on the seabed environment near offshore installations, but it is not known how many years it will take before the environment is restored to its original state. Another aspect that makes it difficult to carry out cost-benefit analyses for environmental effects is that there are no single parameters which can be used as a measure of the benefits. There are a lot of uncertainties associated with the cost-benefit analyses which are carried out in respect to the environment.

It is currently not possible for the petroleum industry to operate efficiently without using large quantities of chemicals. One of the solutions to get the companies to maintain the focus on emission-reduction is to make them buy a quota for the estimated amount of yearly discharge. This is an important incentive for the companies to continue to reduce the emissions – reduced emission, reduced quota to buy. The price of the quota will be included in the valuation of the risk-reducing measures.

Another reason to keep focus on the environment, and also on keeping the accident frequency low, is in respect to the company's reputation. Reputation has no direct influence on the cost-benefit analysis, but it is often evaluated in relation to good offshore practice. A good reputation is important for the companies' competitiveness in contracts and for competent employees. Not everybody include reputation as a part of the cost-benefit analysis, but it will be considered in most cost-benefit assessments.

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When including the development of the risk level, the most important factor was to find out whether the risk level might affect the valuation and implementation of the cost-benefit analyses. This turned out only to be partially correct. Even though the risk level is decreasing, it shows that there is still room for improvement. In this way risk levels have had its effect on the cost-benefit analyses, but it also has showed a contrary influence – the cost-benefit analyses' effect on the risk level. As mentioned earlier, the results from a risk-reducing measure is not always visible. For the risk level to decrease, some measure most have been carried out and resulted in a reduced risk. This shows a mutual influence between the risk level and the cost-benefit analyses' risk-reducing measures.

7. CONCLUSION

Every decision made offshore will be cost-benefit evaluated, but not every evaluation leads to a total analysis. The cost-benefit analysis is in general carried out when there is need for risk-reducing measures. To ensure the cost-benefit analysis provides the decision maker with the best possible information about the different risk-reducing measures, mostly it involves other analyses as well. This might be a QRA, to identify the aspects which have the greatest mitigating effect on the risk level and as input for determining whether a proposed risk-reducing measure would be reasonably practicable. A sensitivity analysis to evaluate the uncertainty of the cost estimates is also used to show the ruggedness in the results.

Practical use of cost-benefit analyses is very similar to the theoretical presentations of the analysis. There are some differences, like the use of the term “value of a human life” that seems to be a regular term based on the theory, but is not permitted to use in most of the companies. There are also some companies that use LCC instead of NPV when calculating the profitability of a risk-reducing measure. This shows the benefit in risk reduction as a result of the invested costs. To see the whole effect of the risk reduction, one prefers to use NPV, as it includes both gain and costs from the measure.

The legislation is an underlying cause which, among others, is of importance in every decision made when suggesting and choosing risk-reducing measures. All the companies involved in this thesis are international companies, and are therefore subject to both national and international legislation, even though only the Norwegian regulations were used in this context. In relation to the practical use of the cost-benefit analysis, there were a couple requirements that were more fitting than others; these were within the Framework regulations, the Management regulations and the Facilities regulations. Several of the regulations were formulated as goals, and it is a common aim to get the companies to find their own way to fulfil them.

Over the past years there has been a visible reduction in accidents affecting both personnel and environment. This indicates previous risk-reducing measures have had its

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effects. There is not always a simple way to measure the effects from a risk reduction, nor to actually be certain that the measure had any effect at all. Even if the risk-reducing measure has reduced the probability of an accident to occur, there is still a possibility for it to happen. It is also possible that the accident never would happen even without the risk-reducing measure.

Regarding risk reduction of environmental impact, there is limited knowledge about the long term effects from the discharge. And it is currently not possible for the petroleum industry to operate efficiently without using large quantities of chemicals. Therefore it is important for the companies to maintain focus on risk-reducing measures in respect to reduce discharge.

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APPENDIX A:

CHECKLIST FOR COST-BENEFIT ANALYSIS

1 Problem description

- 1.1 Describe the present situations and further development without taking action on the identified area (basis alternative).
- 1.2 What is the purpose with the measures that is to be evaluated?
- 1.3 Who is the responsible on the area?

2 Specify the measures

- 2.1 What measures are to be taken? Remember to specify all possible alternatives.
- 2.2 Describe the measure and how it is to be carried out.
- 2.3 Evaluate whether the measures should be implemented now, or if it is best to wait. At the same time, evaluate whether the actual measure should be implemented as a whole, or if it should be implemented gradually and more flexible.

3 Specify the effects

- 3.1 Give each measure a qualitative description of the effects in form of advantages and disadvantages. Include also the effects that neither can be quantified in physical form nor can be valued into kroner. Remember to include all relevant effects, not just the ones appearing in one's own department. Remember also to consider unintended changes in individual behaviour, e.g. in combination with measures meant to reduce the accidental risk.
- 3.2 Quantify advantages and disadvantages as far as possible in form of physical dimensions. Value the effects in kroner where it is possible and where it gives meaningful information. Use expected values if there is uncertainty attached to any of the quantifiable numbers/dimensions. Remember in that case to consider different effects and also extreme effects with low probability as e.g. unexpected high costs.
- 3.3 Explain which data sources, assumptions and methods that are used for identifying the effects, quantification and valuation. Emphasize particularly an evaluation of the data quality.
- 3.4 Describe the total uncertainty attached to the measure. Take a stand to how much of the uncertainty that is systematic. Integrate this uncertainty into the valuation of the measure.

