On the Use of Cost-Benefit Analysis in ALARP Processes

T. AVEN and E. ABRAHAMSEN

University of Stavanger, Norway

(Received on July 3, 2006)

Abstract: The ALARP principle expresses that risk should be reduced to a level that is low as reasonably practicable, and risk reducing measures should be implemented provided the costs are not grossly disproportionate to the benefits gained. To verify ALARP, different tools are being used, including cost-benefit analyses and cost-effectiveness analyses. In this paper we discuss the role of such analyses in the ALARP process; in particular we address the common procedures for increasing the value of a statistical life and adjusting the discount rate to check against the gross disproportion criterion. We conclude that standard cost-benefit analyses should be used with care as the expected net present value calculations to large extent ignore uncertainties. The adjustment procedures to account for the uncertainties are considered ad hoc with a strong element of arbitrariness.

Key words: ALARP, gross disproportion, cost-benefit analysis, cost-effectiveness analysis, uncertainties

1 Introduction

A basic principle in safety management is the cautionary principle [1], expressing that in the face of uncertainty, caution should be a ruling principle. For example, in a process plant, major hydrocarbon leaks might occur, requiring investments in various safety systems and barriers to reduce the possible consequences - we are cautious. Uncertainties in phenomena and processes justify investments in safety.

On the other hand, safety management is based on the use of cost-benefit analyses to support decision making on safety investments and implementation of risk reducing measures, see e.g. the standard [2]. Cost-benefit analyses means that we assign monetary values to all relevant attributes, including costs and safety and summarise the performance of an alternative by the expected net present value, \( E[NPV] \). The main principle in transformation of goods into monetary values is to find out what the maximum amount society is willing to pay to obtain an improved performance. Use of cost-benefit analysis is seen as a tool for obtaining efficient allocation of the resources, by identifying which potential actions are worth undertaking and in what fashion. By adopting the cost-benefit method the total welfare is optimised. This is the rationale for
the approach. Although cost-benefit analysis was originally developed for the evaluation of public policy issues, the analysis is also used in other contexts, in particular for evaluating projects in firms. The same principles apply, but using values reflecting the decision maker’s benefits and costs, and the decision maker’s willingness to pay.

The ALARP principle gives strong weights to the cautionary principle: The ALARP principle expresses that the risk should be reduced to a level that is as low as reasonably practicable. Furthermore, a risk reducing measure should be implemented provided it cannot be demonstrated that the costs are grossly disproportionate to the possible benefits obtained, ref. e.g. [1] and [3]. The ALARP principle may be considered to give a stronger weight to the cautionary principle than the industry would find adequate, but it is a way for the society to control the risks for human beings and the environment. Practical procedures for implementing the ALARP principle are found in e.g. [1], [4], [5], [6] and [7]. See also [8]. These procedures are mainly based on engineering judgments and codes, but also to some extent traditional cost-benefit analyses. As these analyses to large extent ignore uncertainties, this latter practice is questioned.

This issue is the topic of the present paper. A main purpose of the paper is to demonstrate that the use of traditional cost-benefit analyses in verifying that risk is ALARP is in fact not consistent with the ALARP principle. The cost-benefit analyses do not give sufficient weight to uncertainties, they are based on an attitude to risks and uncertainties which is risk neutral and are thus in conflict with the use of the cautionary principle and ALARP.

Our problem is to make a “good” decision in a situation involving possible consequences (outcomes) which are subject to uncertainties. In theory, our problem has been solved; the optimization of the expected utility. This theory, which is the ruling paradigm among economists and decision analysts in such a situation, see e.g. [9], [10] and [11], gives a rational basis for determining an optimal decision. The expected utility is in mathematical terms written like Eu(X), where u is the utility function and X is the outcome expressing a vector of different attributes, for example costs and the number of fatalities. The expected utility approach is theoretically attractive as it provides recommendations based on a logical basis.

