Methods for the economic valuation of loss of life

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ABSTRACT: In risk management literature the economic valuation of loss of life is often depicted as a difficult question as it raises numerous ethical and moral questions. The actual investments in risk reduction are however always finite, indicating that the implicit value assigned to loss of human life is finite. In this paper, an overview of methods for the valuation of human life is presented. The backgrounds and basic assumptions of the different methods are discussed. Two distinct approaches can be discerned: behavioural and non-behavioural valuation methods. Non-behavioural approaches can be divided into stated and revealed preference methods. The different approaches lead to distinctly different valuations of human life. Loss of life will generally be a marginal cost item in a societal cost-benefit analyses for hazardous industrial activities due to stringent risk regulations that have resulted in a low probability of harm to humans. For such cost-benefit analyses it is therefore proposed to present loss of life separately and to weigh it politically against the net financial balance.

1 INTRODUCTION

As a society without risk is impossible, risk regulation is to maintain the delicate balance between socio-economic development and a safe society. This paper focuses on the use of cost-benefit analysis for the management of large-scale risks associated with industrial hazards in the Netherlands.

In the Netherlands, regulations for land-use planning in the vicinity of major industrial hazards are explicitly risk-based. In risk-based regulation, not only potential adverse physical effects are considered but also the probability of failure. Three main elements constitute the Dutch regulatory framework: (i) quantitative risk assessment, (ii) the adoption of individual and societal risk as risk-determining parameters and (iii) acceptability criteria for individual and societal risk [1]. Besides these criteria, the ALARA-principle is adopted. Also when the risk criteria are met, risks should be reduced to levels that are as low as reasonably achievable. Whether additional investments in risk reduction are reasonable is determined by implicit or explicit societal cost-benefit analysis.

Investments in safety require a trade-off between the costs of risk reduction and the benefits thus obtained. Cost-benefit analysis is a useful tool for comparing the costs and benefits of an activity or action. In cost-benefit analyses, both costs and benefits are expressed in a single unit, commonly currency. This poses some difficulties in risk regulation since the benefits of a risk reducing prospect might not easily be expressed in monetary terms. When potential damages include loss of life, a benchmark value would have to be adopted for the value of human life. For instance, UK's Health and Safety Executive has adopted a benchmark value of preventing a fatality of one million pounds for industrial safety [2]. This value is derived from the Department of Transport, Local Government and the Regions (DLTR). In case death is caused by cancer a value of preventing a fatality of two million pounds is used. Official values of preventing a fatality in road safety range from less than 100.000 euros to about 3.5 million euros [3]. These values can however not simply be extrapolated to industrial safety.

In literature on risk management the valuation of human life is often depicted as a difficult problem as it raises numerous moral questions. Some claim it is unethical to put a price on human life and that life is priceless. The actual expenditures on risk reducing prospects show however that the investment in the reduction of risks to humans is always finite. In this paper the term "valuation of human life" is adopted to signify the implicit or explicit investment in reduction of loss of human life.

This paper presents an overview of the backgrounds, basic assumptions, strengths and criticisms of the various methods for the valuation of loss life. A distinction can be made between behavioural and non-behavioural valuation methods [4]. Behavioural valuation is based on micro-economic theory and assumes utility maximizing individuals. Two behavioural approaches can be discerned: stated preference and revealed preference methods. Non-behavioural valuation is based on an individual's productivity and opportunity cost.

2 INVESTING IN SAFETY

Investments in safety require a trade-off between the costs of risk reduction and benefits thus obtained. Societal cost-benefit analysis (SCBA) is a method for comparing the societal costs and benefits of an economic activity. The Netherlands Bureau of Economic Policy Analysis has concluded that a cost-benefit analysis is a suitable instrument in the field or industrial safety for proper mapping of the effects of alternatives [5]. From an economic perspective, an option is preferable over other when it has the highest expected value of benefits of all options, or:

$$Max\left(B_i - P_{f\,i} \cdot C_i\right) \quad (1)$$

where B_i = benefit produced by option i; P_f = probability of failure of option i; C = cost associated with failure of option i

