A tool for intelligent budget allocation of prevention measures related to major accidents

T. Brijs[1] & G. Reniers[1,2]
[1]*Faculty of Applied Economic Sciences, Research Group ARGOSS, University of Antwerp, Antwerp, Belgium*
[2]*Faculty of Economics and Management, Research Group CEDON, HUB-KULeuven, Brussels, Belgium*

Abstract

A tool (called CESMA) was developed to carry out cost-benefit analyses and cost-effectiveness analyses of prevention investments for avoiding major accidents. A wide variety of parameters necessary to calculate both the costs of the considered preventive measures and the benefits related with the avoidance of accidents were identified in the research. The benefits are determined by estimating the difference in (hypothetical) major accident costs without and with the implementation of a preventive measure. We included as many relevant costs and benefits as possible into the tool, based on literature and expert opinion, in order to be able to deliver an all-embracing cost-benefit analysis and cost-effectiveness analysis to assist in the investment decision process. Because major accidents are related to extremely low frequencies, the tool takes the uncertainty of the unwanted occurrence of a major accident into account through the usage of a so-called 'disproportion factor'.

Keywords: cost-benefit analysis, cost-effectiveness analysis, major accidents, disproportion factor, excel tool.

1 Introduction

Companies operating in the process industry face many risks. There are some important reasons as to why prevention investment decision-makers really require more objective and more adequate aids and tools for deciding about

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major accident prevention. The first reason is optimization, as company management often has difficulties with this decision-making process: Paltrinieri *et al.* [1] and Gavious *et al.* [2] indicate that there is a general lack of knowledge concerning the full range of costs related to (major) accidents, as well as difficulties to determine these costs and benefits. Moreover, there is a widespread believe that major accident costs are often inevitable. Secondly, analyses of major accidents show that some could have been prevented if similar historical accidents were analyzed carefully and costs' and benefits' information was used to make prevention decisions for similar situations in similar plants. For example the Buncefield accident was a disaster with huge financial repercussions for the company, and if the company would have considered the scenario of this major accident, and made a thorough cost-benefit analysis, it is rather evident in this case that the averted disaster benefits would outweigh the prevention costs by many orders of magnitude. The decision to invest in certain preventive measures or not, might have been different.

2 Accident typology and existing cost-benefit models

Major accidents are defined in our study as 'accidents that deviate from normal expectations with an extremely low probability of occurrence, and which cause at least several fatalities on site and/or one fatality and many injured off site and/or important environmental damage and/or material damage worth of tens of millions of euros and/or huge international press attention.' This definition makes very clear that major accidents are quite different from (much more frequent) occupational accidents.

Existing cost-benefit models described in literature are focused on occupational accidents instead of major accidents and their scope is rather limited. Some examples are the CEOccAcc model [3], the Safety pays model [4], the Prevention Matrix model [5], the TYTA model [6], and the SZW model [7]. However, in contrast with occupational accidents consequences, the outcome of major accidents is much harder to identify and to quantify, and analyses for major accidents involve much greater levels of uncertainty. Therefore the CESMA tool that we elaborated ('CESMA' is an acronym for 'Cost-Efficient Safety for Major Accidents'), allows the user to execute both cost-benefit analyses and cost-effectiveness analyses specifically for major accidents, in order to evaluate investments in safety measures to prevent, protect or mitigate against such types of accidents.

3 Theory for cost-benefit analysis and cost-effectiveness analysis related to major accident prevention

According to Rushton [8], cost-benefit analyses are used to determine whether an investment represents an efficient use of resources, what is determined by its current and future costs and benefits. In the case of cost-benefit analysis related to safety investments, the costs going hand in hand with both the situation without and with the prevention measure should be investigated (see also Figure 1) to derive the ‘hypothetical benefits’ of the measure.