Practical use of cost-benefit analyses

3.5 For each measure, calculate socio-economic gain, or potentially costs, to achieve a given goal. Give a thorough description of the effects that is not technical justifiable to transform into a monetary value.

3.6 Account for distributional effects from the different measures. Is there any conflict of interests attached to the measure, poss. which? Is it possible to counter unwanted distributional effects by using alternative project design or special compensation measures?

4 Follow-up and evaluation

4.1 Who is responsible for the evaluation of the measures?

4.2 When and how will the measures be evaluated?

APPENDIX B: RISK MATRIX

The following risk matrix is just an example, and there are several variations of risk matrixes that can be found in the literature. It does not matter which matrix you use as long as you consistently use the same matrix.

LIKELIHOOD	CONSEQUENCE				
	I	II	III	IV	V
A	Low	Low	Low	Medium	Medium
B	Low	Low	Medium	Medium	Medium
C	Low	Medium	Medium	High	High
D	Low	Medium	High	High	Extreme
E	Medium	High	High	Extreme	Extreme

The green area is the acceptable risk level, the yellow area is the ALARP area, and the orange and red areas are the unacceptable risk level.

Likelihood Table

The following can be used as a guide for determining likelihood. However this tool has limitations as likelihood and frequency of events tend to vary between disciplines and functional areas.

Practical use of cost-benefit analyses

Level		LIKELIHOOD
		Expected or actual frequency experienced
A	Rare	May only occur in exceptional circumstances; simple process; no previous incidence of non-compliance
B	Unlikely	Could occur at some time; less than 25% chance of occurring; non-complex process and/or existence of checks and balances
C	Possible	Might occur at some time; 25-50% chance of occurring; previous audits/reports indicate non-compliance; complex process with extensive checks and balances; impacting factors outside control of organisation
D	Likely	Will probably occur in most circumstances; 50-75% chance of occurring; complex process with some checks and balances; impacting factors outside control of organisation
E	Almost certain	Can be expected to occur in most circumstances; more than 75% chance of occurring; complex process with minimal checks and balances; impacting factors outside control of organisation

Consequence Table

The following is a guide to determining consequences. The applicability of the operational definitions of each category of consequence will vary between different areas and thus is recommended as a guide only.

Level		CONSEQUENCES			
		Safety/Health	Environmen	Assets	Reputation
I	Insignificant	Zero harm to minor injury, no lost time	No or slight effect	Zero or slight damage	Zero or slight impact
II	Minor	Minor injury, restricted work case, or lost work case < 4 days	Minor effect	Minor damage	Limited impact
III	Moderate	Major injury, permanent partial disability or lost work case > 4 days	Localised effect	Local damage	Considerable impact
IV	Major	1-2 fatalities (or permanent total disabilities)	Major effect	Major damage	Major national impact
V	Catastrophic	Multiple fatalities (or permanent total disabilities)	Catastrophic effect	Extensive damage	Major international impact

APPENDIX C:

INTERVIEW QUESTIONS ABOUT COST-BENEFIT ANALYSIS

Interviewee:

1. What is your present position in the company?
2. How are you involved in the process of carrying out a cost-benefit judgement or a cost-benefit analysis?

Use of the cost-benefit analysis in the company:

3. At what level in the company and in what occasions are the cost-benefit analysis and cost-benefit judgements most often used?
4. Who is involved in the process of mapping and identifying relevant elements that should be included in the cost-benefit analysis, and who is involved in the decision making process?
 - a. Who decide which elements to use in the analysis?
 - b. Who perform the analyses?
 - c. Who evaluate the analyses?
 - d. Who decide which projects to carry out?
5. How are the cost-benefit analyses carried out when it concerns risk-reducing measures for hazardous large-scale accidents that constitute a threat to human and environment?
 - a. Which elements are often involved in this cost-benefit evaluation?
 - b. How are these elements chosen?
 - c. How are these elements been treated?
6. Are there any other elements included in a cost-benefit evaluation of risk-reducing measures concerning damage and accidents affecting the working environment?
7. How much of the total decision making process is affected by the cost-benefit analysis?
 - a. Will this vary with regard to the size of the decision and the complexity of the decision?

Practical use of cost-benefit analyses

8. How have the cost-benefit analyses been affected by the external circumstances?
 - a. Variation in the environment / Changes in CSR
 - b. The financial crisis
 - c. Change in the amount of hazardous accidents
 - d. (Changes in the management)

Accidents causing risk to human and the environment may damage the company's reputation.

9. Is the value of the reputation included in the cost-benefit evaluations?
 - a. How?
10. How is loss of reputation calculated?
11. How is the company's practice of calculating difficult measurable elements like a human life and damage on the environment?
12. Have you met any problems or challenges with the use of the analysis or in the process of carrying out the analysis? (Something that has changed the way of thinking or the use of the analysis at a later stage?)

The offshore industry is one of the industries that does not get allocated any discharge quotas.

13. Is it possible to get the number of quotas you bought for the period 2008-2013, and how much you paid for them?
14. Has the price on the quotas any influence on the evaluation of discharge reducing projects? How?
15. Has the CO2 fee any influence on the decision making process of the projects?

When the cost-benefit analysis is carried out:

16. How are the effects from the projects measured?
 - a. Are there usually other effects than the ones detected in the analysis?
 - b. Do these effects usually affect later focus on risk-reducing measures? How?
17. Have you encountered any criticism or oppositions against your prioritising of risk-reducing measures conserving human and environment?