However, in practice it is difficult to apply the theory. The proper specification of the utility function means the application of a lottery process, as explained in e.g. [11] and [12]. This lottery process is not straightforward to carry out in practice. The specification of the utility function is particularly difficult when there are several attributes, and in most cases this is the case.

To ease the specifications, several simplification procedures are presented, see e.g. [13], [14] and [12]. Nonetheless, the authors of this paper still see the expected utility theory as difficult to use in many situations, in particular for the situations characterized by a potential of large consequences and relatively large uncertainties what will be the consequences.

It is outside the scope of the present paper to discuss this is its full depth, we refer to [12]. We conclude that even if it were possible to establish practical procedures for specifying utilities for all possible outcomes, decision makers would be skeptical to reveal these as it would mean reduced flexibility to adapt to new situations and circumstances. In situations with many parties, as in political decision making, this aspect is of great importance.
Having rejected the expected utility theory as the solution to our problem, we have to search for other ways of balancing the different concerns, and in particular determine ways of specifying what is grossly disproportionate. Is it adequate to use a cost-benefit analysis or a cost-effectiveness analysis and adjust the value of a statistical life? Do the common procedures for increasing the value of a statistical life and adjusting the discount rate (see e.g. [15], [16] and [17]) to check against the grossly disproportionate criterion provide the solution to our problem? This will be discussed below, but first (Section 2) we briefly review basic principles of safety management, emphasising the cost-benefit analyses and the cautionary principle.

2 Review and Discussion of Basic Principles of Safety Management

Within safety management different principles are used in order to attain and maintain a safety level that conforms to defined policies, goals and requirements. Two basic principles used in safety management are the cautionary principle and the cost-benefit analyses. A short review of these principles will be given in the following. Finally in this section we give an example to illustrate the principles.

2.1 The Cautionary Principle

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 by safety regulations and requirements. For example in the Norwegian petroleum industry it is a requirement by regulation that living quarters on an installation should be protected by fireproof panels of a certain quality, for walls facing process and drilling areas. This is a standard adopted to obtain a minimum safety level. It is based on established practice of many years of operation of process plants. A fire may occur, it represents a hazard for the personnel, and in the case of such an event, the personnel in the living quarter should be protected. The assigned probability for a fire exposing the living quarter on a specific installation may be judged low, but we know that fires occur from time to time in such plants. It does not matter whether we calculate a fire probability of x or y, as long as we consider the risks to be significant; and this type of risk has been judged to be significant by the authorities. The justification is experience from similar plants and sound judgments. A fire may occur, it is not an unlikely event, and we should then be prepared. We need no references to cost-benefit analysis. The requirement is based on a cautionary thinking.

In the face of uncertainties related to the possible occurrences of hazardous situations and accidents, we are cautious and adopt principles of safety management, such as

- robust design solutions, 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, for example a fire,
- improvement of the performance of barriers by using principles such as redundancy and diversification,
• quality control/quality assurance,
• the precautionary principle, i.e. implement measures to reduce the possible damages of an activity, or not carry out the activity, in the case of lack of scientific certainty on the possible consequences of the activity,
• the ALARP-principle.

The level of caution adopted will of course have to be balanced against other concerns such as costs. However, all industries would introduce some minimum requirements to protect people and the environment, and these requirements can be considered justified by the reference to the cautionary principle.

In this paper we draw special attention to the ALARP principle. This principle means that the risk should be reduced to a level which is as low as reasonably practicable. The ALARP principle implies what could be referred to as the principle of 'reversed onus of proof'. This implies that the base case is that all identified risk reduction measures should be implemented, unless it can be demonstrated that there is gross disproportion between costs and benefits. To verify ALARP, procedures mainly based on engineering judgments and codes are used, but also traditional cost-benefit analyses and cost effectiveness analyses. When using such analyses, guidance values are often used, to specify what values that define 'gross disproportion'. See the following section.

