"Deciding how to spend precious resources on risk reduction measures can be daunting set against a background of financial pressures and Regulator expectations.

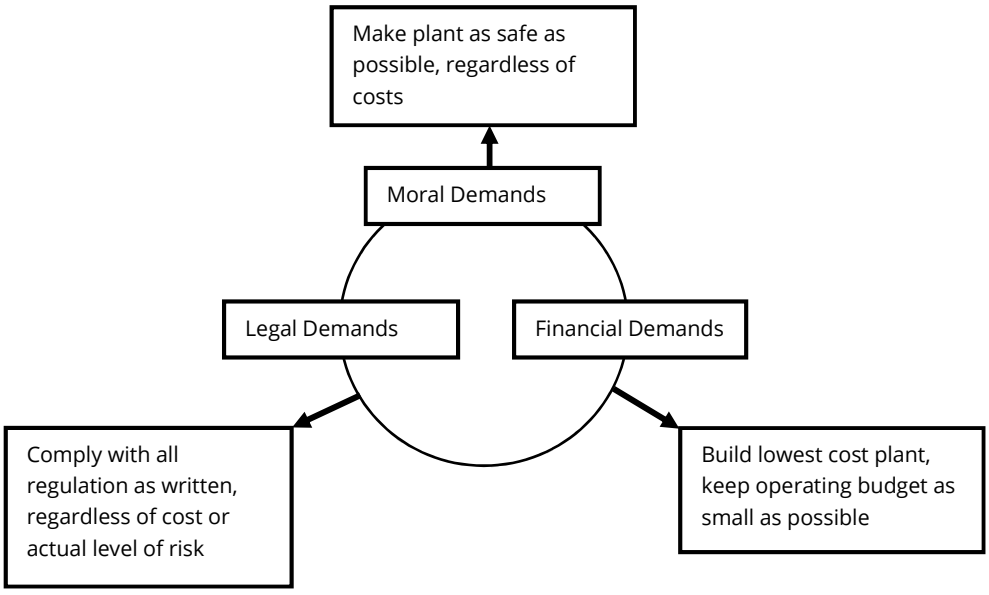
Layer of protection analysis and cost benefit analysis can provide a solution to balancing the cost of risk reduction measures against the many safety, environment and commercial demands made on an organisation."

WHITE PAPER

Introduction

Many organisations experience a range of risks as a result of their operations and need processes and procedures in place to analyse and deal with them effectively. The consequences of the risks can manifest themselves in several ways that can result in safety, environmental and commercial consequences. Each of these risks has financial implications for the organisation concerned.

For those with responsibility for capital expenditure (CAPEX) and operational expenditure (OPEX) budgets, there is an ongoing need to justify expenditure on managing risks to satisfy the often competing moral, legal and financial demands placed on the organisation[1].



This **White Paper** describes a process for negotiating a path through the organisation and Regulator expectations to achieve a set of risk reduction measures that are both justifiable and affordable.

[1] Safety Integrity Level Selection, Systematic Methods including Layer of Protection Analysis, by Ed Marzal and Eric Scharpf.

Market Drivers

The activities of an organisation operating in the industrial technology market often give rise to safety, environmental and commercial risks, all of which, equate to a financial impact on the organisation to some degree. Where there are safety risks, the Regulator (the Health and Safety Executive - HSE, in the United Kingdom) imposes tolerable risk criteria for workers and members of the public[2]. This effectively limits these population groups to a level of risk, deemed morally and legally acceptable.

The above means some form of risk assessment is required to evaluate the magnitude of the risk, how often it occurs and what risk reduction measures are required to reduce the risk to an acceptable level, bearing in mind there is no such thing as zero risk.

Questions often arise, about how to carry out the risk assessment and how to select appropriate risk reduction measures. This is particularly relevant in today's intensely competitive climate, where organisations are under constant pressure to spend scarce resources wisely.

Of course, the cheapest option is to do nothing but it is unlikely that any responsible organisation would condone this approach. Furthermore, operating with known risks and failing to adequately protect against them leaves an organisation open to accusations of negligence and potential financial consequences of unknown proportions.

