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Abstract

Safety management objective is to prevent accidents to occur, thus reducing harm to people as well as preventing damage to environment and assets. To reduce harm, safety measures need to be implemented. In prioritizing which safety measures to be implemented, different industries are using different decision-making principle, depending on the uncertainties being faced and the strength of background knowledge. In this thesis we discuss the decision-making principle used in prioritizing the implementation of safety measures in offshore petroleum industry and transportation industry.

A recent study by Abrahamsen and Abrahamsen (2015) suggested that it can be appropriate to adopt ALARP principle as a general principle in safety management if the layered approach is adopted. We discuss that this approach can be applied in issues related to offshore safety and road traffic safety, which have different characteristic and different context. Therefore, we conclude that the ALARP with layered approach can be applied as general decision-making principle in safety management.

Acknowledgement

This master thesis represents the final work of my master study in Risk Management at the University of Stavanger.

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Stavanger, 15.06.2016

Yanti Widyariny Pamuntjak

Abbreviation

ALARP	As Low As Reasonably Practicable
FAR	Fatal Accident Rate
HSE	Health, Safety and Environment
ICAF	Implied Cost of Averting Fatalities
NPV	Net Present Value
NPRA	Norwegian Public Road Administration
PLL	Potential Loss of Life
PSA	Petroleum Safety Authority
SSIV	Subsea Isolation Valve

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1. Introduction

1.1 Background

Industries nowadays are paying more attention in improving and promoting safety, ensuring that measures are taken to protect people, environment and assets from harmful consequences of the activities being undertaken. This is what safety management does. The goal is to prevent accidents to occur, thus reducing harm to people as well as preventing damage to environment and assets. To achieve this goal, risk analysis is performed to identify risk and formulate the associated risk reducing measures or safety measures. Ideally every safety measure should be implemented, but sometimes not all of the measures can be implemented. In this case, decisions need to be made to prioritize the measures which optimize the use of the resources while improving the safety level.

Different industries are using different methods to support their decision-making process in prioritizing which safety measures to be implemented, depending on the uncertainties being faced and the strength of supporting knowledge. One may make decision with reference to cost and benefit analysis, while others may base their decision on the cautionary principle without giving weight to the cost-benefit analysis (Abrahamsen & Abrahamsen, 2015).

Take for example the offshore safety in offshore petroleum industry and road traffic safety in transportation industry, these two industries base their decision on different grounds. Offshore safety has been familiar with ALARP (As Low As Reasonably Practicable) principle weighting more to the cautionary principle. Cautionary principle, which is the basic principle in safety management, implies that in the face of uncertainty, caution should be the ruling principle (Aven & Vinnem, 2007). On the other hand, for many years, road traffic safety has been using cost-benefit analysis to set priorities for road safety measures (Elvik, 2001).

Is there any generic method that can be applied as a general principle in safety management regardless of the type of the industry?

A recent study from Abrahamsen and Abrahamsen (2015) suggested that the ALARP principle can be used as a general principle in safety management if the layered approach suggested by Aven (2011) is adopted. This approach is formulated in such a way that the ALARP principle can range from one extreme perspective to another, from extreme economic perspective where decisions are made with reference to expected values, to extreme safety perspective in which the cautionary principle is given special weight with no reference to cost-benefit (cost-effectiveness) analysis.

It is interesting to study how different industries base their decision-making process to prioritize the implementation of safety measures. And would it be suitable for industries to adopt the ALARP with layered approach mentioned above as a general decision-making principle in safety management? This will be further discussed in this thesis.

1.2 Purpose of the Thesis

This thesis aims to study, and to discuss, the current decision-making principle used by industries in prioritizing the implementation of safety measures. The thesis will also discuss the suitability to apply the ALARP layered approach as a general decision-making principle in safety management for different industries.

For the purpose of this thesis, the study will be limited only to offshore safety and road traffic safety.

1.3 Methodology

To achieve the purpose of this thesis, a literature and references study will be conducted to collect the information about decision-making principle in offshore safety and road traffic safety. Related regulations and guidelines from the respective authorities will also be studied and presented in this thesis. This information will then be analysed, compared and discussed in order to conclude whether the ALARP with layered approach can be applied as decision-making principle in regards to the implementation of offshore safety and road traffic safety.

1.4 Structure of the Thesis

This thesis will be organized in chapters. The first chapter, this chapter, is the introduction chapter defining the background, purpose, methodology and the structure of the thesis. The second chapter will present the literature and reference study that relevant with the subject in this thesis, included but not limited to the theory of decision-making, including uncertainty, cautionary principle, cost-benefit analysis and ALARP. The ALARP principle with layered approach will also be explained in the second chapter. Another reference study regarding the regulations and the decision-making principle used in offshore safety and road traffic safety will be presented in the third and fourth chapter respectively.

The fifth chapter will then discuss all the information from chapter three and four, supported by the theory in chapter two. Analyse the current decision-making principle used in offshore safety and road traffic safety separately, and discuss the suitability of the ALARP with layered approach to be used in both industries. The last chapter, chapter six, will present the conclusion and recommendations resulted from the study in this thesis.

2. Literature Study

2.1 Risk Management

Risk management purpose is to ensure that necessary measures are taken to protect people, the environment and assets from harmful consequences of the activities being undertaken, as well as balancing different concerns, for example HES (Health, Environment and Safety) and costs. It includes measures to avoid the occurrence of hazards as well as reducing their potential harms. When accidents are being the focus on risk, the term safety management is used. Safety management is part of risk management which covers all activities designed to direct and control safety (Aven, 2011).

The risk management process, according to ISO31000:2009 standard: Risk management principles and guidelines on implementation, comprises of several elements. It starts with the establishment of context follows by risk assessment. Risk assessment comprises of risk identification, risk analysis and risk evaluation. The result from risk assessment then becomes the basis for decision-making to determine how the risk will be treated. Every element in the risk management process has to be communicated and subject for monitoring and review by relevant stakeholders.

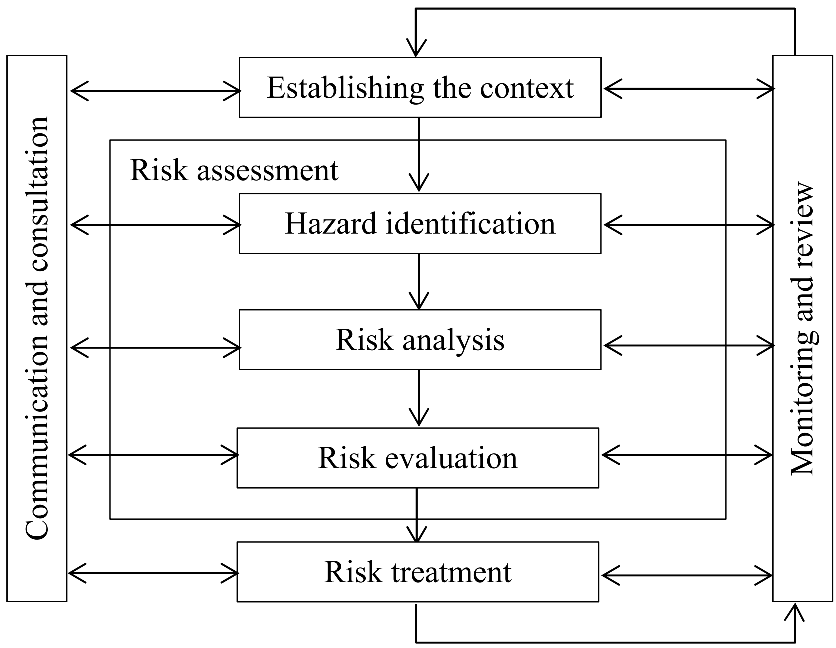

Figure 2.1 Risk management process according to ISO31000:2009

Risk management involves decision-making in situations with high risks and large uncertainties. Such decision-making is difficult as the consequences are hard to predict. A number of tools are available to support decision-making, such as risk and uncertainty analysis, risk acceptance criteria, cost-benefit analyses and cost-effectiveness analyses. These tools have limitations, based on assumptions and presumptions, and also scientific knowledge as well as value judgments reflecting ethical, strategic and political concerns (Aven & Vinnem, 2007).

Risk analysis, as part of risk management process, according to Aven (2008), identifies possible initiating event and develop the causal and consequence picture. When looking at negative consequences like injuries or loss of lives, the initiating event is categorized as accident or hazard or threat. Risk analysis provides risk picture which then evaluated to see the need to implement risk-reducing measure or safety measure.

Risk analysis is often used in combination with risk acceptance criteria or risk tolerability limits, as inputs to risk evaluation. The criteria state what is considered an unacceptable level and used to assess the need for risk-reducing measures. These criteria should be determined before performing the analysis (Aven, 2011).

When risk level is judged not acceptable, several risk-reducing measures shall be formulated, and there will be cost for the implementation of these measures. Whether to implement the measure or not, or to determine which measure to be prioritized and implemented, is the decision-makers' duty. To do so, decision-makers need strategies to base their decision.

2.2 Decision-Making

A decision problem is faced whenever there is a choice between at least two courses of action. In any decision situation, the first thing to do is to consider what courses of action are available and list them. The choice of action will be limited to those included in the list, therefore it is important to make sure that the list exhausts the possibilities (Lindley, 1985).

Decision-making strategy means the underlying thinking and principles that are to be followed in making the decision, which also involved what analysis to be used to support the decision-making process. Decision-making strategy also takes into consideration the effect on risk and the uncertainty dimensions that cannot be captured by the analysis. Figure 2.2 presents a simple model for decision-making process.

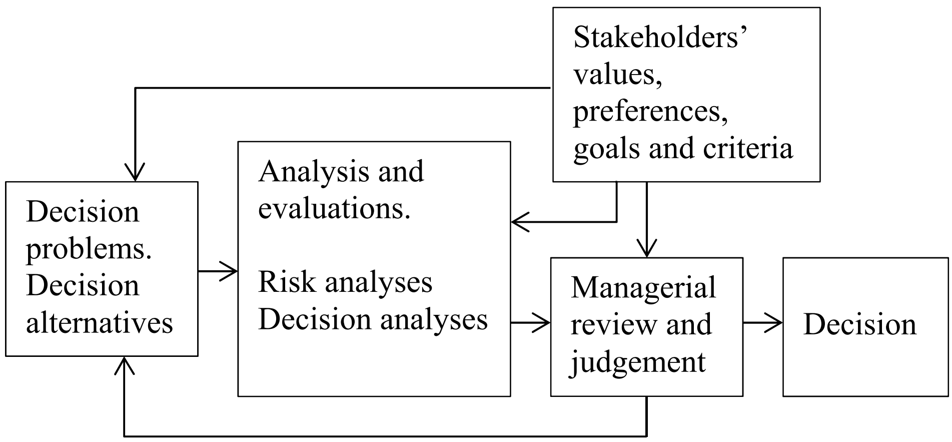

Figure 2.2 A model for decision-making process (Aven, 2003)

The starting point is a decision-maker facing some decision problem, which is usually a problem of choosing between a set of alternatives, such as implementation of risk reduction policy, the use of new technology, or choosing a concept for further evaluation. To evaluate the performance of the alternatives, several analyses are conducted, including risk and cost-benefit (cost-effectiveness) analyses. These analyses may give recommendations on which alternative to choose (Aven & Vinnem, 2007).

Aven (2008) emphasizes that risk analyses, cost-benefit analyses and other decision analyses are tools to provide insight into risk and trade-offs involved. They are just tools to support decision-making process, not to give hard recommendations. The managerial review and judgment will evaluate the recommendations, taking into account the assumptions, limitations and background information of the analyses, before coming to the final decision.

From Figure 2.1 we can see that stakeholders provide input to the analyses regarding their goals, criteria and preferences. They also can influence the final decision process. Stakeholders are defined as people, groups, owners, authorities that have interest related to the decisions to be taken. They can be categorized as internal and external stakeholders. Internal stakeholders could be the owner, shareholders, safety managers, unions etc., while external stakeholders could be the safety authorities, environmental groups, research institutions, etc. (Aven & Vinnem, 2007).

According to Lindley (1985), in selecting the course of action to be taken, the difficulty is usually due to the uncertainties in the situation, such as not knowing exactly what would happen if a particular course of action were to be adopted. This situation is called decision-making under uncertainty, and the natural reaction when dealing with this situation is to reduce as much of the uncertainty as possible by acquiring more information.

How decision-makers weight the basis information provided depends on the degree of confidence he/she has for those who developed the information. The decision sometimes includes difficult consideration and weighting with respect to uncertainty and values. This responsibility cannot be delegated to those who provide the basis information. It is the decision-makers (managers) responsibility to undertake such considerations and weighting to make decision that balances the various concerns (Aven, 2008).

2.3 Uncertainty

Risk has two main dimensions, consequences and uncertainties. A risk description is obtained by identifying the consequences and using a measure of uncertainty (Aven, 2012). There will always be uncertainty about whether certain events will occur or not, what will be the immediate effects, what the consequences for personnel, environment, or assets may be. Uncertainty reflects the insufficient information and knowledge available for assessment, and will be reduced as project progresses. However, there will always be some uncertainty about what may be the consequences of accidental events in every phase of operation (Vinnem, 2014).

To get a clear understanding of the risk and uncertainties, it is important to know about what and who is uncertain. It could be the decision-maker, the analysts, or some other experts involved in the assessment who are uncertain. Clarifying what is uncertain, according to Aven (2014) can be categorized in three main categories:

a) Uncertainty of an unknown quantity, including the occurrence or non-occurrence of events.
b) Uncertainty about the future, refers to not knowing about what the consequences of the risk problem will be.
c) Uncertainty about the phenomena, such as relevant cause-effect relationship, for example the phenomenon of leakages on an oil and gas installation.

Vinnem (2014) stated that there are three main sources of uncertainty. First is related to the variation of the populations being used in the calculations, in terms of whether there is a broad basis of relevant data available or not. The second aspect is related to the simplification made in the modelling of risk. The knowledge about the relevant phenomena and mechanism is the third aspect of uncertainty causation.

To express uncertainties about an unknown quantity, the most common approach is to use subjective probability (judgemental/knowledge-based probability), which is conditioned on the background knowledge at the time of quantifying the uncertainty. Probability in this context is a measure of uncertainty related to an event, as seen from the assessor's point of view, based on assessor's background of knowledge. Knowledge covers historical data, system performance characteristics, knowledge about the phenomena in question, decisions made, as well as models used to describe the world. Assumptions are also an important part of knowledge (Aven, 2012).

Judging the background of knowledge to be poor or strong would affect the total score of the uncertainties, whether the uncertainties is considered high or low. Aven (2014) presents several aspects to consider when judging the strength of background knowledge are:

- Whether the assumptions made represent strong simplifications.
- The availability of relevant data.
- Agreement/consensus among experts.
- The degree of understanding of the phenomena involved.
- The existence of accurate model.