A cost-benefit analysis is based upon the following process: (i) identification of costs of prevention, and benefits of averted accidents, (ii) calculation of the present values of all costs and benefits, and (iii) comparison of the total costs and total benefits. The calculation of the total costs and the total benefits, composed of costs and benefits occurring at different points in time, includes a discount rate and the frequency of occurrence in order to obtain the present values of the costs and benefits.

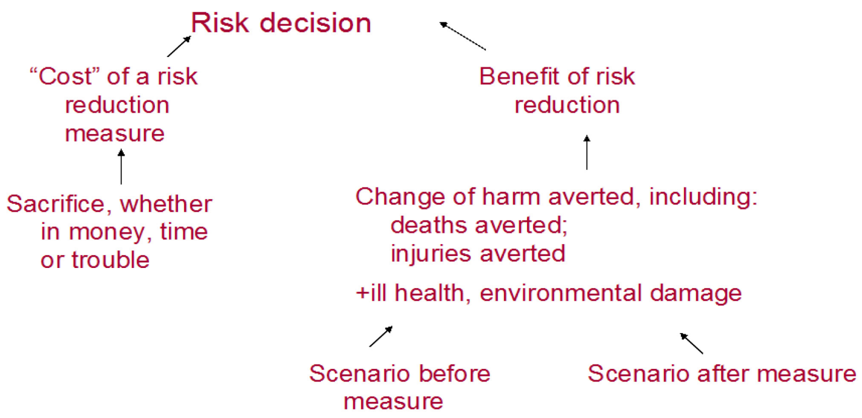

Figure 1: Cost versus benefit for safety investments.

The total present value of all hypothetical consequences during the remaining lifetime of the facility can thus be calculated by taking into account both the likelihood of major accident scenarios and a discount factor, and has to be determined for both the cases with and without the implementation of the prevention measure. An investment project is acceptable when the total net present value (NPV) of all cash flows is positive, and an investment project is usually rejected when the NPV is negative. The NPV of a project expresses the difference between the total discounted present value of the benefits and the total discounted present value of future costs [9].

$$NPV = Present\ Value\ (benefits) - Present\ Value\ (costs).$$
$$If\ NPV \geq 0\ then\ accept$$
$$If\ NPV < 0\ then\ reject$$

As already indicated, major accidents are related to a high level of uncertainty due to the extremely low frequencies of such undesired events. To take this into account, the cost-benefit analysis that we developed involves a disproportion factor in order to reflect an intended bias in favor of hypothetical benefits (above prevention costs) [8, 10]. Usually cost-benefit analyses state that the investment is not encouraged if the prevention costs are higher than the hypothetical benefits. If however a disproportion factor is included, an investment in safety is reasonably practicable (and can be considered to be carried out) unless its investment costs are grossly disproportionate to the hypothetical benefits.

Some suggested values for the disproportion factor are given in literature, and usually vary between 5 and 10. It should be noted however that the principle of 'the higher the risk, the higher the disproportion factor' holds. In certain cases where the risk is very high, literature mentions that it might be acceptable to use disproportion factors up to 30 [8, 10].

Although we mentioned that if the NPV is positive a company should implement the new safety measure, it is not realistic to assume that companies are able to implement all of the safety measures whose NPV is positive, as they are confronted with budget limitations. According to Reniers and Sörensen [11], the optimal combination of safety measures can be determined by a cost-effectiveness analysis, in which the total benefits of the safety measures needs to be maximized, and the total costs of the safety measures cannot exceed the specified safety budget. In addition, a safety measure is either fully taken or not taken at all. These conditions can be translated into the following mathematical formulae:

$$\begin{aligned} &Max\ B_i\, x_i \\ &s.t. \\ &C_i\, x_i \leq Bu_{tot} \\ &x_i \in \{0,1\} \end{aligned}$$

4 Costs and benefits used in the tool

The five different categories of costs that are used in the CESMA tool (that is, initial costs, installation costs, operating costs, maintenance costs, and inspection costs) are represented by negative cash flows. The initial costs and installation costs occur only in the present and thus do not have to be discounted, whereas the operating-, maintenance- and inspection costs occur throughout the whole remaining lifetime of the facility and thus have to be discounted to the present. All costs that are taken into account in the developed tool are displayed in Table 1.