Risk analyses, cost-benefit analyses and similar types of analyses are tools providing insights about risks and the trade-offs involved. But they are just tools - with strong limitations. Their results are conditioned on a number of assumptions and suppositions. The analyses are not expressing objective results. Being cautious also means to reflect this fact. We should not put more emphasis on the predictions and assessments of the analyses than what can be justified by the methods being used, ref. the discussion in [18].

2.2 Cost-Benefit and Cost-Effectiveness Analysis

A traditional cost-benefit analysis is an approach to measure benefits and costs of a project. The common scale used to measure benefits and costs is the country’s currency. The main principle in transformation of goods into monetary values is to find out what the maximum amount the society is willing to pay for the project. Market goods are easy to transform to monetary values since the prices on the market goods reflect the willingness to pay. The willingness to pay for non-market goods is on the other hand more difficult to determine, and different methods such as contingent valuation and hedonic price techniques are used. We refer to [19].

After transformation of all attributes to monetary values, the total performance is summarised by computing the expected net present value, the E[NPV], ref. e.g. [10]. To measure the NPV of a project, the relevant project cash flows (the movement of money into and out of your business) are specified, and the time value of money is taken into account by discounting future cash flows by the appropriate rate of return. The formula used to calculate NPV is:

\[
NPV = \sum_{t=0}^{T} \frac{X_t}{(1+r)^t},
\]
where $X_t$ is equal to the cash flow at year $t$, $T$ is the time period considered (in years) and $r$ is the required rate of return, or the discount rate, at year $t$. The terms capital cost and alternative cost are also used for $r$. As these terms express, $r$ represents the investor’s cost related to not employing the capital in alternative investments. When considering projects where the cash flows are known in advance, the rate of return associated with other risk-free investments, like bank deposits, makes the basis for the discount rate to be used in the NPV calculations. When the cash flows are uncertain, which is usually the case, the cash flows are normally represented by their expected values $E[X_t]$ and the rate of return is increased on the basis of the Capital Asset Pricing Model (CAPM) in order to outweigh the possibilities for unfavourable outcomes. Not all types of uncertainties are considered relevant when determining the magnitude of the risk-adjusted discount rate, as shown by the portfolio theory, see e.g. [20], [10] and [14]. This theory justifies the ignorance of unsystematic risk and states that the only relevant risk is the systematic risk associated with a project. The systematic risk relates to general market movements, for example caused by political events, and the unsystematic risk relates to specific project uncertainties, for example accident risks.

The cost-benefit analysis is based on a risk neutral behaviour. However, several methods have been developed to reflect risk aversion in the analysis. A review is found in [15]. See also [16] and [17]. We will return to such adjustments of the traditional cost-benefit analyses in Section 3.

We distinguish between a cost-benefit analysis and a cost-effectiveness analysis. The latter analysis is an analysis where indices of the form expected cost per expected saved lives (statistical life) are calculated. The analysis method does not explicitly put a value to the benefit, say a statistical life, as is required in the cost-benefit analysis.

A typical number for a value of statistical life used in cost-benefit analysis is 1-2 million £, ref. [7] and [21]. This number applies to the transport sector. For other areas the numbers are much higher, for example in the offshore UK industry it is common to use 6 million £. This increased number accounts of the potential for multiple fatalities and uncertainty [7].

### 2.3 An Example

We consider the following example [18] in order to compare the cost-benefit analysis and the cautionary principle. A riser platform is installed bridge connected to a gas production platform. On the riser platform, there are two incoming gas pipelines and one outgoing gas pipeline. The decision problem is whether or not to install a subsea isolation valve (SSIV) on the export pipeline. The SSIV will in the case of an accident reduce the duration of the fire, and hence the damages to equipment and exposure of personnel.