Uncertainty reflects the predictability of the real outcomes through expected value. Given the occurrence of an accident event, high certainty may express that the assigned expected number of fatalities can give poor prediction of the actual number of fatalities. According to Aven (2011), level or degree of uncertainty can be categorized as low, high and medium uncertainty.

a) Low uncertainty
   All the following conditions are met:
   - Well understood phenomena, where models used are known to give predictions with sufficient accuracy.
   - The assumptions made are judged reasonable.
   - Much reliable data are available.
   - Broad agreement among experts is achieved.

- Low variation in population (low stochastic uncertainty)

b) High uncertainty
One or more of the following conditions are met:
- The phenomena involved are not well understood, where models are non-existent or believed to give poor predictions.
- Strong simplifications on the assumptions made.
- Data are unreliable or not available.
- Lack of agreement or consensus among experts.
- High variation in populations (high stochastic uncertainty).

c) Medium uncertainty
Conditions with characterisation between low and high uncertainty:
- Phenomena involved are well understood, but the models used are considered crude/simple.
- Some reliable data are available.

The degree of uncertainty has to be seen in relation to the effect/influence the uncertainty has on the predicted consequences (Aven, 2011). A high degree of uncertainty combined with high influence on the predicted values will lead to the conclusion that the uncertainty factor is important. However, a high degree of uncertainty with predicted values that are insensitive to changes in the certain quantities, the uncertainty can be classified as low or medium.

How to handle uncertainties in relation to the events occurring and the consequences is an important issue in risk assessment and risk management. The focus shall be on managerial issues. Risk assessment does not prescribe what to do as the decision-maker has to consider aspects that go beyond the result of risk assessment. The decision-maker also has to take into account the assumptions, and limitations of the assessment (Aven, 2014).

2.4 Cautionary Principle

Aven and Vinnem (2007) stated that the main reason for investing in safety is the wish to protect some values in the face of uncertainties. This thinking is cautionary. To invest in safety is to reduce uncertainty and provide assurance if a hazardous situation should occur.

The cautionary principle is a basic principle in safety management, expressing that in the face of uncertainty, caution should be a ruling principle. This principle is being implemented in all industries through safety regulations and requirement, and is considered a standard adopted to obtain a minimum safety level. In cautionary principle, when a risk is considered to be significant, justified by experience and sound judgments, even if the probability may be judged as low, it is not an unlikely event and we should then be prepared. This kind of requirement is based on cautionary thinking with no references to cost-benefit analysis needed (Aven & Vinnem, 2007).

Decision-making strategy is dependent on the decision-making situation, from routine operations to situations with high risk. When dealing with uncertainties related to the possible occurrences of hazardous situations and accidents, according to Aven and Vinnem (2007), we are cautious and adopt principles of safety management, such as:

- Robust design solution, such that deviations from normal conditions are not leading to hazardous situations and accidents,
- Design for flexibility, meaning that it is possible to utilise a new situation and adapt to changes in the frame conditions,
- Implementation of safety barriers, to reduce the negative consequences of hazardous situations if they should occur,
- Improvement of the performance of barriers by using redundancy, maintenance/testing, etc.
- Quality control/ quality assurance,
- The precautionary principle, saying that in the case of lack scientific certainty on the possible consequences of an activity, we should not carry out the activity,
- The ALARP principle, saying that risk should be reduced to a level that is as low as reasonably practicable.

The level of caution adopted will have to be balanced against other concerns such as cost, but the cautious goes beyond balancing the expected benefit of risk reductions expressed in monetary terms against expected costs (Aven, 2014). All industries would introduce some minimum requirements to protect people and environment, and these requirements can be justified by reference to the cautionary principle.

2.5 Cost-Benefit Analysis

Traditionally, cost-benefit analysis was used to evaluate public policy issues. The analysis measures the benefits and costs of a project using a common scale, which is the country's currency. Cost-benefit analysis requires a transformation of goods into monetary value. The purpose is to find out what is the maximum amount the society is willing to pay for the project (Aven & Vinnem, 2007).

Cost-benefit analysis is used to support decision-making on safety investments and implementation of risk reducing measures, by measuring the cost and the benefit of decision problem. The analysis transforms all relevant attributes to monetary value, including costs and safety, and summarizes the total performance by computing the expected net present value, $E[NPV]$. Here, cost benefit analysis tries to find out the maximum amount the society is willing to pay to obtain improved performance. Aven and Vinnem (2007) also stated that cost-benefit analysis can be seen as tool to help determine the efficient allocation of resources, by identifying which potential actions are worth undertaking.

<u>Measuring *NPV*</u>

To measure the *NPV* of a project, the relevant project cash flows are specified, and the time value of money is taken into account by discounting future cash flow by the appropriate rate of return. A measure should be implemented if the expected net present value is positive, $E[NPV] > 0$. The formula used to calculate *NPV* is:

$$NPV = \sum_{t=0}^{n} \frac{X_t}{(i+1)^t},$$

where:
X_t = the cash flow at time t,
t = the time period considered, usually in years,
i = the required rate of return or discount rate at year t.

Discount rate i

The discount rate i represents the investor's cost related to not employing the capital in other alternative investments. When cash flows are known in advance, the *NPV* calculation can use the rate of return associated with other risk-free investment, like bank deposits. Unfortunately the cash flows are usually uncertain. In this case, the cash flows are represented by their expected values $E[X_t]$ and the rate of return is increased on the basis of Capital Asset Pricing Model (CAPM) to outweigh the possibilities of unfavourable outcomes (Aven & Vinnem, 2007).

In determining the risk-adjusted discount rate, cost-benefit analysis ignores the unsystematic risk and consider only systematic risk associated with the project. The systematic risk relates to general market movements, while unsystematic risk relates to specific project uncertainties like accident risks (Aven, 2008).

Value of statistical life

When decisions need to be taken that balance benefits and risks for loss of life, the value of a statistical life can be used as a decision-support tool. This method focuses on the maximum amount the society is willing to pay to reduce the expected number of fatalities by 1.

A typical number used for the value of statistical life in cost-benefit analysis range between 1-2 million GBP, corresponds to around 25 million NOK, which is applied in the transport sector. For other areas, the numbers can be much higher due to the increased potential for multiple fatalities and uncertainty. The UK offshore industry, for example, uses 6 million GBP for their value of statistical life to be used in cost-benefit analysis (Aven & Vinnem, 2007). The value at approximately 2 million euros is recommended by The Ministry of Finance to be used for official cost-benefit analysis in Norway (Aven, 2008).

Challenges with cost-benefit analysis

One of the challenges with cost-benefit analysis is that it is based on expected values, which means that the analysis to a large extent ignores uncertainties. Based on its attitude toward risk and uncertainties, cost-benefit analysis is said to have a risk neutral attitude and thus in conflict with the cautionary principle as the basic principle in safety management (Aven & Abrahamsen, 2007).

Another challenge faced by cost-benefit analysis is related to the need to transform all of its attributes into monetary values. The relevant costs and benefits were assumed to be capable of being measured and compared in monetary terms. However, not all attributes can easily be transformed to monetary values. Market goods can be easily transformed to monetary value due its prices that reflect the willingness to pay. Assigning monetary value to non-market goods, like environmental damage and safety, is more difficult. This is when the alternative procedure called cost-effectiveness analysis can be considered (Nas, 1996).

2.6 Cost-Effectiveness Analysis

Cost-effectiveness analysis as a decision support tools has been proven to give useful support for comparison between safety measures. Quantitatively, the cost-effectiveness can be expressed as a cost-effectiveness ratio, defined as the change in expected costs to the change in expected effects (Aven, 2014). It is commonly used either to select an alternative that have the least cost of a given output, or to choose an alternative that give the maximum output at a given cost (Nas, 1996).

When comparing two safety measures, the cost-effectiveness for both measures is calculated. These notations are used to express cost-effectiveness analysis:

C_i = the investment cost associated with safety measure *i*
Z_i = the total effect related to loss of lives if safety measure *i* is implemented
C_i/Z_i = the cost-effectiveness ratio
R = the reference value, clarifies how much money the decision-maker is willing to pay to obtain one unit of effectiveness

The cost-effectiveness analysis for safety measure 1 is C_1/Z_1, and the cost-effectiveness for safety measure 2 is C_2/Z_2. Safety measure 1 is said to be more cost-effective than safety measure 2 if $C_1/Z_1 < C_2/Z_2$. To decide whether to implement the safety measure or not, the cost-effectiveness ratio has to be compared with the reference value R. Safety measure 1 can be implemented if $C_1/Z_1 < R$. When costs and effects are unknown, C and Z can be replaced by their respective expected values (Aven, 2014).

In cost-effectiveness analysis, when dealing with the risk related to loss of life, it is important to know the expected cost per expected number of lives saved. For example, a specific measure which costs 1 million euros can reduce the number of expected fatalities by 0.1, the cost-effectiveness index would be 1/0.1=10 million euros. This 10 million euros is defined as the *implied value of a statistical life* or the *Implied Cost of Averting Fatalities* (ICAF), which then can be compared with the reference value to assess the effectiveness of the measure (Aven, 2008).

ICAF is one of the cost-effectiveness indices that commonly used for making judgement about gross disproportion in relation to ALARP principle. The computation of ICAF is based on the expected number of saved lives by implementation of risk-reducing measure, compared with the expected cost:

$$ICAF = E[cost]/E[number\ of\ lives\ saved]$$

The uncertainties in the costs are often small, but the uncertainties related to the estimates of the expected number of saved lives could be large. To take the uncertainties into account, a proportion factor can be defined. For example, the ICAF limit defined in UK is equal to 1 million GBP, but ICAF of 6 million GBP is used as the minimum level in the offshore industry. This proportion factor of six is said to account for the potential for multiple fatalities as well as uncertainties. However, as with the cost-benefit analysis, ICAF is also based on expected values. The use of adjustment factor should be used carefully, as it may not reflect the level of uncertainties (Aven, 2011).

2.7 ALARP Principle

ALARP principle means that the risk should be reduced to a level that is as low as reasonably practicable, where the benefits of a measure should be addressed in relation to the costs of the measure. The ALARP principle is based on "reversed burden of proof" way of thinking, which means that an identified risk reducing measure should be implemented, provided it cannot be demonstrated that the disadvantages/costs are grossly disproportionate to the benefits gained (Aven, 2008).

ALARP principle is closely related to the risk acceptance criteria. Risk acceptance criteria are used in relation to risk analysis and express the level of risk tolerable for the activity. If the calculated risk is lower than a pre-determined value, then the risk is acceptable (tolerable). Otherwise, the risk is unacceptable (intolerable), and risk–reducing measures are required. This is the starting point for further reduction according to the ALARP principle (Standard Norway, 2010).

Applying ALARP principle according to the UK standard approach is to consider three regions:

- Intolerable risk, in which ALARP cannot be demonstrated and action must be taken to reduce the risk regardless of the cost.
- Tolerable risk, in which the residual risks are not considered high and kept as low as reasonably practicable.
- Broadly acceptable risk region represents risks that are generally regarded as insignificant and adequately controlled.

The ALARP region according to Norwegian legislation, as stated in NORSOK Z-013 (Standard Norway, 2010), is the region below the intolerable level where the risk shall be demonstrated to be ALARP regardless of the risk level as illustrated by Figure 2.3.

The region above the intolerable level is called the intolerable region. In intolerable region, risk cannot be justified except in extraordinary circumstances. The intolerable level is represented by a horizontal line which defines the upper level of risk above which the risk is considered to be intolerable. This upper level of risk is determined based on authority requirements, corporate requirements, international standards and recommended practice.

ALARP evaluation should be carried out with a 'reversed burden of proof' way of thinking, emphasizing that it is not required for a proposed risk reduction measure to prove it's merit, but rather to prove why it is justifiable not to implement a proposed measure. To verify ALARP, engineering judgments and codes are use, and also traditional cost-benefit analysis and cost-effectiveness analysis (Aven, 2011).

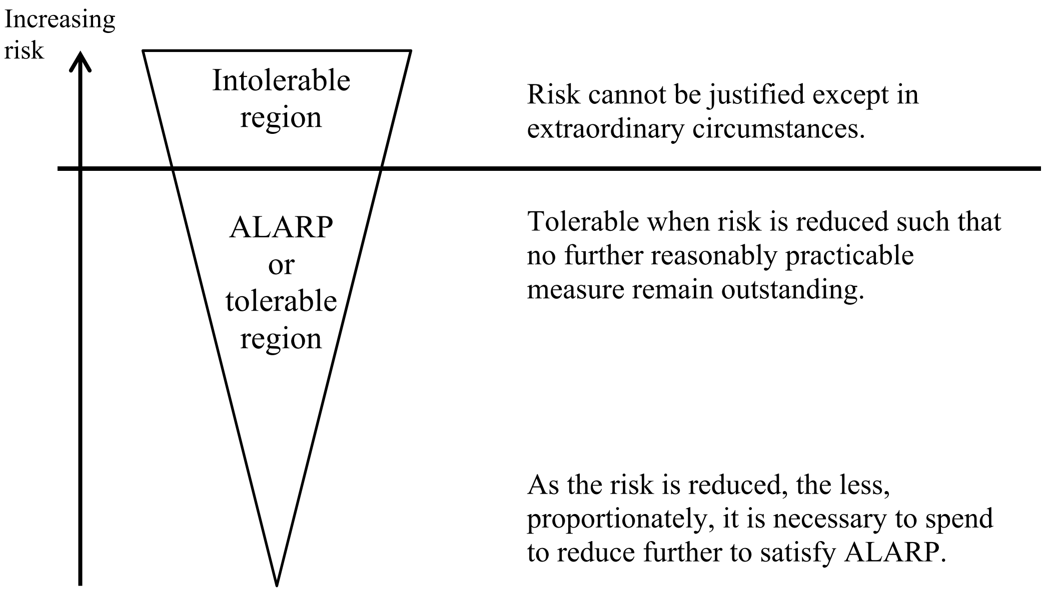

Figure 2.3 ALARP principle according to Norwegian legislation (Standard Norway, 2010)

2.6.1 ALARP Verification

<u>Grossly disproportionate factor</u>

One way to verify ALARP is by applying a guidance value to define gross disproportion when using cost-benefit analysis and cost-effectiveness analysis (Aven & Abrahamsen, 2007). This value, *x*, represents the grossly disproportionate factor between the costs and the benefits, and is defined by the decision-makers. The costs can be defined as grossly disproportionate to the benefits obtained if the expected cost (*EC*) is considered *x* times higher than the expected benefit (*EX*), or $(EC) > x(EX)$ (Abrahamsen & Abrahamsen, 2015).

This way of verifying ALARP is considered static if only one value of *x* is used for all different types of decision context. The ALARP principle can be seen as dynamic if different value of *x* is used for different decision context. This value of *x* can be seen as a way to give weight to the cautionary principle. Uncertainty can be taken into consideration, depends on the value of *x*. A high value of *x* can be interpreted that strong weight is given to the uncertainties. A very high, infinite *x*, can be categorized as extreme safety perspective where a very strong weight is given to the cautionary principle.