Indiscriminate application of risk reduction measures may involve high cost and become ineffective in the long term. In addition, simply adding more risk reduction measures in the belief that this will solve the problem is unlikely to have a satisfactory outcome and may also give rise to additional new hazards.

This situation therefore presents a number of challenges to an organisation;

- What type of risk analysis to use?
- What is an acceptable (tolerable) risk criteria to compare against?
- How to select risk reduction measures which offer the most benefit for the least cost.
- How to justify the cost to senior management and satisfy the expectations of the Regulator.

Qualitative risk analysis is easy to apply but the results can be subjective and the outcome is not in a format suitable for further quantitative steps in the process. At the other extreme, quantitative analysis is accurate but is expensive to implement and sometimes is not justified because of the cost. An alternative course of action is to use a semi-quantitative approach which incorporates the best features of qualitative and quantitative analysis and is one which produces results in the required format. An effective tool for carrying out this task is layer of protection analysis (LOPA).

For risk reduction measures (protection layers), the priority is to ensure the available options are technically capable of providing the necessary risk reduction. Following this, some form of decision process is required to identify the solution that provides the most benefit for the least cost. The solution to this problem is to use cost-benefit analysis (CBA).

[2] Reducing Risks Protecting People, UK Health & Safety Executive.

The application of LOPA followed by CBA is a credible approach that provides the following key benefits.

- Accident scenarios defined in a form which is comparable with an organisations tolerable risk criteria.
- A set of 'Rules' available to consistently test the suitability of protection layers.
- A transparent and auditable process that is flexible enough to accommodate new or more up to-date information.
- Provides financial justification for expenditure on risk reduction measures to senior management.
- Suitable for demonstrating to the Regulator that health and safety risks are as low as reasonably practicable (ALARP).

How it Works

Layer of Protection Analysis

Layer of protection analysis, or LOPA is a simplified semi-quantitative risk analysis methodology developed during the 1990's. It has its origins in the chemical process industries, although its principles find application in many other sectors.

Any organisation that has activities that can give rise to accident scenarios and undesired consequences can use LOPA to judge the effectiveness of risk reduction measures that it has in place or proposes to install.

LOPA begins with a description of the accident scenario that can cause the undesired consequences, if unprotected, and an estimate of how often the cause is likely to occur. The existing or proposed protection layers are then analysed for their effectiveness through application of the LOPA 'Rules'.

The LOPA 'Rules' are a predetermined set of criteria compiled before the analysis takes place. The main purpose of the rules is to ensure the analysis of each accident scenario is consistent and in accordance with the organisations tolerable risk criteria.

The protection layers have to be able to act independently to prevent the undesired consequences so the 'Rules' include the following tests to ensure they comply.

- **Effective:** the protection layer must be effective in preventing the undesired consequence when it functions as designed (quantified by a probability of failure to act).
- **Independent:** the protection layer must be independent of the initiating cause and any part of other independent protection layers already taken account of in the same accident scenario.
- **Auditable:** the effectiveness of the protection layer, in terms of consequence prevention and probability of failure to act, must be capable of validation in some manner (e.g. by documentation, review, testing etc.).

Having several different protection layers is desirable rather than relying on one in case of failure. In industry, having multiple protection layers in place is termed 'Defence in Depth'.