Assume that economic project evaluations are performed for the two decision alternatives, in line with a cost-benefit analysis. The main result of the analyses is the $E[\text{NPV}]$ with or without an SSIV installed on the export pipeline. For the base case, the results show that the SSIV can be justified according to the $E[\text{NPV}]$ calculations if a statistical life has a value in the order of 300 million £. Hence the conclusion is clear, the cost is in gross disproportion to the benefit.

But let us examine the results more closely. It should be noted that if the frequency of ignited failure is 10 times higher, $10^{-3}$ per year, the conclusion is reversed, the SSIV should be installed. The valve actually implies an expected cost saving. The expected
reduced damage costs (related to production and the installation) as a result of lower
accident frequency is higher than the expected investment and operational costs.

We see that the expected net present value of the reduced costs is strongly dependent
on the analyst’s assignment of the annual frequency for pipeline or riser failures. The
values produced in the risk analysis need to be seen in view of the assumptions made in
the analysis, the limitations of the analyses etc. We should be careful in making
conclusions just based on the calculated numbers. Sensitivity analyses should always be a
part of the decision basis provided.

The increase in the frequency from \(10^{-4}\) to \(10^{-3}\) is large, but realistic changes in some
assumptions and suppositions could imply that the frequency become closer to \(10^{-3}\) than
\(10^{-4}\) and the conclusion is not obvious. Also changes in other quantities may reduce the
cost of a saved life.

Hence the cost-benefit analysis does not provide a clear answer. The analysis has a
message that says that in expectation it is grossly disproportionate to invest in an SSIV,
but rather small changes are required in assumptions to weaken this conclusion. The issue
is to what extent the cautionary principle should be weighted. There is a probability that a
pipeline or riser failure occurs. This probability is considered small, but we cannot
disregard it. If an ignited leak occurs, the duration of the fire will be limited, due to the
valve cutting off the gas supply, and this will give large benefits measured in the expected
number of fatalities and the expected economic loss.

From the portfolio theory, and a corporate risk point of view, it is still a reasonable
approach to use statistical expected values as a tool for evaluating the performance of this
project. But it cannot be justified to perform a mechanical decision-making based on the
expected value calculations. We need to take into account the above factors. We may
dislike the possible occurrence of an extreme outcome so much that we are willing to pay
the investment cost and cost for inspection and maintenance of the SSIV to avoid these
outcomes – we give weight to the cautionary principle.

To give weight to the cautionary principle, the common procedure is to use a higher
value of a statistical life, as in the UK offshore industry where this value is increased by a
factor of 6. Our concern is that this procedure is not sound, as the uncertainty is not
adequately reflected in the verification method. This will be discussed in the coming
section.

3 Discussion and Conclusion

How can the gross disproportion criterion be verified? Can it be justified to use a
traditional cost-benefit analysis for this purpose, as is a common procedure today?

Our conclusion is a clear no. Cost-benefit analyses calculating expected net present
values to large extent ignore the unsystematic risks (uncertainties) and the use of this
principle to weight the unsystematic risk can therefore be questioned. Is it then possible to
modify the traditional cost-benefit analysis to cope for this problem?

Well, several methods have been suggested as mentioned in Section 2.2. In these
methods, adjustments are made on either the discount rate or the contribution from the
cash flows. This latter case could be based on the use of certainty equivalents for the
uncertain cash flows. Although arguments are provided to support these methods, their
rationale can be questioned. There is a significant element of arbitrariness associated with
the methods, in particular when seen in relation to the standard given by the expected
utility theory.
To explain this in more detail, say that the net present value relates to two years only, and the cash flows are $X_0$ and $X_1$. Then an approach based on certainty equivalents means an expected utility approach for the cash flows seen in isolation. The uncertain cash flows are replaced by their certainty equivalents $c_0$ and $c_1$, respectively, which means that the uncertain cash flow $X_i$ is compared to having the money $c_i$ with certainty, $i = 0, 1$. The specification of such certainty equivalents is not straightforward, ref. the comments on the expected utility theory in the introduction section. However, the important point here is not this specification problem, but the fact that this procedure is not necessarily reflecting the decision maker’s preferences. If we ignore the discounting for a second, the utility function of the cash flows $X_0$ and $X_1$ are not in general given by the sum of the individual utility functions. By introducing certainty equivalents on a yearly basis, we take uncertainties into account, but the way we do it has not been justified.