However, this approach of using grossly disproportionate factor as a basis in comparing the expected cost and expected benefit is not considered appropriate, because it is focusing on expected values which does not take uncertainties properly into consideration (Abrahamsen & Abrahamsen, 2015), thus inconsistent with the ALARP principle itself.

<u>Layered approach for implementing ALARP</u>

Aven (2011) introduced a layered approach procedure for implementing ALARP and addressing the gross disproportion criteria as illustrated in Figure 2.4. The approach consists of three steps and takes the uncertainties into consideration better. The first step is crude analysis suggesting that the safety measure should be implemented in low cost situations. If the crude analysis results in high cost, a more detailed analysis is needed before decision is made.

The second step shows that safety measure should be implemented according to ALARP principle if the investment is appropriate from the cost-benefit (cost-effectiveness) analysis point of view. If cost-benefit (cost-effectiveness) analysis concludes upon no investment, the decision-maker may, as shown in the third step, assess other issues including uncertainties. High uncertainties can justify investment in a safety measure.

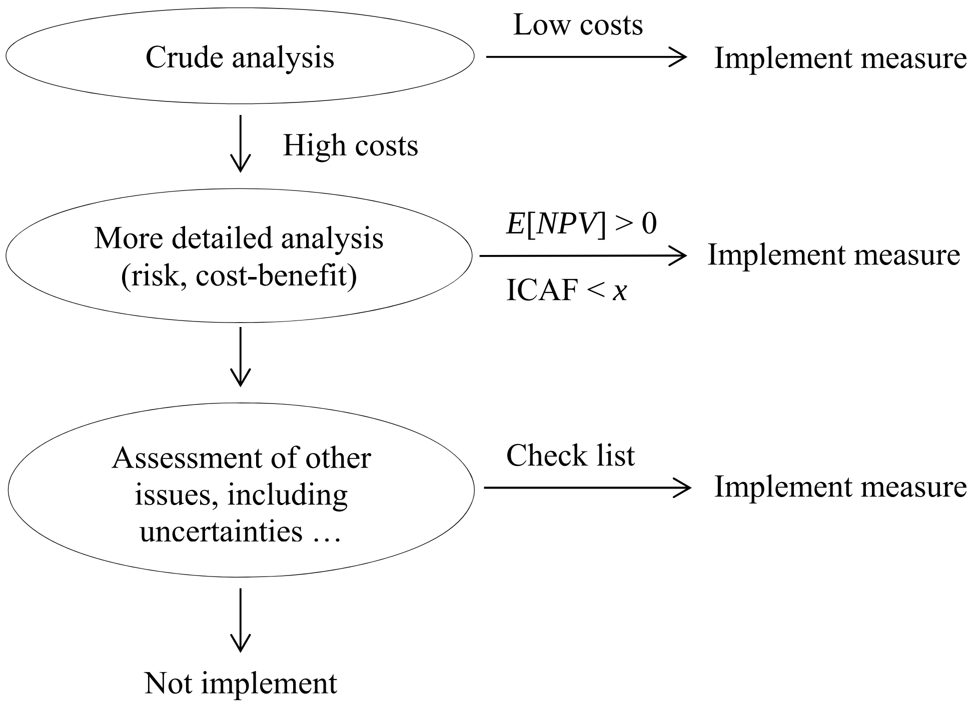

Figure 2.4 Procedure for implementing ALARP and the gross disproportion criterion (Aven, 2011)

The layered approach procedure as explained by Aven (2011) can be summarised as follows:

- Perform crude qualitative analysis of the benefits and burdens of the risk reducing measure. If the costs are not judged to be large, implement the measure. Gross disproportion has not been demonstrated.
- If the costs are considered large, quantify the risk reduction and perform an economic analysis (for example ICAF or $E[NPV]$). If $E[NPV] > 0$ or ICAF is low, implement the measure. Gross disproportion has not been demonstrated.

If these criteria are not met, assess uncertainty factors and other issues of relevance not covered by the previous analyses. A checklist is used for this purpose. Aspects that could be covered by this list are:

- Is there considerable uncertainty (related to phenomena, consequences, conditions) and will the measure reduce these uncertainties?
- Does the measure significantly increase manageability? High competence among the personnel can give increased insurance that satisfactory outcomes will be reached.
- Is the measure contributing to obtaining a more robust solution?
- Is the measure based on best available technology (BAT)?
- Are there unsolved problem areas: personnel safety-related and/or work environment-related?
- Are there possible areas where there is conflict between these two aspects?
- Is there a need for strategic considerations?

If the risk-reducing measure scores high on these factors (many yes answers), gross disproportion has not been demonstrated. Otherwise, the costs are in gross disproportion to the benefits gained, and the measure should not be implemented.

2.6.2 ALARP as General Decision-Making Principle in Safety Management

Abrahamsen and Abrahamsen (2015) have shown in their study that the ALARP principle can be considered appropriate to be used as a general decision-making principle in safety management if it is interpreted in a dynamic way. To see ALARP in a dynamic way, the gross disproportion criteria must be interpreted ranging from one extreme perspective to another, from extreme economic perspective to extreme safety perspective. These perspectives are strongly related to the weight given to the uncertainties when decisions are made in safety management. There are different perspectives exist in weighting uncertainties. To choose the one that is the most appropriate to use in safety management depends on the decision-making context, which means that different contexts would require different decision-making principle.

The first perspective is extreme economic perspective. This perspective refers to the use of expected values in safety management. The common example is the use of cost-benefit (cost-effectiveness) analysis. In extreme economic perspective, the decisions are made with reference to expected value, where limited or no weight is given to the uncertainties.

The expected value is based on risk neutral behaviour, thus ignoring uncertainties. Therefore, expected value only cannot be used as a general decision-making principle in safety management, unless the decision-maker is faced with a situation with high knowledge and low uncertainties. In such case, giving stronger weight to cautionary principle will lead to an inappropriate use of resources.

In contrast with the extreme economic perspective, extreme safety perspective, the second perspective, gives strong weight to cautionary principle without any references to cost-benefit and cost-effectiveness analyses. Decision-making based on extreme safety perspective is considered appropriate for situations with extreme risk or extreme vulnerability. Decisions made with strong weight to cautionary principle without giving any attention to balance the costs and benefits may turn out not cost-effective, thus extreme safety perspective also cannot be used as general decision-making principle in safety management.

To interpret ALARP in a dynamic way, a third category of perspective on how to weight uncertainties is introduced. This perspective lies somewhere between the two extremes and depends on how the gross proportion criterion is interpreted.

The most appropriate approach for implementing ALARP as suggested by Abrahamsen and Abrahamsen (2015) is using the layered approach as shown in Figure 2.4. By using the layered approach, uncertainties are better taken into consideration than using the expected value alone. Different weights to uncertainties are applied to different decision-making context, so that the ALARP principle becomes dynamic. Within the layered approach, a checklist or guideline is given to help management in assigning weight to uncertainties. This checklist formulation is a management task and shall contribute to the ALARP principle ability to range from extreme economic perspective on how to weight uncertainties to extreme safety perspective.

To show that the ALARP principle, by the layered approach, can range from extreme economic to extreme safety perspectives, Abrahamsen and Abrahamsen (2015) redrew an alternative visualization of the approach as shown in Figure 2.5.

The approach consists of two steps. The first step is to perform crude analysis of the benefits and burdens of the risk reducing measures and implement the measure if the costs are not judged to be large. The second step consists of two parts. The first part classified the decision context with reference to some issues of relevance not covered in crude analysis. In the second part, the guideline/ checklist gives support to determine which perspective is appropriate for the various decision contexts.

ALARP principle can be equal to traditional cost-benefit (cost-effectiveness) analysis if all the issues assessed are considered unproblematic (low uncertainty, best available technology, etc.). For such context, costs are grossly disproportionate to the benefits obtained if the expected cost is higher than the expected benefit. On the other hand, when all issues are considered problematic, (high uncertainty, best available technology not being used, etc.), extreme safety perspective with strong weight to cautionary principle may be used. For all other decision context, a perspective which is somewhere between the two extremes may be adopted.

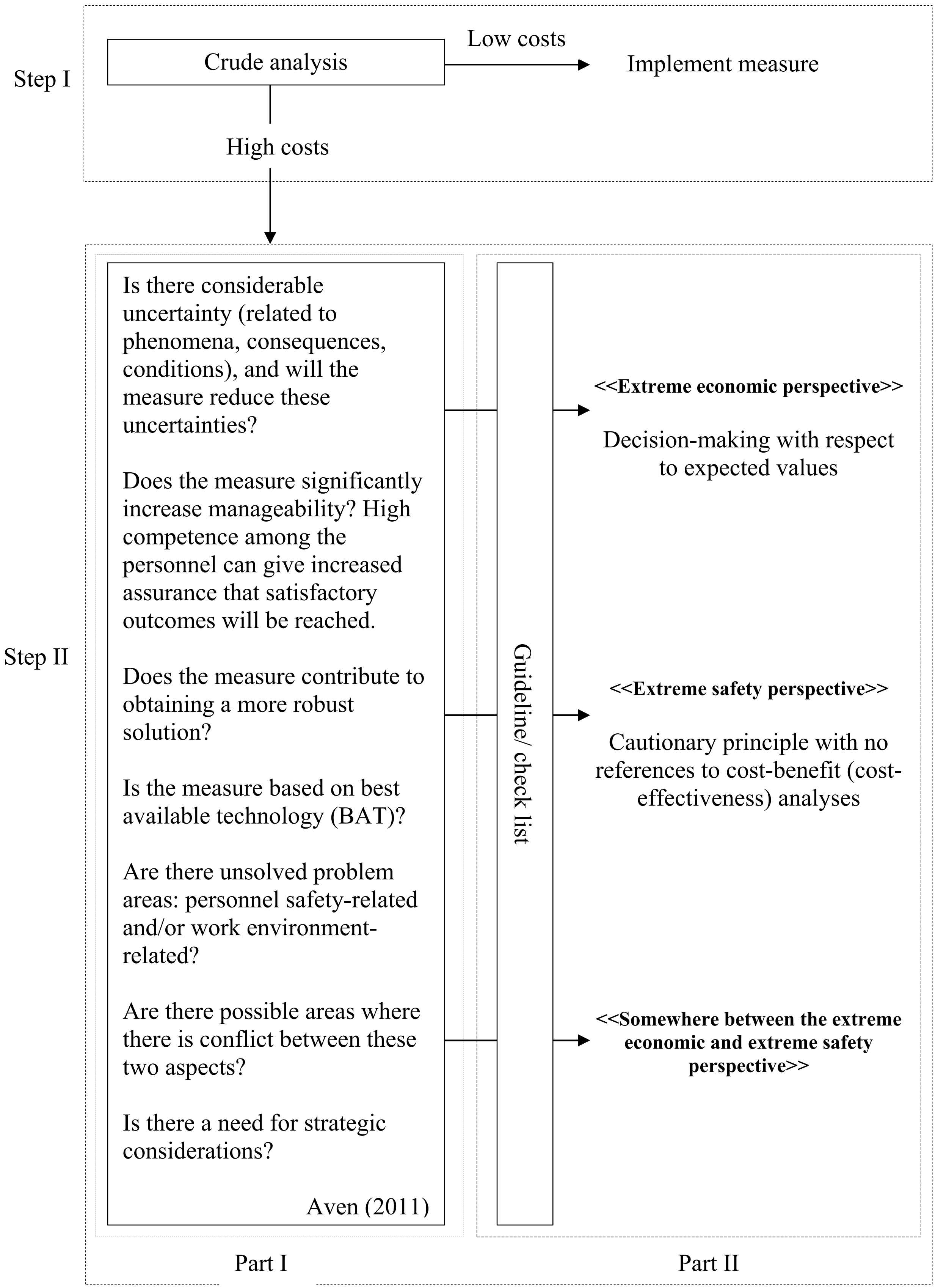

Figure 2.5 An alternative visualization of the layered approach for implementing the ALARP principle (Abrahamsen & Abrahamsen, 2015)

3. Decision-Making in Offshore Safety

3.1 HSE Regulations on Risk Reducing Principle

Offshore safety in Norway is regulated by the Petroleum Safety Authority (PSA) under the Health, Safety and Environment (HSE) management regulations. HSE management involves managing, controlling and handling all aspects of health, safety and the environment in the petroleum industry – with the focus on major accident risk (PSA, 2013b).

PSA has five sets of regulations used to control HSE in Norway:

- The Framework Regulations, relating to health, safety and the environment in the petroleum activities and at certain onshore facilities.
- The Management Regulations, relating to management and the duty to provide information in the petroleum activities and at certain onshore facilities.
- The Activities Regulations, relating to conducting petroleum activities.
- The Facilities Regulations, relating to design and outfitting of facilities, etc. in the petroleum activities.
- The Technical and Operational Regulations, relating to technical and operational matters at onshore facilities in the petroleum activities.

The Framework Regulations and The Management Regulations are two of the five regulations with relevant requirements related to the risk reducing principles:

3.1.1 Framework Regulations

The Framework Regulations covers overall principles and explained in more detail by the other regulations. One of the requirements only found in the Framework Regulations, and not in the other regulations, is the ALARP evaluation which explicitly mentioned in the first and second paragraphs of section 11 about risk reduction principles, mentioning that risk shall be further reduced to the extent possible provided the costs are not significantly disproportionate to the risk reduction achieved.

The requirement for reducing risk implies the use of acceptance criteria for major accident risk and environmental risk which shall be met regardless of costs. Further, the requirement implies that risk shall be further reduced beyond the established minimum level for health, safety and environment that follows from the regulations, if this can be done without unreasonable cost or drawback.

The regulation also addressed the uncertainty, saying that in the case of insufficient knowledge, the solution that will reduce the uncertainty shall be chosen. The complete section 11 is quoted below as copied form the Framework Regulations (PSA, 2013a).

Section 11: Risk reduction principles

> *"Harm or danger of harm to people, the environment or material assets shall be prevented or limited in accordance with the health, safety and environment legislation, including internal requirements and acceptance criteria that are of*

significance for complying with requirements in this legislation. In addition, the risk shall be further reduced to the extent possible.

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

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

Factors that could cause harm or disadvantage to people, the environment or material assets in the petroleum activities, shall be replaced by factors that, in an overall assessment, have less potential for harm or disadvantage.

Assessments as mentioned in this section, shall be carried out during all phases of the petroleum activities.

This provision does not apply to the onshore facilities' management of the external environment."

3.1.2 Management Regulations

Several sections are found in the Management Regulation (PSA, 2015) that relates to the risk reduction, risk acceptance criteria and decision-making. These sections are section 4, section 5, section 9 and section 11.

<u>Section 4: Risk reduction</u>

"In reducing risk as mentioned in Section 11 of the Framework Regulations, the responsible party shall select technical, operational and organisational solutions that reduce the likelihood that harm, errors and hazard and accident situations occur.

Furthermore, barriers as mentioned in Section 5 shall be established.