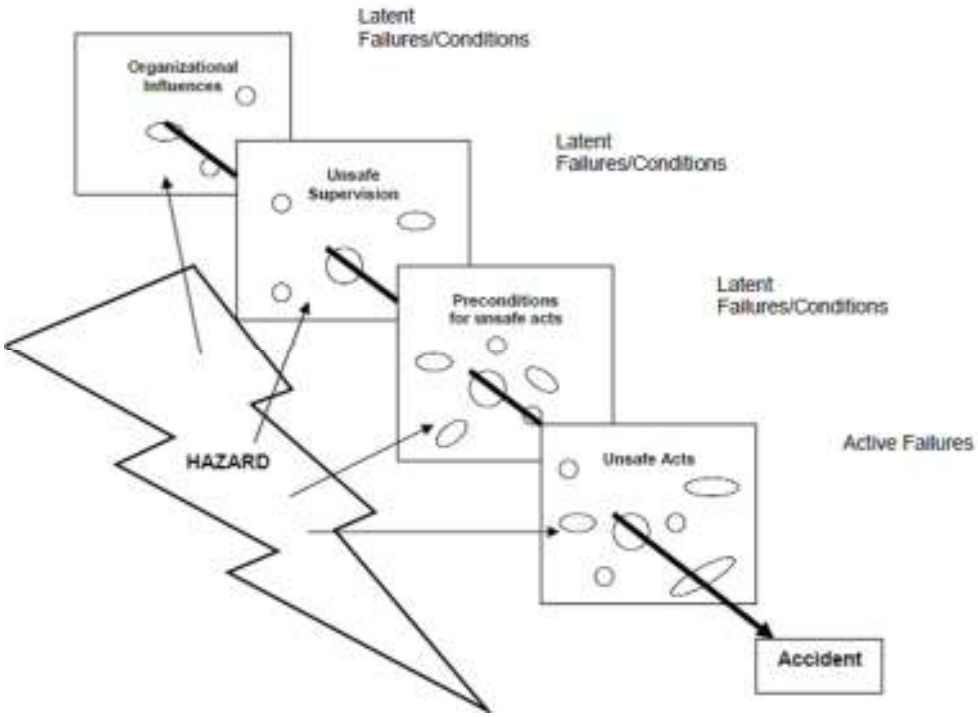
In addition to protection layers, other 'latent or conditional' states can be included in the analysis to reduce the likelihood of the accident scenario. These are conditions that must be in place

before the accident scenario takes place and could for example, include an ignition source being present when a gas pipe ruptures, leading to explosion and fire.

The mathematics of the analysis is relatively straight forward. The likelihood of the initiating cause is expressed in the same terms as the organisations tolerable risk criteria, e.g. in events/year. The performance of the protection layers and the latent / conditional states are however, expressed as probabilities. The relationship between these parameters is as follows, the outcome being a reduced accident scenario likelihood, in events/year.

Accident scenario likelihood (Events/year)	X	Latent / conditional states (Probabilities)	X	Active protection layers failure to act (Probabilities)	=	Reduced accident scenario likelihood (Events/year)

The 'Swiss Cheese' model[3] below illustrates the relationship, which requires all the holes in the 'slices of Swiss Cheese' to line-up for the accident scenario to take place, albeit at a reduced likelihood.



The final step in the process is to compare the reduced accident scenario likelihood with the risk tolerance criteria set by the organisation. If the reduced accident scenario likelihood is less than the organisation's tolerable risk criteria, then no further action is required. But, if it is greater than the organisation's tolerable risk criteria, then action is necessary to reduce the risk to an acceptable level. This can be in the form of additional risk reduction measures or by improving the performance of the existing ones.

[3] Adopted from 'Managing the Risks of Organisational Accidents' by J Reason, Cambridge, UK, Ashgate.

Tolerable Risk

Before an organisation can take decisions on what protection layers to put in place, it needs to decide what level of risk it is willing to tolerate.

Countries around the world deal with tolerable risk in difference ways. In the United Kingdom (UK), tolerable risk levels applied to workers (voluntary) and the general public (involuntary) are mandated. The UK Health and Safety Executive have set out these tolerable levels in the public domain. In other countries, such as the United States of America, individual organisations set their own tolerable risk levels.

Regardless of location, organisations have an obligation not to expose workers or members of the public to a level of risk greater than what is morally acceptable. In the UK, the level of tolerable risk to the public is more onerous than that for workers because there is an assumption that an individual 'voluntarily' accepts there is some risk involved at the workplace.

In addition to health and safety risks to workers and the public, organisations must also take account of environment and commercial risk including environmental pollution, clean-up costs, equipment damage, business interruption and the intangible but potentially disastrous consequence of loss of reputation.

The impact of tolerable risk is that organisations find themselves having to balance their moral, legal and financial responsibilities in deciding on their own risk tolerance criteria. Whilst the application of tolerable risk criteria will help an organisation meet its moral and legal obligations, it has no bearing on cost implications of putting protection layers in place. This is an important issue because committing scarce resources on costly risk reduction measures that bring little benefit could jeopardise the financial wellbeing of an organisation.