The alternative approach by adjusting the discount rate seems plausible as the systematic risk is incorporated in the net present value calculations by such a procedure. But how large should the adjustment be? There is a rationale for the systematic risk adjustment - the CAPM model – but such a rationale does not exist for the unsystematic risk. It will in fact be impossible to find such a rational as the calculations are based on expected cash flows, which ignores the uncertainties. Hence we have to conclude that such an adjustment cannot be justified.

The common procedure for verifying the grossly disproportionate criterion using cost-benefit analysis therefore fails, even if we try to adjust the traditional approach. We should be careful in using an approach which to large extent is based on a conflicting perspective.

So what would we then suggest in place? In theory our answer would be the expected utility theory, but as emphasised in the introduction, this theory is impossible to carry out in practice in most cases of a certain complexity.

In our view we have to acknowledge that there exist no simple and mechanistic method or procedure for balancing different concerns. When it comes to the use of analyses and theories we have to adopt a pragmatic perspective. We have to acknowledge the limitations of the tools, and use them in a broader process where the results of the analyses are seen as just one part of the information supporting the decision making. And the results need to be subject to an extensive degree of sensitivity analyses.

This kind of approach recognises the need for simplifications of the analyses and theories. Unfortunately, the interpretation of the results could be difficult, as the scope and validity of the methods and theories then become less clear. Nonetheless, we are in favour of this kind of pragmatic approach to the analyses and theories - it is the best we can do. However, we should not consider the cost-benefit analyses and/or the expected utility theory as the main reference point of the decision making process. The starting point and key reference is the risks involved, i.e. the possible consequences and associated uncertainties, linked to the various alternatives considered. There exists no method and theory that can prescribe an objective best way of handling these risks. We need to be cautionary, as the same time as we may encourage risk-taking activities. We may for example like to increase offshore petroleum activities in the Barents Sea, as the same time as we would like to be cautionary. Certainly a balance has to be made. We believe the following principles should be adopted for the safety management:

1. Use some minimum safety requirements to protect human beings and the environment, ref. the fireproof example in Section 2.1.
2. Assess the risk, i.e. the possible consequences, and the associated uncertainties. An important element here is to what extent we are able to manage the risks, the level
of manageability. Professional risk assessments are performed, describing and evaluating the risks.

3. Balance the different concerns (safety, costs, etc.); implement risk-reducing processes. Cost-benefit analyses may be used to support decision making.

4. Adopt managerial review and judgement. The decision support is evaluated in a broader context, taking into account additional concerns and information, as well as the assumptions and limitations of the tools used.

A framework implementing these principles is presented in [22] and [23].

The safety management process may sometimes be rather trivial, but in other situations it could be difficult to choose between different decision alternatives. A comprehensive analysis of risk is then needed. In such situation we should address specific features of both the possible consequences and of the uncertainties, as well as the level of manageable during project execution. Different approaches for such a risk evaluation are presented in the literature; see e.g. [24], [25] and [26]. The assessments of risk provide decision support by structuring and communicating the analysts’ knowledge to the decision maker. As a part of this support we may use cost-benefit analyses or related analyses that explicit reflect the weight the decision maker gives to the various attributes. However, such analyses still provide decision support and not decisions. There is a need for managerial review and judgement.

Hence we cannot conclude what is the right decision in the SSIV example. The cost-benefit analysis provides insights, but as discussed above, the weight we put on uncertainty has to be placed outside the frame of the net present value calculations.

Acknowledgments

The authors are grateful to anonymous reviewers for useful comments and suggestions to improve the original version of the paper.

References