The solutions and barriers that have the greatest risk-reducing effect shall be chosen based on an individual as well as an overall evaluation. Collective protective measures shall be preferred over protective measures aimed at individuals."

<u>Section 5: Barriers</u>

"Barriers shall be established that at all times can

a) identify conditions that can lead to failures, hazard and accident situations,

b) reduce the possibility of failures, hazard and accident situations occurring and developing,

c) limit possible harm and inconveniences.

Where more than one barrier is necessary, there shall be sufficient independence between barriers.

The operator or the party responsible for operation of an offshore or onshore facility, shall stipulate the strategies and principles that form the basis for design, use and maintenance of barriers, so that the barriers' function is safeguarded throughout the offshore or onshore facility's life.

Personnel shall be aware of what barriers have been established and which function they are intended to fulfil, as well as what performance requirements have been defined in respect of the concrete technical, operational or organisational barrier elements necessary for the individual barrier to be effective.

Personnel shall be aware of which barriers and barrier elements are not functioning or have been impaired.

Necessary measures shall be implemented to remedy or compensate for missing or impaired barriers."

Section 9: Acceptance criteria for major accident risk and environmental risk

"The operator shall set acceptance criteria for major accident risk and for environmental risk associated with acute pollution.

Acceptance criteria shall be set for:

a) the personnel on the offshore or onshore facility as a whole, and for personnel groups exposed to particular risk,

b) loss of main safety functions as mentioned in Section 7 of the Facilities Regulations for offshore petroleum activities,

c) acute pollution from the offshore or onshore facility,

d) damage to third party.

The acceptance criteria shall be used when assessing results from risk analyses, cf. Section 17. Cf. also Section 11 of the Framework Regulations."

Acceptance criteria shall express and represent an upper limit for what is considered an acceptable risk level, however additional risk reduction shall always be considered even if the results of risk assessments indicate a level of risk that is within the acceptance criteria. It is important that the acceptance criteria are formulated in accordance with the requirement for suitable risk analyses and are suitable for providing decision-making support in relation to the risk analyses and risk assessments carried out.

It is stated in the regulation that acceptance criteria shall be defined for major accident risk. Major accident, as defined by PSA, means "an acute incident such as a major spill, fire or explosion that immediately or subsequently entails multiple serious personal injuries and/or loss of human lives, serious harm to the environment and/or loss of major financial assets". Some events that have the greatest probability to result in major accidents are hydrocarbon leaks, serious well incidents, damage to load-bearing system and maritime system, and ships on collision course.

Section 11: Basis for making decisions and decision criteria

> *"Before decisions are made, the responsible party shall ensure that issues relating to health, safety and the environment have been comprehensively and adequately considered.*
>
> *The decision criteria shall be based on the stipulated objectives, strategies and requirements for health, safety and the environment and shall be available prior to making decisions.*
>
> *Necessary coordination of decisions at various levels and in different areas shall be ensured so that no unintended effects arise.*
>
> *Assumptions that form the basis for a decision shall be expressed so they can be followed up."*

The regulations emphasize the necessity that different alternatives and consequences have been studied, and that relevant experts and user groups have been involved in making the decision.

3.2 Acceptance Criteria

In the offshore petroleum industry, the focus is on major accidents, which defined in this context as acute incidents that have the potential to cause several serious injuries and/or loss of human life, serious harm to environment and loss of substantial material assets. PSA regulates that it is the operator's duty to formulate the acceptance criteria related to major accidents and to the environment. Therefore, there is no standard about the value sets for tolerability or acceptance criteria within the industry. Risk acceptance criteria, as stated in NORSOK Z-013 (Standard Norway, 2010), used as a reference for the evaluation of the results from the risk assessment and shall be established prior to the assessment.

Formulation of RAC according to NORSOK Z-013 standard shall be based on:

- regulations that control safety and environmental aspects of the activities,
- ALARP principle,
- recognized norms for the activity,
- criteria and risk level of the similar industry.

Risk acceptance criteria shall be formulated for the risk to personnel, environment and assets, expressed by risk parameters. To express risk for loss of lives, according to NORSOK Z-013 standard, parameters for individual risk and parameters for group and societal risk are separated as follows:

- Risk parameters for individual risk
  - FAR (Fatal Accident Rate)
    FAR is the number of fatalities per 100 million exposed hours. It is used as a measure for overall risk for all personnel at a facility or for defined groups.
  - IR (Individual Risk)
    IR is the annual probability of fatality for the individual person.
  - GIR (Group Individual Risk) or AIR (Average Individual Risk) for defined groups.

- Risk parameters for group and societal risk
  - PLL (Potential Loss of Life)
    PLL is the expected number of fatalities per year.
  - f-N curve
    f-N curve represents the frequency (f) of accidents causing ≥ N fatalities. It specifies a tolerable and no-tolerable area within the diagram.

Aven and Vinnem (2007) give examples of some typical risk acceptance criteria used:

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

Risk acceptance criteria have been extensively used for many years in Norwegian offshore petroleum industry. It is still continued to be used and still required by the regulations, but at the same time there is also an increasing focus on the use of ALARP principle.

3.3 Risk Management in Offshore Petroleum Industry

Norwegian petroleum industry uses the NORSOK Standard Z-013 (Standard Norway, 2010) for risk and emergency preparedness assessment to ensure safety, value adding and cost effectiveness for petroleum industry developments and operations. The standard is regarded as the most extensive and explicit standard for offshore risk assessment (Vinnem, 2014). This standard adopted the risk management approach based on ISO31000:2009 standard, as illustrated in Figure 2.1.

NORSOK Z-013 standard is focusing on the risk assessment process to decide on risk reducing measures in the context of a structured, systematic and documented process (Vinnem, 2014). This standard does not cover the risk treatment process, which is the process and decisions related to how to deal with identified risks. Therefore, the complete risk reduction process or the ALARP process is also not part of this standard (Standard Norway, 2010).

Risk analysis provides risk picture that shall be presented in accordance with the structure of risk acceptance criteria and for the relevant risk elements. An informative risk picture means identifying appropriate risk indices and assessing uncertainties.

Based on the outcome from risk analysis, risk evaluation establishes a basis for decision-making about which risks need treatment and the treatment priorities. The process involves comparing the level of risk being assessed with risk acceptance criteria. If the level of risk does not meet the risk acceptance criteria, the risk should be treated. The risk evaluation also may lead to a decision to undertake further analysis or not to treat the risk and maintain existing risk control (Vinnem, 2014).

Risk treatment involves selecting options for addressing risks, and implementing those options. These options, listed by Vinnem (2014), include the following:

- Avoiding the risk by not doing the activity that gives rise to the risk.
- Seeking opportunity to start an activity that can maintain the risk.
- Changing the likelihood.
- Changing the consequences.
- Risk sharing with other party.
- Retain the risk, by choice or by default.

Treating the risk may involve cyclical process of assessing risk treatment plan, deciding that residual risk levels are not tolerable, generating new treatment plan and assessing the effect of the treatment until a level of residual risk is tolerable based on the risk acceptance criteria.

To prioritize risk reduction, Vinnem (2014) adopt the following order of priority for risk reduction:

- Probability reducing measures, with order of priority:
  - measures which reduce the probability for a hazardous situation to occur,
  - measures which reduce the probability for a hazardous situation to develop into an accident event.
- Consequence reducing measures, with order of priority:
  - measures relating to the design of the installation,
  - measures relating to safety and support system,
  - measures relating contingency equipment and organization.

3.4 Decision-Making in Prioritizing the Implementation of Safety Measure in Offshore Petroleum Industry

3.4.1 Current decision-making principle

Safety legislation in Norwegian petroleum industry has been focusing on the use of risk acceptance criteria. Safety objectives and risk acceptance criteria are operator's responsibility to define. Risk analysis is conducted to see if these criteria are met and, according to the assessment results, the need for risk reducing measures is determined. Risk assessment provides the decision-maker with the risk picture and also the related risk reducing measure alternatives (Aven & Vinnem, 2007).

In addition to the use of risk acceptance criteria, the regulation also stated the requirement for ALARP assessment of risk. NORSOK Z-013 (Standard Norway, 2010) has formulated steps for demonstrating ALARP, these steps are:

- Identification of potential risk reducing measures
- Evaluation of risk reducing measures
- Decision-making
- Documentation of accepted risk reduction measures and rejected measures

The ALARP principle carries the "reversed onus of proof" principle where it is not required for a proposed risk-reducing measure to prove its merit but rather to prove why it is justifiable not to implement the proposed measure. The default is to implement all identified risk-reducing measure, unless it can be demonstrated that there is gross disproportion between costs and benefits.

Engineering judgements and codes are usually used to verify ALARP, as well as traditional cost-benefit analyses and cost-effectiveness analyses. When such analyses are used, guidance values are often used to specify gross disproportion (Aven & Vinnem, 2007). One of the common procedures is to use higher value of statistical life, as adopted in UK offshore industry where this value is increased by a factor of 6 (Aven & Abrahamsen, 2007).

3.4.2 Suggested decision-making framework

(Aven & Vinnem, 2007) presented a suggested decision framework for risk management and decision-making under uncertainty. The framework is formulated based on the understanding of the following building blocks:

a) Risk is characterized by the combination of possible consequences with an activity and assessor's uncertainty about these consequences. The consequences are expressed by quantities that can be measured (such as money, loss of lives, etc.), referred as observable quantities or observables.
b) Risk (uncertainty) is quantitatively expressed by probabilities and expressed values. However, it is meaningless to speak about uncertainties in assigned probabilities and risk numbers, as these values express uncertainties which conditioned on some information and knowledge.
c) Risk analyses provide decision support, by analysing and describing risk (uncertainty). Risks are analysed and evaluated, compared to the possible criteria. The analyses need to be evaluated in the light of their premises, assumptions and limitations. The background information that based the analyses also must be reviewed together with the analyses results in a managerial review and judgement.
d) Risk treatment means the process of selection and implementation of measure to modify risk.
e) Differentiate between expected values determined at the point of decision-making and the real outcomes. Expected values give good prediction of the future observations. Uncertainty and safety management are justified by reference to these observations and not the expected values alone.
f) Proper uncertainty management and safety management provide insight about the uncertainties relating to possible consequences as well as controlling and reducing the uncertainties, to produce more desirable outcomes.
g) A decision rule based on the expected NPV with a risk-adjusted discount rate or risk-adjusted cash-flows, should be supplemented with uncertainty assessments to see the potential for uncertainty and safety management in a later phase.
h) What is acceptable risk and the need for risk reduction cannot be determined just by reference to the risk analysis results.
i) Cost-benefit analysis means calculating expected net present value with a risk-adjusted discount rate or risk-adjusted cash-flows.
j) Cost-effectiveness analysis means calculating measures such as the expected cost per number of expected lives saved.
k) Risk and decision analyses need extensive use of sensitivity and robust analyses.

Figure 3.1 below illustrates the suggested structure of decision framework suggested by Aven and Vinnem (2007).

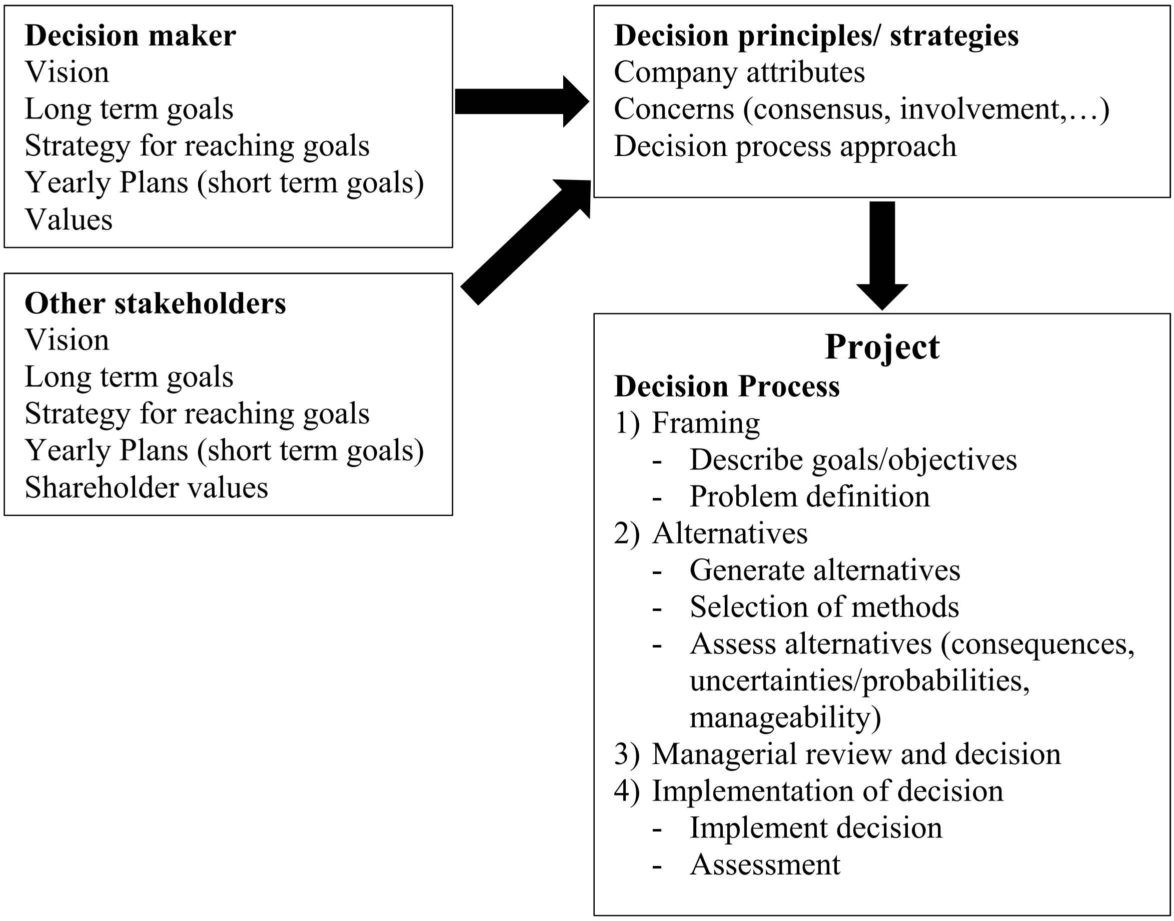

Figure 3.1 The structure of the suggested decision framework (Aven & Vinnem, 2007)

It is shown from the figure that the decision-maker and other stakeholders influence the decision principle and strategies. Decision-makers and stakeholders have defined visions and long term goals for their activities, and strategies and plans for meeting these visions and goals. Their values, visions and goals, strategies and plans are the basis for forming the decision principles and strategies to steer the decision in the desired direction. The use of the cautionary principle, an overall procedure to perform decision-making process and a procedure for implementing ALARP principle are examples or the decision principle and strategies.

The decision-making process comprises of four main elements. These elements are:

- Framing of decision problem and decision process,
- Generation and assessment of alternatives,
- Managerial review and decision, and
- Implementation of the decision.