Justifying Risk Reduction Measures

The cost of implementing risk reduction measures can be significant so it is important that they are targeted, technically feasible and cost effective.

From an organisations point of view, the financial impact of risk reduction measures is of primary concern. Where the Regulator is concerned, the criterion to meet is ensuring that health and safety risks are as low as reasonably practicable (ALARP).

The common denominator in meeting the expectations of the organisation and the Regulator is one of finance. Cost-benefit analysis is a frequently used tool to find the optimum cost effective solution in both cases. For health and safety risks, additional analysis is required to make sure the cost of the risk reduction measures are not disproportionate to the benefit gained.

Cost Benefit Analysis

Cost-benefit analysis is a widely used and accepted tool for comparing a number of financial options before committing funds to projects. Its purpose is to determine the optimal amount of risk reduction that can be justified financially for cases involving personnel safety, environmental contamination, clean-up costs, property damage and business interruption. It is an analysis of the anticipated costs and benefits of a project option considered on the basis of two important factors, i.e. costs and benefits expressed in terms of money and the concept of 'the time value of money', which translates to;

'A pound today is worth more than a pound tomorrow'

The variables that make up a cost-benefit analysis are virtually limitless, and are selected on the basis of which key factors are likely to have an impact on costs and benefits, e.g. inflation, taxation regimes, advances in technology, obsolescence, etc.

There are many financial tools to perform a cost-benefit analysis. Two commonly used methods are net present value (NPV) and benefit cost ratio (BCR).

Net Present Value

The net present value calculation, involves conversion of all future costs and benefits to present values in monetary terms using a discount rate and discount rate period (usually a year). The sum of the present value of costs subtracted from the sum of the present value of benefits gives the net present value of the project option. If the outcome is a positive NPV, the benefits outweigh the costs and the option is a candidate for future implementation. If the NPV is negative, the option is financially unattractive and an alternative should be sought. Where there are a number of options with positive NPV's, these should be prioritised with the highest NPV selected first.

Benefit Cost Ratio

In a similar manner to NPV calculation, benefit cost ratio involves conversion of all future costs and benefits to present values in monetary terms. The sum of the present value of costs divided into the sum of the present value of benefits gives the benefit to cost ratio of the project option. If the benefit to cost ratio is greater than 1, the benefits outweigh the costs and option is a candidate for future implementation. If the benefit to cost ratio is less than 1, the option is financially unattractive and an alternative should be sought. Where there are a number of options with benefit to cost ratios greater than 1, these should be prioritised with the highest benefit to cost ratio selected first.

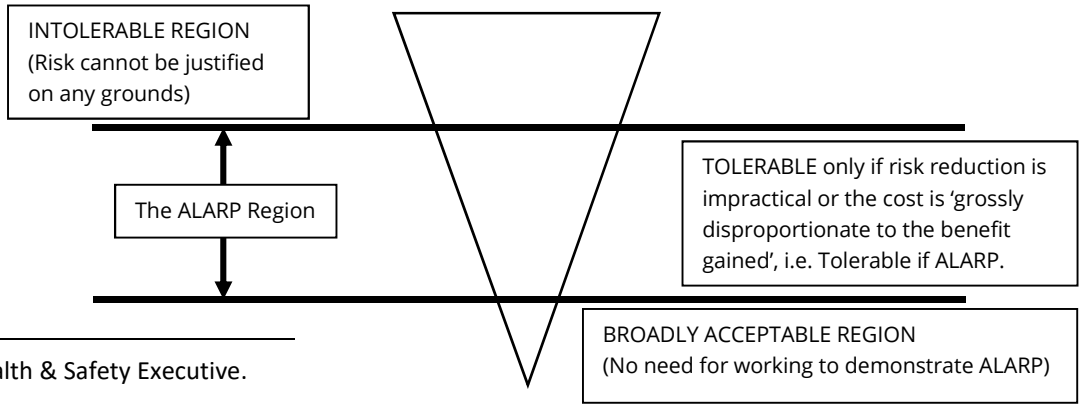
Comparing NPV to BCR

It is advisable that a cost-benefit analysis uses both NPV and BCR to present the results of the analysis, since using only one method may not give the full picture of the available benefits.