The present values of the cost categories that have to be discounted can be calculated by using annuities, in which 'C' represents the yearly costs, 'n' the remaining lifetime of the facility, and 'r' the discount rate [8]:

$$C.\left((1+r)^n - 1\right) \big/ \left((1+r)^n .r\right)$$

The eight different categories of hypothetical benefits (that is, supply chain benefits, damage benefits, legal benefits, insurance benefits, human and environmental benefits, intervention benefits, reputation benefits, and other benefits) represent positive cash flows, which all occur throughout the whole

$C.\left((1+r)^n - 1\right) / \left((1+r)^n . r\right)$ remaining lifetime of the facility and thus will all have to be discounted to the present. All benefits that are taken into account in the developed CESMA-tool are displayed in Table 2.

Table 1: Cost categories.

Cost Category	Cost Subcategory
Initial costs	Investigation costs Selection and design costs Material costs Training costs Changing of guidelines and informing costs
Installation costs	Production loss costs Start-up costs Equipment costs Installing costs
Operating costs	Utilities costs
Maintenance costs	Material costs Maintenance team costs Production loss costs Start-up costs
Inspection costs	Inspection team costs

Table 2: Benefit categories.

Benefit Category	Benefit Subcategory
Supply chain benefits	Production loss benefits Start-up benefits Schedule benefits
Damage benefits	Damage to own material/property Damage to other companies' material/property Damage to surrounding living areas Damage to public material property
Legal benefits	Fines benefits Interim lawyers benefits Specialized lawyers benefits Internal research team benefits Experts at hearings benefits Legislation benefits Permit- and license benefits
Insurance benefits	Insurance premium benefits
Human and Environmental benefits	Compensation victims benefits Injured employees benefits Recruit benefits Environmental damage benefits
Intervention benefits	Intervention benefits
Reputation benefits	Share price benefits
Other benefits	Manager work-time benefits Cleaning benefits

There are a number of indirect consequences of major accidents, next to the direct consequences, that should be taken into account to calculate the benefits. For example, the legal and reputation consequences can present very large indirect costs for the company. The legal department will have to hire additional workforce and experts to handle the complexity of such a major accident [12].

In addition, the legal environment in which the company operates will change according to the occurrence of catastrophes, and the company will need to make sure that it complies with these changes [13]. However, by acting proactively if a major accident would occur, expensive lawsuits, negative media attention and reputational damage can be reduced significantly [12]. The reputation consequences due to a major accident can be translated by the share price decrease, as share prices display the investors' image of the current performance and future expectations of the company.

Because the consequences of a major accident only become reality when the major accident occurs, the frequency of occurrence is taken into account in the calculation of the consequences. Therefore the consequences are multiplied by the estimated likelihood (probability or frequency of occurrence) of the major accident. This way, the estimated 'yearly' consequences are obtained, under the assumption that these 'yearly' consequences are constant for the remaining lifetime of the facility.

All benefits are summed up in order to obtain the total benefits, which are then compared to the total costs of the prevention measure, in order to come to a safety investment recommendation.

5 Conclusions

The developed CESMA tool allows the user to execute both a cost-benefit analysis and a cost-effectiveness analysis, in order to evaluate investments in preventive measures to prevent, protect or mitigate against major accidents. The tool is able to carry out such analyses taking into account six different safety measures for one major accident scenario at the same time. In addition, the optimization tool included in the CESMA-tool is able to consider up to fifty different safety measures (saved in a 'history' spreadsheet) for identifying an optimal bundle of preventive measures within a certain budget, for a multitude of major accident scenarios.

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