The following explanation about the decision-making elements listed above is all based on Aven and Vinnem (2007).

Framing of decision problem and decision process

Describe goals and objectives.
This is the key element in the decision-making process. The concern is related to the goals of the activities and the decision to the goals and objectives of the company or the organisation.

Define the decision problem.
This step defines the problem to be addressed and solved and also the results to be obtained by making the right decision. Furthermore, the frame conditions, including relevant criteria and requirements for solving the problem are also determined.

Generation and assessment of alternatives

Generate alternatives.

Generation of alternatives is the activity to generate a list of alternative solutions to the described decision problem, for example whether to implement risk reducing measures or do nothing and accept risk. Alternatives are generated and the performance of these alternatives are evaluated is evaluated in order to support decision-making.

Selection of method.

The method used for evaluating alternatives will depend on the type of decision problem. Some decision problem may need detailed analysis while some others may just need a more crude analysis. Choosing the most efficient decision process for the relevant decision problem, Aven and Vinnem (2007) introduced a categorisation of decision problem:

a) Standard decision problem:
   - Applies for most decision.
   - Characterised by limited expected loss/gain and limited uncertainties.
   - The project management team facilitates the decision process without external assistance, no need for detailed quantitative analysis.

b) Advanced decision problem:
   - Characterised by significant expected loss/gain and significant uncertainties.
   - The project management team facilitates the decision process, but there is a need for detailed analysis on selected issues and external assistance will be required.

c) Complex decision problem:
   - Characterised by large expected loss/gain and large uncertainties.
   - The project management team engages external expertise for facilitation and documentation of decision process.
   - Require detailed analysis.

Evaluation of alternatives.

Different evaluation approach is assigned for different categorisation of decision problem as explained above. For standard decision problem, the decision alternatives are evaluated based on checklists, codes and standards. For some cases, there may be a need for ranking the alternatives.

Advanced decision problem covers all aspects that are covered by complex decision problem, except the degree of quantification. However, advanced decision problem performs more crude analysis providing results in categories, expressing different levels of risks, costs, etc. A comparison of alternatives is performed by summarising their pros and cons using a matrix, showing the degree of performance for each alternative and each attribute.

A complete quantitative analysis is required for complex decision problem, meaning that observables are quantified for all relevant attributes, such as costs, incomes, NPV, number of fatalities, etc. Different types of risk and uncertainty analyses are conducted to predict the observables and assess uncertainties. Expected values are assigned, however the analysis must see beyond the expected values.

For every alternative, the consequences are assessed in relation to the defined attributes. Therefore, the relevant attributes (X_1, X_2,…) need to be defined first, and then assess the consequences of the alternative with respect to the attributes. The assessment can involve qualitative or quantitative analysis. The assessment also needs to consider the expected consequences as well as the uncertainties related to the possible consequences. The recommended structure for the assessment can be summarised as follows:

a) Identify the relevant attributes (HES, costs, reputation, alignment with main concerns)
b) Assign expected consequences, $E[X_i]$, based on the available knowledge and assumptions.
c) Are there special features of the possible consequences? Aside from assessing the consequences of the quantities X_i, there may be some aspects of the possible consequences that need special attention.
d) Whether the large uncertainties related to the underlying phenomena, and whether the experts have different views on critical aspects. The aim is to identify factors that could deviate the consequences X_i far from the expected consequences $E[X_i]$.
e) The level of manageability during project execution. To what extent is it possible to control and reduce the uncertainties, and obtain desired outcomes? Some risks are more manageable than others, which mean that the potential for reducing the risk is larger for some risks compared to others.

Managerial review and decision

The analyses need to be evaluated by taking into account the premises, assumptions and limitations of the analyses. The analyses are also based on background information which needs to be reviewed together with the result of the analyses. Management or decision-makers will consider decision support provided by both quantitative and qualitative input. Decisions would depend on how the decision-makers weigh the different concerns. To evaluate the decision support, several things need to be considered by the decision-makers:

a) Is the decision-making process managed and documented according to the decision principles and strategies?

b) What is the ranking of the alternatives based on the analyses and evaluations? What are the assumptions used for the analyses, evaluations and ranking? What are the limitations of the analyses and evaluations?
c) Are there concerns not taken into account in the analyses and evaluations?
d) Are all relevant stakeholders taken into account? Would different weights of some stakeholders affect the conclusion?
e) Robustness in the decision. What is required to change the decision?

3.4.3 Good implementation of ALARP

A good demonstration of ALARP should be a broad ranging decision-making process involving a wide range of stakeholders. Gross disproportion is defined is by demonstrating why the proposed remedial measure should not be implemented. Good reasons will have to be found to show why benefit of the proposed measure is not sufficient in relation to costs and other burdens of implementation. If such reasons cannot be demonstrated, then the measure must be implemented (Aven & Vinnem, 2007).

According to NORSOK Z-013 (Standard Norway, 2010) an ALARP demonstration process consists of:

a) Identification of risk-reducing measures
b) Evaluation of risk-reducing measures
c) Decision-making
d) Documentation of accepted risk-reduction measures and rejected measure.

Norwegian regulations require companies to perform ALARP evaluations, but only give limited explanation about how it should be conducted and documented. The following is how the ALARP demonstration supposed to be conducted and documented according to Aven and Vinnem (2007).

Identification of possible risk-reducing measures

Useful approaches to search for possible risk reducing measures:

a) Good Practice
   Good engineering and procedural practice for common situations is one useful approach in searching for possible risk reducing measures. It may be in a form of solutions which have been found to be successful in the field but have not been incorporated into design standards. Benchmarking is a source of good practice.

b) Codes and Standards
   Lesson learnt from the past years are embodied in codes and standards. They often provide solution for well understood hazards and situations.

c) Engineering Judgement
   Engineering judgement involves sound application of engineering and scientific principles and methods to a control situation. It includes a subjective judgement for

what is considered acceptable. It is useful for filtering out extreme situations to allow more rigorous analysis of the less clear situations.

d) Stakeholder Consultation
It is important to do a consultation with stakeholders as part of the ALARP evaluation, especially when the stakeholders have different views, concerns and perceptions.

e) Tiered Challenge
A team of operations and specialist staff work together to identify possible measures and list them from the highest. Each measure is challenged why it cannot be applied. When one measure is agreed not to be applied, the team move to the next measure on the list. They go down the list until eventually find the option which is most acceptable by everyone. In this approach, the range of team ensures a widely thought out solution.

Evaluation of risk-reducing measures

Evaluation of individual risk-reducing measures

The previous step resulted in a list of risk-reducing measures. Each of the listed measures is then evaluated to see:

- Whether the proposed measure is in accordance with the present good practice as well as codes and standards.
- Whether the implementation of the proposed measure is recommended from the engineering point of view.
- Whether the stakeholders favour and accept the proposal to implement the measure.
- How the measure, if implemented, will change the risk result.

Each of the proposed measures is also evaluated by calculating the effect of the risk result. The risk result of the proposed measure is compared to the base case risk result to see how significant the risk reduction is, presented in numbers. The base case is the condition before any risk-reducing measure is implemented. FAR and PLL values are the most common risk parameters used when evaluating risk related to the loss of human lives.

The result from the evaluation of individual risk-reducing measures is the recommendation whether the risk-reducing measure is recommended or not for further consideration. The recommended risk-reducing measure is judged to be able to achieve the required safety improvement and considered feasible to be implemented. On the other hand, risk-reducing measure can be not recommended for further consideration because of some negative effects related to it.

Overall evaluation of risk-reduction measures

As a basis for overall decision-making, these dimensions shall be taken into account:

- Aspects related to consequences
- Aspects related to uncertainties
- Aspects related to manageability.

The calculation of risk result expresses the conditional probability regarding the occurrence of accident event and the expected consequences. The analysis is based on assigned probability and expected value, expressing the analyst's judgement based on his/her background information and knowledge, which may strongly deviate from the actual value. These factors that could lead to such deviations need to be communicated to management as part of the description of risk picture. Sensitivity and robustness analyses are useful tools to illustrate the dependency of these factors.

Decision-making

In the final selection of risk-reducing measures, the full list of proposed risk-reducing measures is presented. The previous evaluations have concluded which measures are recommended and which measures are not.

To decide which recommended risk-reducing measure to be implemented, a cost-benefit/ cost-effectiveness analyses may be helpful to provide further insight. In cost-benefit/ cost-effectiveness analyses, parameters like $E[NPV]$ and ICAF are calculated. The rule is to implement the measure if $E[NPV] > 0$, ICAF low and the cost of implementing the measure is not judged to be grossly disproportionate in relation to the benefit obtained.

Documentation of accepted risk-reduction measures and rejected measure

The following should be documented:

- Measures accepted for implementation
  The measures accepted for implementation are documented and the reason for choosing one over another is given.
- Measures not accepted for implementation
  The measures not accepted for implementation should be documented together with the arguments for not accepting the measures.
- Residual risk
  The residual risk as the result of implementing the chosen risk-reducing measure shall be presented alongside the base case risk result, showing the effect of the changes.
- Overall evaluation of risk
  The overall evaluation of risk is focused on several aspects or conditions. NORSOK Z-013 (Standard Norway, 2010) has formulated the minimum conditions that need to be evaluated in ALARP process in order to prove whether it can be justified to not to implement a proposed measure. In other words, proves that the residual risk is as low as reasonably practicable. The following evaluations shall be performed:

  a) Are authority requirements satisfied?
  b) Are all corporate and local requirements, guidelines and philosophies as well as national and international standards and recommended practices satisfied?
  c) Is the quantified risk level at least on par with risk levels of similar concept?
  d) If there are solutions that do not meet the condition of item b) and c), can it be satisfactory demonstrated that no significant increase in risk level will result as a consequence of these deviations?

e) Where quantitative requirements have been defined, is there a sufficient margin, which may allow some increases later in the design process to be absorbed without massive need for improvement?
f) Is best available technology (BAT) being utilised?
g) Have inherent safe solutions been chosen whenever possible?
h) Are precautionary and cautionary principles considered?
i) Are there unsolved aspects relating to risk to personnel and/or working environment, or possible areas where there is a conflict between these two aspects?
j) Are there unsolved aspects relating to risk of major oil spill?
k) Is the concept chosen robust with respect to safety?
l) Are the latest research and development results and new technology aspects reflected in the solutions that are adopted?
m) Are societal concerns met, if required to consider?
n) Are the associated costs significantly disproportionate to the risk reduction achieved?

3.4.3 Example of decision-making in offshore safety

This section presents the example of decision-making proses in selecting risk-reducing measure in the offshore industry. Example is taken from the textbook 'Risk Management With Applications from the Offshore Petroleum Industry' by Aven and Vinnem (2007).

The case is a modification of an existing production platform involving an addition of new production equipment. New equipment units mean additional potential gas and/or oil leak sources. This may cause fire and/or explosion if ignited, thus will have an impact on the risk level. The decision to be made is whether or not to install additional fire protection for personnel to reduce the expected consequences should the event of critical fire occur on the platform.

The operator sad formulated risk acceptance criteria for personnel risk expressed in FAR values. It is later known that the FAR values for both before and after the installation of additional equipment are below the risk acceptance limit, so that these values have no influence on decision-making.
Another relevant regulation is regarding the maximum annual impairment frequency for main safety function, which functions is to protect personnel in the case of severe incidents, is regulated at maximum $1*10^{-4}$ per year. One of these main safety functions is the need to provide safe escape ways from hazardous area to safe area. The escape way impairment frequency for the base case design is $3.8*10^{-4}$ per year. It is noted that this value is higher than the limit, but the installation was designed before the regulation came into force, which does not have retrospective applicability. Table 3.1 shows the impairment frequencies of the escape ways.

The operator goal is to satisfy the acceptance limit. FAR value is already below the limit for both before and after the installation of new equipment. The operator interpreted that the additional new equipment should not increase the escape ways impairment frequency, so the minimum solution is to adopt risk reduction to reduce the impairment frequency to at least the same as the frequency of the base case installation.

Table 3.1 Impairment frequencies for the escape ways function

Case	Annual impairment frequency
Base case	$3.8 * 10^{-4}$
New equipment	$4.0 * 10^{-4}$
Risk reduction implemented	$3.8 * 10^{-4}$
Acceptance limit	$1.0 * 10^{-4}$

The operator in this case is taking minimum scope approach to management HSE, only to satisfy the risk acceptance criteria. This practice does not address the fundamental issue of ALARP principle which says that risk should be further reduced to the extent possible as long as the costs are not grossly disproportionate to the benefits obtained.

Framing of decision problem and decision process

The decision problem is defined as follows:

- New installation has been designed and installed with unsatisfactory protection of personnel during the use of escape ways against fire and explosive effects.
- The installation is intended to have an important function at the field which expected to continue to operate for the next 30-40 years.
- Adding new equipment from time to time will increase the probability of a severe fire or explosion, thus improvement is needed.
- The need to find solution to the problem with respect to protection of escape ways.

Generation and assessment of alternatives

The following alternatives have been proposed:

a) Minor improvement to compensate the increased risk with no further reduction.
b) Installation of protective shielding on existing escape ways to avoid smoke ingress.
c) Installation of additional escape way with sufficient protection.
d) Do nothing and accept the situation as it is.

These alternatives then analysed to get the information about the risk reduction in terms of escape ways impairment frequency, the change in potential loss of life (ΔPLL) and the expected cost of each alternative. These information are presented in Table 3.2, Table 3.3 and Table 3.4.

Table 3.2 Key risk parameters for the decision alternatives

Options	Alternative	Annual impairment frequency (escape ways)	FAR	PLL (/yr)	ΔPLL (/yr)
0	Base case	$3.76 * 10^{-4}$	4.2	0.0147	
1	Limited risk reduction	$3.75 * 10^{-4}$	4.4	0.0154	-0.0007
2	Protective shielding	$1.25 * 10^{-4}$	3.4	0.0118	0.0029
3	Additional escape way	$9.40 * 10^{-5}$	2.5	0.0088	0.0059
4	Do nothing	$3.9 * 10^{-4}$	4.8	0.0168	-0.0021

Table 3.3 Expected cost parameters for the decision alternatives

Options	Alternative	Investment cost (mill NOK)	Annual operating cost (mill NOK)
0	Base case	0	0
1	Limited risk reduction	2	0.05
2	Protective shielding	30	0.4
3	Additional escape way	110	0.1
4	Do nothing	0	0

Table 3.4 Key risk and cost parameter for the decision alternatives

Options	Alternative	NPV (40 yrs) (mill NOK)	ΔPLL (40 yrs)	ICAF E(Cost)/E(saved lives) (mill NOK)
0	Base case			
1	Limited risk reduction	2.7	0.0	(Extreme)
2	Protective shielding	35.7	0.1	315
3	Additional escape way	111.4	0.2	467
4	Do nothing			

From the assessment, it is observed that only option 3 has annual impairment frequency below the acceptance limit of $1*10^{-4}$ per year, and option 2 just slightly over. Option 2 and option 3 also have considerable ICAF, which may be considered grossly disproportionate to the benefits if only seen in quantitative context.