In view of this difference, it is good practice to include both analyses, to fully understand the relative benefits and costs in the financial decision process.

Combining Cost-Benefit Analysis and ALARP

The principle of ALARP involves weighing the risk (the benefits of risk reduction) against the sacrifice (time, trouble and money needed to control the risk)[4]. The heart of the concept is what is 'reasonably practicable'. The following diagram illustrates the ALARP principle[6].



[4] UK Health & Safety Executive.

The definition of what is 'reasonably practicable' has its origins in a legal case[5], which in simple terms, used the analogy of weighing scales to compare 'Risk' and 'Sacrifice'. The ALARP principle states that a risk reduction measure must always be adopted unless the sacrifice is grossly disproportionate to the risk.

For low level risks, applying 'Relevant Good Practice' is sometimes enough to qualify as an ALARP demonstration. Where the risk is greater, in addition to 'Relevant Good Practice' a more formal approach is needed using Cost Benefit Analysis (CBA) to assist in making judgements as to whether ALARP has been achieved.

In applying ALARP, the process is not simply one of balancing the costs and benefits of risk reduction measures but, rather one of adopting measures, except where they are discounted because they are grossly disproportionate to the benefit gained[6]. Applying ALARP can be challenging because it relies on judgement to determine whether or not protective measure are cost effective and sufficiently robust to mitigate the hazard. Because of this complexity, a detailed discussion on ALARP is outside the scope of this white paper.

The UK HSE publishes guidance on what to include in a cost-benefit analysis for a health and safety ALARP demonstration to help an organisation to judge which risk reduction measures are reasonably practicable. The term which links these two processes is 'Grossly Disproportionate'.

Simply put, a risk reduction measure is reasonably practicable unless its costs are grossly disproportionate to the benefits gained. This is represented by;

Costs / Benefits > 1 x DF (Where DF is the disproportion factor)

Generally speaking, disproportion factors greater than 1 indicate that the risk reduction measure is not justified for the benefit gained and need not be undertaken. The disproportion factor is dependent on the severity of the scenario consequences and the frequency of occurrence.

In developing an ALARP case, cost-benefit analysis is only part of the demonstration. Other things to consider are adopting 'relevant good practice', applicable industry standards and the general approach of 'what else can reasonably be done'.

It is interesting to note that studies of hazards in the process industries suggest that the financial aspect of risk reduction projects always justify a greater amount of risk reduction compared to risk reduction based on moral or legal considerations[1].

Key Features

- Layer of protection analysis is a simplified, but structured risk analysis method that uses a system of 'Rules' to ensure it is applied consistently.
- It is a credible method for justifying expenditure on risk reduction measures and meeting the expectations of the Regulator.
- It actively compares the frequency of undesirable events to what is tolerable to the organisation and the Regulator.
- The output of layer of protection analysis can be used as the basis of a cost benefit analysis to select optimum risk reduction measures.

[5] The definition set out by the Court of Appeal (in its judgment in Edwards v. National Coal Board, [1949] 1 All ER 743).

[6] UK Health & Safety Executive, ALARP at a Glance.

- The cost benefit analysis part of the process can be used to underpin an ALARP demonstration.
- Adopting layer of protection analysis, followed by cost benefit analysis enables an organisation to apply a consistent methodology to their ongoing activities in risk management.

Next Steps

- To make full use of layer of protection analysis, a guideline document is needed giving instructions on how to apply the technique and a list of typical variables for reference to ensure application consistency.
- An organisation needs to establish its own tolerable risk criteria for safety, environment and commercial risks. In the UK, these are mandated by the Health & Safety Executive for safety risks. For environment and commercial risks, the onus is on the organisation to develop its own tolerable limits based on its attitude to risk, financial acceptability and what is reasonably achievable.
- To implement Cost-Benefit analysis, a set of financial criteria is needed to form the basis of judgements and what factors need to be taken into account.