From quantitative point of view, the following prioritization of alternatives is likely to be preferred:

1) Do nothing, because no costs involved and most likely there will be no protection needed during 40 years. However, there is no guarantee that the accident is not going to happen.
2) Limited risk reduction, because the cost is limited and the impairment frequency can be reduced to the base case level.

3) Protective shielding alternative is less preferred due to high cost, but does provide a significant reduction in risk.
4) Additional escape ways alternative has the higher cost among other alternatives, thus it is the least preferred.

Quantitative consideration only does not provide sufficiently broad support for making the decision. Of equal importance are the qualitative considerations of the risk aspects and the risk reduction proposals, which involve aspects related to the consequences, aspects related to the uncertainties and aspects related to manageability. An overall evaluation of risk also need to be performed.

<u>Managerial review and decision</u>

Based on the assessment of the alternatives, it is suggested that:

- The additional safety investments are difficult to justify.
- Applying the cautionary principle, suggesting that the company should pay attention to the uncertainties, it may be justified to choose option 2.

Management will consider both qualitative and quantitative input from the assessment. However, what the final decision is will depend on how management and decision-maker weigh the different concerns.

4. Decision-Making in Road Traffic Safety

4.1 Road Traffic Safety in Norway

The risk in road traffic in Norway is among the lowest in the world. Norway is committed to continue the reduction of the number of fatalities and serious injuries, in line with Vision Zero. Vision Zero is a vision of a transport system in which no one is killed or severely injured in road traffic. This vision is included in the National Plan of Action for Road Traffic Safety 2014-2017 (Statens vegvesen, 2014b) which has been compiled by the Norwegian Public Roads Administration (NPRA) or *Statens vegvesen* together with other related government agencies as well as non-governmental organisations.

The action plan provides collective measures that are expected to be carried out during the period. The measures aim to give contribution in reducing the number of fatalities and severe injuries on Norwegian roads by at least 20 percent by 2018.

Options for improving road safety has been described in terms of four main policy options (Elvik, 2007):

1) Optimal use of road safety measures.
   All road safety measures are being used up until the marginal benefits equal marginal costs. The surplus of benefits over costs will then be maximised.
2) "National" optimal use of road safety measures.
   Not all road safety measures are controlled by Norwegian government, in particular new motor vehicle safety standards are adopted by international bodies.
3) Continuing present policies.
   Road safety measures continue to be applied as they are without any increase in police enforcement or introduction of new laws.
4) Strengthening present policies.
   Cost-effective road safety measures are used more extensively than today. This also implies an increase in police enforcement.

4.2 Risk Assessment in Road Traffic

Risk assessment in road traffic is explained in Handbook V721 issued by Statens vegvesen (2014a). Risk is an expression of the danger incidents represents for humans, environmental and economic values. Risk assessment involves the incidents that can occur, how often they may occur, and what are the consequences. It gives the result about the total risk level and the conditions which contribute most to risk.

A risk assessment is part of a decision-making basis, giving necessary knowledge for decision-makers to make a choice. The risk assessment process, according to the guideline (Statens vegvesen, 2014a), consists of the following five steps:

a) Describe the object of analysis, objectives and assessment criteria.
   This step defines the delimitations, purpose and requirements of the analysis. The assessment means what risk result may be assessed against. There is no blueprint of what is acceptable and unacceptable risk, but solution can be assessed from Vision Zero requirement, best knowledge, regulations, standards and checklists.

b) Identify vulnerabilities.
   Assess what accident may occur and identify any conditions or risk factors that may contribute to the undesirable events. It is usually made on the basis of collected data and checklists.
c) Evaluate risk.
   Risk assessment should say something about the size of the problem, how often it is assumed that the undesirable event may occur and what are the consequences. Uncertainty should also be discussed. Uncertainty will primarily relate to the scope, relevance, quality of data, as well as group's expertise. On the basis of the frequency or the consequences, the undesirable events and the dangerous condition can be rank, which will constitute a priority list in taking action.
d) Propose measure.
   Based on the ranking of the hazardous conditions from the risk assessment, possible risk-reduction measure is proposed. A rough assessment relative to costs is conducted for the measures, to see the cost-effectiveness of the measures.
e) Documenting.
   Base data, assessments and conclusions must be documented and traceable to be used as a basis for decision-making in choosing the action to be taken.

4.3 Road Safety Measures

A road safety measure is defined as any technical device or programme that has at least one of its objectives to improve road safety. Road safety measures can be at any element of the road system, such as patterns of land use, the road itself, road furniture, traffic control devices, motor vehicles, police enforcement, and road users and their behaviour. Improving road safety refers to a reduction in the expected number of accidents, a reduction in accident or injury severity, or a reduction in a rate of accidents or injuries expressed in per kilometre of travel (Elvik & Vaa, 2004).

For measures which affect the number of accidents, the level of accident severity is categorized as:

- Fatal accidents, which refer to accidents where at least one person is killed immediately or dies within 30 days of the accident.
- Injury accidents, which are all accidents where injuries occur.
- Property damage only accidents refer to all accidents which have led only to property damage, not injuries.
- Accidents or unspecified severity, which includes a mixture of fatal accidents, other injury accidents and property damage only accidents in unknown proportions.

For measures which affect injury severity, the level of accident severity is specified as:

- Killed or fatally injured.
- Serious injuries, which are often injuries which require hospitalisation.
- Less serious injuries, which do not normally require hospitalisation, but which require medical treatment.
- Uninjured.

Known effects of a wide range of measures are documented in The Handbook of Road Safety Measures (Elvik & Vaa, 2004).

The following are steps used in Elvik and Vaa (2004), to come up with the recommendation of the proposed road safety measure as a solution to a road safety problem:

a) Problem and objective
b) Description of the measure
c) Effect on accidents
d) Effect on mobility
e) Effect on environment
f) Costs
g) Cost-benefit analysis

Cost-benefit analysis has been applied for many years to set priorities for road safety measures. However the use of cost-benefit analysis as the basis for decision-making for road safety policy is controversial (Elvik & Vaa, 2004). One of the objections to using cost-benefit analysis to assess road safety measures is that cost-benefit analysis not equally well suited for all types of policy issues.

Another objection is related to the assumption that cost-benefit analysis values all relevant impact in monetary terms, but in reality it is difficult to know when all relevant impact have been included in cost-benefit analysis. Despite the growing list of impacts being included in cost-benefit analysis, there are still impacts that are not included in the analysis, like the road user feeling of safety.

In recommending a specific road safety measure, the following need to be considered:

a) Many road safety measures are controversial, where the fact that a certain measure is effective does not always mean that people like it.
b) To choose between several measures, policy maker need to know more that the fact that they are all likely to reduce the number of accidents. Some considerations like, perhaps costs differ significantly, perhaps the impact on mobility and environment are different, perhaps public opposition is strong, and so on, show that making road safety policy involves complex trade-offs that may be overlooked.
c) Knowledge about the effects of road safety measures need to be firmly established, although this is not always the case, otherwise unexpected surprises might happen when introducing measure that was erroneously believed to be effective.

4.4 Road Safety Policy Making

4.4.1 Analytical road safety policy making

Figure 4.1 presents an analytical model of decision-making process identifying the stages of the road safety policy making process suggested by Elvik and Vaa (2004). The first stage is the description of road safety problems with its contribution to the number of road accident fatalities and injuries. The second stage relates to the political activity in setting the target for improving road safety. The next stages, starting from stage 3, are the road safety impact assessment. One of the objectives of the road safety impact assessment is to determine which road safety measures need to be carried out to achieve a long term road safety target. These stages will be explained in more detail with reference to Elvik (2007).

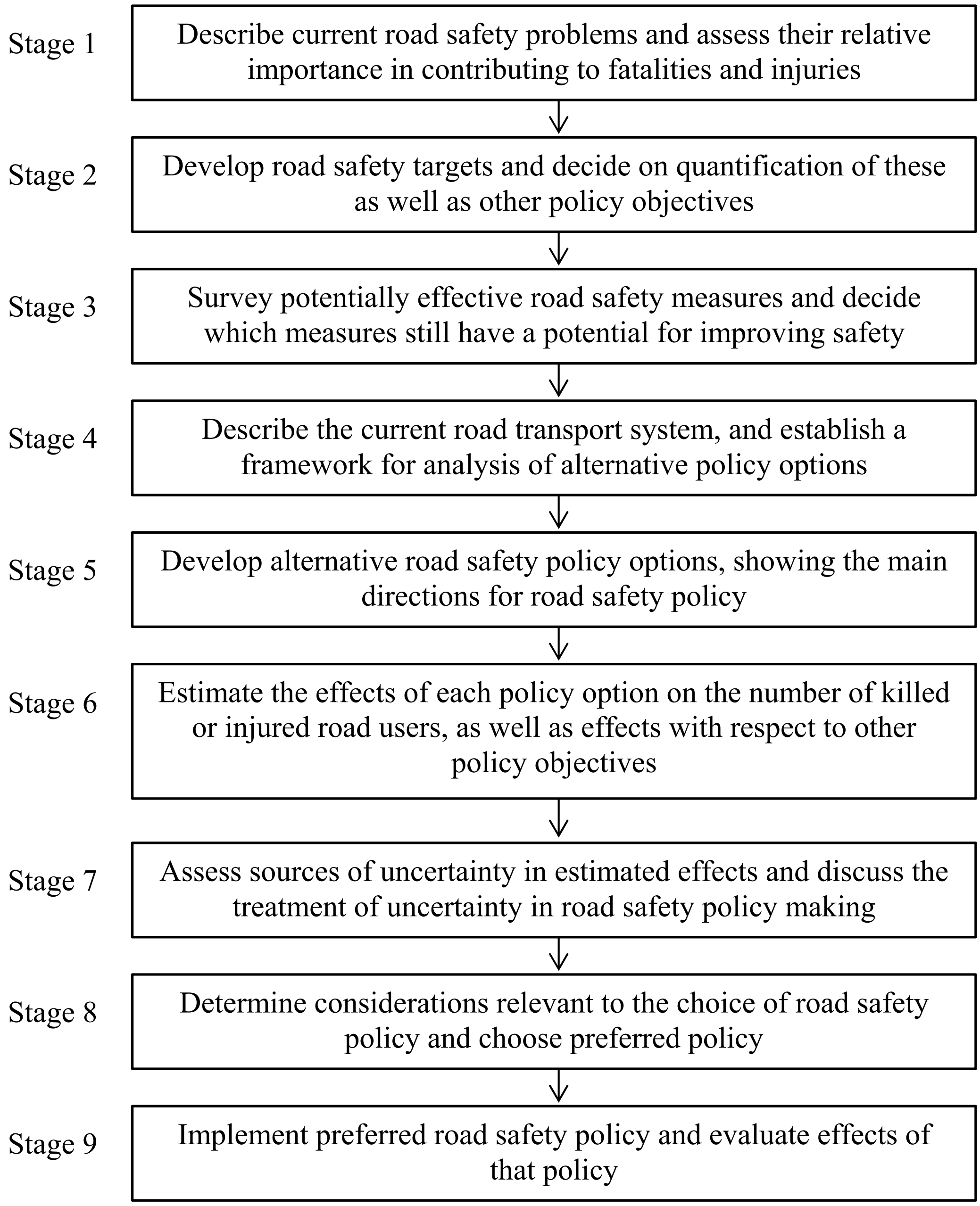

Figure 4.1 Analytical model of road safety policy making (Elvik & Vaa, 2004)

Selection of potentially effective road safety measures

The first step of a road safety impact assessment is to select the road safety measures to be included in the assessment, which ideally should include the broadest possible range of road safety measures to make sure that all potentially effective measures are included. For a measure to be considered as potentially effective, it should be known to reduce the number of accidents or the severity of injuries, or to favourably influence risk factors that are associated with accident occurrence or injury severity. A potentially effective measure also should not be fully implemented, because it will no longer contribute to further improving safety.

The screening process of potentially effective road safety measures to be included into formal assessment of their potential for improving safety and cost-effectiveness is carried out in two stages:

1) Prepare as exhaustive list as possible of road safety measures, which includes all known measures that have improving road safety as one of their objectives.
2) Screening these measures using the following set of screening criteria:
   - Knowledge of costs and effects.
     A measure cannot be included in formal impact assessment if neither the costs nor any of the effects of the measure are sufficiently well known to be quantified.
   - Effects on safety.
     No point in including measures that are not known to improve safety.
   - Overlap of other measures.
     Only one measure from a set of overlapping measures can be included.
   - Measure has been fully implemented.
     Measure that has been fully implemented is not included in the assessment.
   - Measure is analytically intractable.
     Some measures are just too complex to fit into the framework of a formal impact assessment.

A large number of road safety measures have been summarised in the Handbook of Road Safety Measures (Elvik & Vaa, 2004). These measures have been used extensively and have been evaluated to provide estimates of their effects. The measures listed in this handbook can be taken as the basis for preparing an exhaustive list of road safety measures.

Framework for road safety impact assessment

Determining the framework for road safety impact assessment consists of:

a) Developing forecast of accidents to show expected future development for a baseline scenario, which likely to occur if past trends continue and no intervention are made to change the trends.
b) Determining the value parameters for analysis, such as the discount rate, the opportunity cost of public money, the monetary valuation of road safety, the monetary valuation of other impacts of measures, including travel time, vehicle operating costs and environmental impacts.
c) Determining the service life (depreciation time) of road safety measures.

Developing policy options and formal priority setting

To develop efficient policy options, the most efficient schedule for implementing road safety measures should be determined for each measure. Priorities for implementing each road safety measure should be set so that total benefits are maximised. To implement road safety measures in a way that produces maximum benefits, it is necessary to select areas or units for implementation that have the highest expected number of accidents or injuries.

Estimating expected effects of road safety measures

The following information is needed to estimate the effects of road safety measures:

a) Definition of a suitable unit for implementation of the measure.
b) Definition of the target group of accidents influenced by each road safety measure.
c) Estimate of the expected number of accidents for each unit of implementation of each road safety measure.
d) Estimate of the expected effects of each road safety measure on the target accidents or injuries.

Sources of uncertainty and their treatment

Quantified targets for improving road safety and programmes do not always produce the expected results. It is commonly found that the actual number of fatalities and injuries caused by road accidents exceeds the numbers that were predicted according to the road safety programme.

Estimates of the effect of road safety measures are uncertain. The monetary valuation of the benefits of road safety measures is highly uncertain. There are several sources of uncertainty in the estimated benefits of road safety programmes, which are rarely discussed. Elvik (2010) has identified the following ten sources of uncertainty in road safety impact assessments:

a) Random variation in the recorded number of accidents or injuries in the target group of a road safety measure.
b) Incomplete on inaccurate reporting of accidents or injuries in official accident statistics.
c) Uncertainty about the definition of the target group of accidents or injuries influenced by a road safety measure.
d) Random variation in the effects of a road safety measure on accidents or injuries.
e) Unknown sources of systematic variation in the effects of a road safety measure on accidents or injuries.
f) Unknown duration or stability over time of the effects of a road safety measure.
g) Uncertainty with respect to if and how the first order effects of a road safety measure are modified when it is combined with other road safety measure.
h) Uncertainty with respect to assumptions made about the effects of exogenous factors influencing road safety.
i) Uncertainty about the degree to which planned road safety measures will actually be implemented.
j) Uncertain monetary valuation of the benefits of road safety measures.

One of the key elements in cost-benefit analysis is the monetary valuation of non-market goods like a reduced number of fatalities and injuries in road traffic. At current state of knowledge, it is difficult to quantify the monetary valuation for non-market good in coat-benefit analyses. Therefore, these valuations are, to some extent, highly uncertain.

Not all of the sources of uncertainty can be quantified as per current knowledge. This means that any estimate of the uncertainty associated with the benefits of a road safety programme will be incomplete and understate the true uncertainty. More research may lead to the quantifications of more sources of uncertainty, but it is unlikely that all sources of uncertainty can be meaningfully quantified.

Considerations relevant to policy choice and implementation

The purpose of a road safety impact assessment is to inform policy makers about the expected effects of road safety measures and road safety programmes. Costs and benefits of alternative policy options are made comparable by measuring them in monetary terms. To spend scarce resources as to maximise total benefits for road safety is to use all road safety measures according to the principle of marginal utility, which means to apply all measures up to the point at which marginal benefits are equal to marginal costs. When road safety measures are used optimally, the surplus of benefits over costs is maximised.

Policy based on such efficiency analysis, in particular cost-benefit analysis, disregards a number of considerations, such as:

a) Who pays and who gets the benefits.
   As long as the benefits are sufficiently great, it does not matter if those who pay are not the same individuals as those who get the benefits. This criterion is usually considered satisfied if benefits are greater than costs.
b) Net changes in the distribution of costs and benefits.
   Those who gain from public policies should, in principle, be able to compensate those who lose. However there is no requirement that compensation actually takes place.
c) Current allocation of spending.
   If the benefits of a measure are greater than the costs, it should be introduce. There is no consideration of the current allocation of spending. If the current budget does not allow all cost-effective road safety measures to be implemented, the implication of the efficiency analysis is simply that the budget is too small and should be increased, and vice versa.
d) Public acceptance.
   An efficient road safety measure should be popular or public supported. However, a social dilemma often occur when the benefits of a measure is smaller than the cost when viewed from private perspective, but seen greater than cost if a societal perspective is adopted. For example, the environmental gains from lowered speed limits will count as social benefit, but not count as private benefit from each motorist point of view.
e) Democratic process and legitimacy.
   Efficiency analysis is a technical analysis, representing input from technical experts into the policy making process. Cost-benefit analysis is considered violating ideals of democratic decision-making, and that its findings are often irrelevant from a political point of view.

Ignoring the above considerations makes efficiency analysis cannot be made the sole basis for decision-making. Cost-benefit analyses of road safety measures does not eliminate the potential presence of competing criteria for priority-setting, in particular criteria referring to the size of effects on road safety and to the distribution of safety effects between different groups of road users. Policy makers may regard such criteria for priority-setting as more relevant than the benefit-cost ratio, and the actual policy priorities may depart from the results of cost-benefit analyses.

4.4.2 Actual road safety policy making

Figure 4.1 have shown the analytical model of policy making as an ideal model, and does not reflect how the real policy making process. Figure 4.2 shows a more realistic model as presented by Elvik (2007).

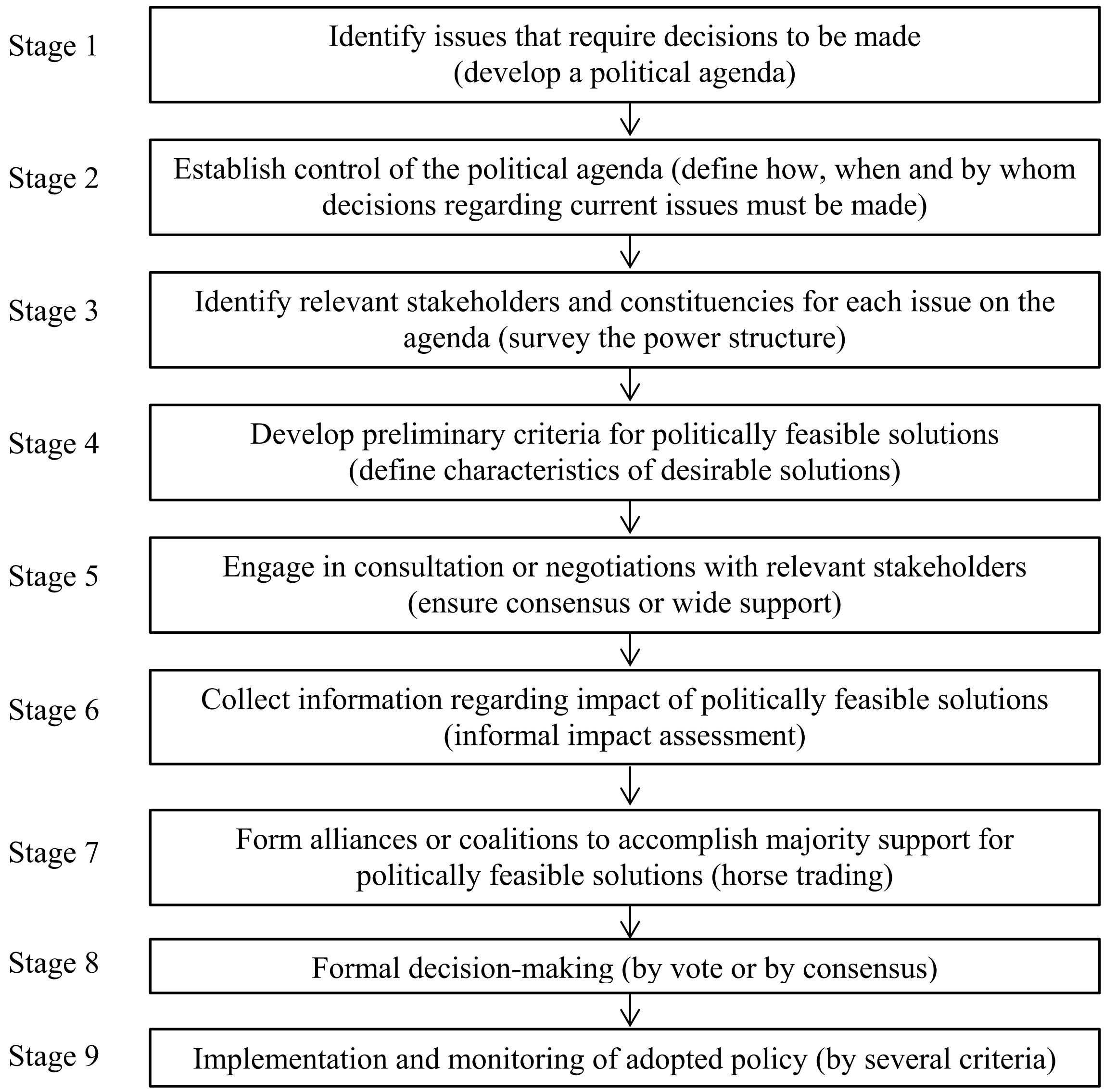

Figure 4.2 Model of actual road safety policy making (Elvik, 2007)

There are big differences between the analytical model and actual model of road safety policy making. In the actual model, efficiency is considered an important criterion in policy making, but political decision-makers do not always look for the most efficient solution to the problem. It is always the political realities that determine the outcome, and not the input provided by technical experts. Elvik (2007) stated that the following considerations become relevant for the implementation of road safety measures that have been developed by means of efficiency analysis:

a) Empowerment.
   Some political actions may weaken policy options based on efficiency analysis and results in inefficient priority settings. Issues related to empowerment:
   - National government often makes road safety programmes but may not have the power to implement all cost-effective road safety measures. Some standards are beyond the power of national governments, such as the adoption of new vehicle safety standards that require decisions to be taken by international bodies.
   - Ideally, road safety programmes developed by national government should be enforced at all levels of government. However, regional and local government may refuse to do as instructed and set their own policy priorities.
   - A target in road safety programmes serves as important element of commitment to improving road safety. However, Norwegian politician seems reluctant to support such target, arguing that it is unethical to set a specific numerical target for road accident fatalities.
b) Reallocation mechanisms.
   Public budgeting is a result of political negotiations and compromises. The resulting allocations can be very stable and resistant to change, even if they are grossly inefficient. Investments may not be allocated according to efficiency criteria, while a disproportionate share of investment funds are spent in sparsely populated area to promote regional development.
c) Competing incentives.
   The fact that a measure is cost-effective does not necessarily mean it will be implemented. This can happen when another measure competing for the same scarce resources is considered more cost-effective.
d) Social dilemmas.
   It is essential to identify measures that may give rise to social dilemmas, as these measures may be more difficult to implement. To overcome social dilemma, it may be necessary to provide incentives for road users so that they will support options that are cost-effective from the societal point of view.
e) Public acceptance.
   It is important to collect information about public acceptance of various road safety measures and a certain minimum of public acceptance is needed to introduce a measure. The reason is sometimes a road safety measure still not widely accepted even if the measure provides benefits that are greater than the costs form both private and societal perspectives.

4.4.3 Example of road safety policy making

This section presents the example of road safety policy making involving the selection of road safety measure. Example is taken from the textbook 'The Handbook of Road Safety Measures' by Elvik and Vaa (2004).

The example is about the implementation speed-reducing devices to control high speed in residential areas and access roads. The intention of speed-reducing devices is to force vehicles to keep to low speed to reduce the risk of accident.

Problem and objective

In a residential street, access roads and other places where children play, high speeds driving can result in high accident rate and feelings of insecurity. Reduced speeds in residential areas can lead to a lower risk. Road signs stating the speed level, does not always give the desired effect.

To get speed down to desired level, a speed-reducing device is needed. The intention is to make fast driving uncomfortable or impossible, forces vehicles to keep on low speed, so that the risk of accident is reduced and feeling of safety is increase.

Description of measures

Speed-reducing devices include these measures:

- Humps
  Humps are artificial elevations on carriage way designed as part of a circle or as a sinusoidal curve, to give increasing discomfort when driven over at increasing speeds.
- Raised intersections
  The intersection area is raised to the same level to the surrounding pavement.
- Rumble strips
  Rumble strips are changes in the road surface which cause knocks, vibration and/or noise to the car, and can be constructed, for example, using strips of plastic placed across the road on top of the road surface.
- Narrowing road width
  Reduction in the width of the carriageway, e.g. using kerbstones, or widening the pavement at an intersection is regarded as road narrowing.
- Speed zones
  This measure is known as the "30 km per hour zone" and "quiet roads". In addition to the extensive use of humps, other measures can also be added in 30 km per hour zones, for example raised intersections.

Effect on accidents

Humps reduce the number of injury accidents, for a given amount of traffic, by around 50%. On average, mean speed are reduced from 36.4 to 24.4 km per hour in roads where humps were installed, corresponds to 33% reduction in speed. The effect of humps on accidents is related to the size of the reduction in speed. The effect of speed-reducing devices on accidents is shown in Table 4.1.

Effect on mobility

Some effects of speed-reducing devices on the mobility:

- Speed-reducing measures may deter traffic, in particularly heavy vehicles.
- On a typical access road with length up to 0.5 km, a speed reduction from 35km/hr to 25 km/hr may lead to delay of a maximum 20 seconds per car.
- Bus companies were against humps, with concerns related to back injuries to the drivers, injuries to passengers and wear and tear on materials.
- It is not known if humps create problems for winter maintenance of roads.

Table 4.1 Effects on accidents of speed-reducing devices.

Accident severity	**Types of accident affected**	**% change in number of accidents (best estimate)**
Humps		
Injury accidents	All accidents	-48
Raised intersections		
Injury accidents	Accident at intersections	+5
Property damage only accidents	Accident at intersections	+13
Rumble strips		
Injury accidents	Accident at intersections	-33
Property damage only accidents	Accident at intersections	-25
Unspecified severity	Accident at intersections	-20
Speed zones (30 km per hour zone with humps)		
Injury accidents	All accidents	-27
Property damage only accidents	All accidents	-16

Effect on environment

Some effects of speed-reducing devices on the environment:

- Humps that have been installed show a reduction in noise.
- Rumble strips can increase noise level.
- At low speed, the emission of pollutants from vehicles can increase. However, when the traffic volume is low, it can be assumed that differences in amount of emissions have little or no health-related effect.

Costs

Several costs for implementing speed-reducing measures:

- Humps construction on road in Norway with normal width (4-8 metres) costs NOK 10,000-30,000.
- Signs warning of the measure costs NOK 2,000 per sign.
- Marking rumble strips using plastic costs NOK 30-40 per metre of marked road.

Cost-benefit analysis

Numerical examples are given for constructing humps and laying rumble strips.

a) Humps

   Assumptions:
   - The road carries 200 vehicles per day.
   - Accident rate at 1.0 injury accidents per million vehicle kilometres.
   - The road in concern is 1 km long.
   - Reduction of speed from 35 to 25 km per hour.
   - Number of accidents goes down by 50%.
   - Environmental costs related to emission discharge increases by NOK 0.10 per vehicle kilometre.
   - 10 humps are constructed with total cost of NOK 150,000.

   Under these assumptions, costs and savings are estimated:
   - Savings in accident costs at NOK 960,000.
   - Increased cost of travel time to NOK 970,000.
   - Increased vehicle operating costs to 210,000.
   - Increased environmental costs to NOK 85,000.

   The calculated overall benefit is found to be negative at minus NOK 305,000. However, the analysis does not reflect the increase feelings of safety or improvements to other qualities of the residential environment. Speed-reducing devices are in demand in many residential areas, therefore those who live in these areas may consider the benefits of the measure is greater than the costs.

b) Rumble strips

   Assumptions:
   - Annual average daily traffic of 5000 at the intersection.
   - Accident rate of 0.10 injury accidents per million entering vehicles.
   - Cost for laying rumble strips is NOK 5,000.
   - Number of injury accidents goes down by 33%.
   - Property damage only reduced by 25%.
   - The speed goes down from 35 to 25 km per hour, which correspond to a delay of around 4 seconds per vehicle.
   - The effect of the measure is assumed to last for three years, after that the rumble strips must be renewed.

   The reduction of accident costs is estimated at NOK 350,000, meanwhile costs of travel time is increased at NOK 530,000. It is clear that the increase in costs of travel time is greater than the reduction in accident costs, resulting in negative total benefit.

Decision-making

Although efficiency is an important criterion, political decision-makers do not always look for the most efficient solution to a problem. Efficiency analysis assumes that there is consensus on political objectives and that a suitable technical tool exists for implementing cost-effective policy options. However, these assumptions may not correspond to political realities. In actual policy making processes, it is always the political realities that determine the outcome and not the input provided by technical experts (Elvik, 2007).

5. Discussion

5.1 Decision-Making in Offshore Safety

5.1.1 Characteristics of offshore oil and gas industry

Accidents have been parts of offshore development and operations, they are the sources of fatalities and environmental pollution at all stages of oil and gas production. The causes, scale and the severity of the consequences are variable, depending on a combination of many natural, technical and technological factors (Odland, 2014).

Experience from major accidents in the past is an important source of information to prevent the occurrence of similar accidents in the future, and there have been a number of major accidents in offshore operations worldwide that we can learn from (Vinnem, 2014). The accident events can be grouped according to the type of event that initiated the sequence of events:

- Blowout
- Hydrocarbon leaks on installation, leading to fire and/or explosion
- Hydrocarbon leaks from pipeline/risers, leading to fire and/or explosion
- Marine and structural failures, possibly leading to total loss
- Other accidents.

The biggest offshore accident happened in 1988 when Occidental's Piper Alpha platform was destroyed by explosion and fire which was initiated by a gas leak. The accident caused 167 fatalities and total loss of the platform.

Another major accident in offshore petroleum industry that happened quite recently was the blowout of BP Macondo well in 2010 causing explosion and oil spilled to the sea. The rig sank and 11 lives were taken by the accident. The blowout was stopped after 87 days resulting in the total amount of oil spilled to have been 650,000 tons.

In terms of risk to personnel, it should be noted that risk exposure is limited to the employees and no exposure of the public from offshore petroleum activities (Aven & Vinnem, 2007). In addition to loss of personnel, accidents involving loss of platform or some damages to the environment are very expensive. The main environmental hazard is related to the spills and blowouts of oil, gas and other chemical substances and compounds. Environmental consequences can be very severe (Odland, 2014).

The above accidents showed us how risky the offshore petroleum industry is to the personnel, environment and company's assets. The accident events may have an extremely low probability to occur, but it can and do occur, and the consequences can be extremely high. The combination of very low probability event with high or severe consequences makes the nature of offshore petroleum industry is very uncertain (Odland, 2014), in other words high degree of uncertainty.

5.1.2 Review of the decision-making principle in offshore safety

The HSE Framework Regulation regulates that risk shall be prevented or limited in accordance with legislation and acceptance criteria. Further, risk shall be reduced to the extent possible provided that the costs are not significantly disproportionate to the risk reduction achieved. The latter is known as the ALARP (as low as reasonably practicable) principle. The use of risk acceptance criteria and ALARP principle in decision-making is the main focus in this section.

Norwegian offshore petroleum industry has been, for so many years, using risk acceptance criteria as upper limit of acceptable risk. Aven and Vinnem (2007) argued that care should be taken when using acceptance criteria due to several problems related to it. The implication of the term "acceptable" often gives the wrong focus, which is to meet the criteria rather than obtaining overall good and cost-effective risk-reducing measures. This implication, to some extent, does not go in line with the ALARP principle.

The HSE Management Regulation further regulates that setting the acceptance criteria is the operator's responsibility. This practice seems to have conflict of interest when the one who is going to make decision about risk is the one who sets the limit for the risk itself. It is also argued by Abrahamsen and Aven (2012), that the setting of risk acceptance criteria by operator would not in general serve the interest of the society as a whole. The operator's activity usually will cause negative externalities to society and the society would want to adopt stricter risk acceptance criteria than what the operator has formulated.

As previously stated, risk shall be reduced to the extent possible provided that the costs are not significantly disproportionate to the reduction of risk achieved. The known term for this principle is ALARP principle. In ALARP principle, the default is to implement risk reducing measure to reduce risk, even if, from the acceptance criteria point of view, the risk is on the acceptable/tolerable region.

ALARP principle, to some extent, has already been implemented in Norwegian system, and the implementation usually carried out in mechanistic way based on cost-benefit/cost-effectiveness analysis (Aven & Vinnem, 2007). However, with high degree of uncertainty that characterised offshore petroleum industry, the implementation of ALARP should pay more attention to the uncertainties.

Moreover, the implementation of ALARP is still operated around the context of risk acceptance criteria. This implies that efforts are often limited to satisfying the risk acceptance limit, with little or no margin, and no encouragement to consider if further risk reduction is possible or achievable (Aven & Vinnem, 2007).

ALARP principle should be able to be used independently from the risk acceptance criteria, so that it can promote continuous risk reduction while balancing (not grossly disproportionate) the cost and benefit of the measure. But, this does not imply that we should stop having the risk acceptance criteria. Risk acceptance criteria have been used will continue to be used in offshore petroleum industry. However, risk acceptance criteria should not be regarded as an upper limit, rather as a reference value to check against the residual risk.

5.2 Policy Making in Road Traffic Safety

5.2.1 Characteristic of traffic safety work

Traffic safety work in Norway is based on the Vision Zero target, which is a vision of a transport system in which no one is killed or severely injured. It is a long-term, systematic and determined work that influences road traffic safety. This vision is explained in the National Plan of Action for Road Traffic Safety 2014-2017 (Statens vegvesen, 2014b).

Vision Zero, as illustrated in Figure 5.1., is followed by the Plan of Action that provides a collective description of 122 measures expected to be carried out during the period. The measures aim to contribute to reducing number of fatalities and severe injuries by at least 195 (20%) by 2018. This target is a subsidiary goal against government targets in the National Transport Plan 2014-2023: In 2024 there will be a maximum of 500 killed and seriously injured in road traffic. This target represents almost half compared with the current situation (Statens vegvesen, 2015).

Figure 5.1 Illustration of Vision Zero (Statens vegvesen, 2014b)

The intention of the Plan of Action is that by applying all 122 road safety measures extensively during the next ten years, the number of road accident fatalities and severe injuries could be reduced by 40%. This implies that at least a large portion of road accident fatalities and severe injuries are preventable (Elvik & Vaa, 2004).

The Plan of Action is based on a number of assumptions (Statens vegvesen, 2014b). However, there is a high degree of confidence that the selected measures will reduce the number of fatalities and severe injuries. This level of confidence must be supported by reliable historical data and strong knowledge, characterising road traffic safety in a low level of uncertainty.

5.2.2 Review of the policy making principle in road traffic safety

For many years, cost-benefit analysis has been used as a method to set priorities for road safety measures, but has remained controversial. Many believe that we should not rely on cost-benefit analysis to decide whether road safety measures should be implemented or not, objecting the idea of putting monetary value on human life (Elvik & Vaa, 2004).

In actual policy making processes, political decision-makers do not always look for the most efficient solution to a problem. It is always the political realities (i.e. budget allocation, social dilemma, public acceptance) that determine the outcome and not the input provided by technical experts (Elvik, 2007).

The above is in line with Elvik and Vaa (2004) explanation, that a cost-benefit analysis is a simple way to show, in common scale, the relative importance of various impacts of a programme. It is not a policy recommendation. It does not mean that an action should always be adopted if the benefits are greater than the costs, and vice versa. To determine the weight that cost-benefit analysis should carry in road safety policy requires judgements made outside the framework of cost-benefit analysis.

Traditional cost-benefit analysis was first developed for the evaluation of public policy issues, expressing the society's willingness to pay to gain certain benefit. Road traffic safety is a public issue. Therefore the cost-benefit analysis is used and will continue to be used in prioritizing road safety measure. How policy-makers weight the use of cost-benefit analysis will depend on other concerns that policy-makers opt to address.

5.3 The Use of ALARP with Layered Approach as a General Decision-Making Principle in Safety Management

The implementation of ALARP principle using the layered approach is about how the decision-makers weight the uncertainties related to the problem. Abrahamsen and Abrahamsen (2015) have introduced three perspectives on how to weight uncertainties:

1) Extreme economic perspective, where traditional cost-benefit analysis is used with reference made to the expected value and limited or no weight is given to the uncertainties.
2) Extreme safety perspective, where strong weight is given to the cautionary principle without any reference to cost-benefit analyses.
3) Somewhere in between extreme economic perspective and extreme safety perspective.

To be able to use ALARP as a general principle for decision-making in safety management, ALARP has to have the ability to be interpreted in a dynamic way, meaning that the grossly disproportionate criterion ranges from one extreme perspective to another. The gross disproportionate criterion can be referred to the extreme economic perspective, extreme safety perspective, or somewhere in between the two extreme perspectives, depending on the decision-making context, i.e. the degree of uncertainty.

For decision problem that considered unproblematic and low uncertainty, the ALARP principle is carried out by traditional cost-benefit analysis. The grossly disproportionate criterion between the costs and the benefits obtained is defined simply if the expected cost is higher than the expected benefit. In this context, the extreme economic perspective is adopted.

On the contrary, problematic decision problem with high uncertainty may adopt extreme safety perspective, and ALARP principle is carried out by giving strong weight to cautionary principle.

For all other decision context, a perspective which is somewhere between the two extremes may be adopted. In this context, the problem may lean towards the extreme safety perspective or extreme economic perspective, but never on the extreme end.

5.3.1 The use of ALARP with layered approach as decision-making principle in offshore safety

Decision-making process in offshore safety has been familiar with the term ALARP principle, but there is no standard or guideline telling the industry how ALARP principle should be demonstrated and how to verify the gross disproportionate criterion.

The most common way used to check whether the cost of a measure is grossly disproportionate to the benefit obtained is using cost-benefit/cost-effectiveness analysis. The problem with this analysis is that it does not properly take uncertainty into consideration, whilst the issues with offshore petroleum industry itself are considered having a high degree of uncertainty.

Let consider a decision problem whether or not to install a subsea isolation valve (SSIV) on export pipeline, taken from Aven and Abrahamsen (2007). In case of accident, SSIV will reduce the duration of fire, thus limit the damage to equipment and exposure to personnel. Cost-benefit analysis is conducted with result that the SSIV can be justified according to the $E[NPV]$ calculations if a statistical life has a value in the order of 300 million £, hence the cost is in gross disproportion to the benefit. From the expected value perspective, the evaluation will stop here and the investment in an SSIV will not be justified.

If the layered approach for verifying ALARP is adopted, the result from cost-benefit analysis above will not be simply a recommendation to not invest in an SSIV. Instead, it will be used as an input for assessment of other concerns, including uncertainty, manageability, robust solution, best available technology, etc. (refer to Figure 2.4. and Figure 2.5.).

The cost-benefit analysis implies that it is grossly disproportionate to invest in the SSIV. However, pipeline failure may occur. The probability of the pipeline failure may be considered small, but we cannot disregard it. Without the SSIV, if fire occurs, the consequences can be very large in terms of number of fatalities and economic loss. Other concerns including uncertainty need to be assessed (Aven, 2011):

- Is there considerable uncertainty (related to phenomena, consequences, conditions) and will the measure reduce these uncertainties?
- Does the measure significantly increase manageability? High competence among the personnel can give increased insurance that satisfactory outcomes will be reached.
- Is the measure contributing to obtaining a more robust solution?
- Is the measure based on best available technology (BAT)?
- Are there unsolved problem areas: personnel safety-related and/or work environment-related?
- Are there possible areas where there is conflict between these two aspects?
- Is there a need for strategic considerations?

The checklist shapes the ALARP principle's ability to range from extreme economic to extreme safety perspectives. Many yes answers from the checklist means that the gross disproportion has not been demonstrated. The investment in SSIV will then be justified by giving weight to cautionary principle. In this example we adopt the extreme safety perspective by giving strong weight to cautionary principle without any attention given to cost-benefit analysis.

From this example we can see that the ALARP with layered approach can be used as a decision-making principle in prioritizing the implementation of safety measure in offshore petroleum industry. The layered approach supports the dynamic interpretation of ALARP, in which decision-making process in offshore safety can adopt the three perspectives depending on the decision-making context.

5.3.2 The use of ALARP with layered approach as policy-making principle in road traffic safety

Decision or policy making in road safety does not familiar with the term ALARP. In choosing the road safety measure to be implemented, the recommendation is given based on the cost-benefit analysis. Policy makers will decide how much weight they should give to cost-benefit analysis in making their decision, by also considering other concerns that are not captured in the cost-benefit analysis, such as social dilemma, public acceptance, etc.

Road traffic safety work in Norway is based on the Vision Zero target. It is a vision of a transport system in which no one is killed or severely injured on the road (Statens vegvesen, 2014b). This vision can be seen as a commitment to continuously improve traffic safety, in other words reducing risk. This commitment, to some extent, can be seen in line with the continuous reduction of risk as promoted by ALARP. Therefore, applying the ALARP principle in issues regarding road traffic safety may also promote the achievement of Vision Zero in the long run.

Unlike the offshore safety issues that have high degree of uncertainty, road traffic safety issues most likely have low degree of uncertainty. When adopting the ALARP with layered approach, most decision problem in road traffic safety will adopt the extreme economic perspective. Some decision problem may fall somewhere in between the extreme economic and extreme safety perspective, leaning towards the extreme economic perspective.

Rarely there will be decision problem in road traffic safety that needs to adopt the extreme safety perspective. Most likely, the decision/policy making in road traffic may not adopt all of the perspective offered by the ALARP with layered approach. Nevertheless, the ALARP with layered approach is considered suitable to be used for decision/policy making in road traffic safety.

6. Conclusion

We have studied two different industries with different characteristic. First, is the offshore petroleum industry where its safety issues have a high degree of uncertainty due to the severe consequences that may happen in the case of major accident event. Second, is the transportation industry where its road traffic safety issues considered having a low degree of uncertainty due to its strong knowledge about the risk.

The two industries have different characteristic and different decision-making context regarding the safety issues. Both also have different decision-making principle that currently used in their safety management, particularly in prioritizing the implementation of safety measures. Nevertheless, we have also seen that the ALARP with layered approach can be applied as decision-making principle in both offshore safety and road traffic safety. This is due to the flexibility, on how to weight the uncertainties, given by the approach.

The ALARP with layered approach offers a dynamic interpretation of grossly disproportionate criterion, ranging from extreme economic perspective to extreme safety perspective, depending on the decision-making context. Extreme economic perspective is where decisions are made with reference to expected value. Extreme safety perspective gives strong weight to cautionary principle with no reference to cost-benefit (cost-effectiveness) analyses.

It has been suggested by Abrahamsen and Abrahamsen (2015) that it can be appropriate to adopt ALARP principle as a general principle in safety management if the layered approach (as suggested by Aven (2011)) is adopted. It has been shown that this approach can be applied in issues related to offshore safety and road traffic safety, which have different characteristic and different context. Therefore, it is strongly believed that this approach can also be suitable to be applied as decision-making principle in the safety management in another industry.

Different contexts require different decision-making principle, and this is what ALARP with layered approach offers, one decision-making principle that can accommodate different decision-making context. Therefore, it can be fruitful to have one principle, the ALARP with layered approach principle as a general decision-making principle in safety management.

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