Using a similar expression, one could state that an activity is beneficial when its net expected value of the financial balance is positive. Cost-benefit analysis can also be used as a method for evaluating the cost-effectiveness of investments in risk reduction. The benefit of these investments consists of the reduction of the expected value of the costs of failure. The economically optimal investment is:

$$Min\left(I(P_f) + P_f \cdot C\right) \quad (2)$$

where $I(P_f)$ = investment in risk reduction; P_f = probability of failure; C = cost associated with failure

Economic optimization has been used to determine the optimal investment in flood protection in the Netherlands [6]. Because the economic value of dike ring areas varies considerably, design standards and hence probabilities of flood vary across dike ring areas [7]. In the economic optimization of the flood defences, only material damages were taken into account and loss of life was not valued in monetary terms [6].

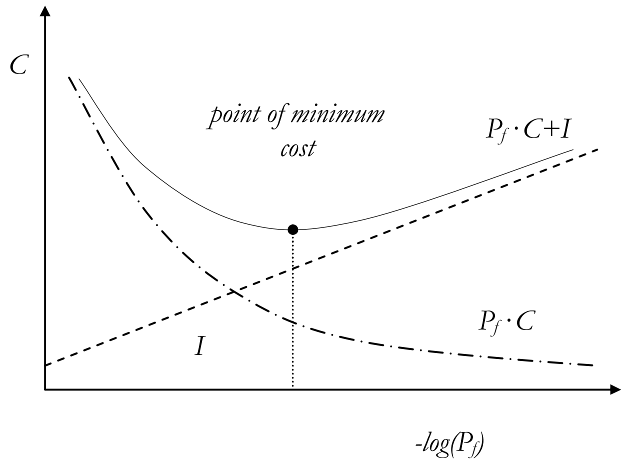

Figure 34 The economically optimal probability of failure (adapted from [8])

Valuation of loss of life might be relevant for the economically optimal investment flood safety. Depending on the probability and extent of material damages given failure and the probability of death given failure, assigning a value to a statistical life in the order of one million euros could result in a lower economically optimal probability of failure.

Industrial activities are initiated to generate economic benefits rather than to control natural hazards. For these technological systems, such as chemical installations, risks to human life are generally a marginal item in the outcome of a societal cost-benefit analysis for the activity as a whole. This is because regulations ensure that the probability of harm is already low [1].

In the Netherlands, industrial risks are evaluated from an individual and a societal perspective. The individual perspective is to ensure that no individual is disproportionally exposed. It is defined as the probability of death of an average, unprotected person that is ever-present at a certain location. Individual risk is limited by law to 10^{-6} per year for new installations [9]. The societal perspective reflects that society as a whole does not appear to accept the too frequent occurrence of large accidents. For this purpose, an FN-criterion has been adopted. An FN-criterion prescribes maximum exceedance frequencies of accidents with N fatalities. The Dutch criterion is $10^{-3}/N^2$ per installation per year (where N is the number of fatalities in an accident).

Risk regulation has thus resulted in very low probabilities of loss of life. Because of the low probability of harm, the cost assigned to loss of life will have to be enormous if the costs of failure are to outweigh the benefits of the hazardous activity as a whole. It thus seems important to make a distinction between economic optimizations of risk control systems and cost-benefit analyses for industrial activities as a whole.

3 BEHAVIOURAL VALUATION: STATED PREFERENCE

The main example of the stated preference approach is contingent valuation. It is a method in which people's willingness to pay for an intangible loss is determined by creating an artificial market and asking respondents to value the availability of that asset. An influential report on contingent valuation was written by the NOAA Panel [10] in which guidelines were presented for performing contingent valuation studies for estimating the passive-use value of environmental resources. The method has also been applied to determine the willingness to pay for risk reduction, e.g. the reduction of flood risk [11].

The societal willingness to pay can be found by aggregating all individual *WTPs* of the respondents and by extrapolating the results to the selected population:

$$SWTP_{CV} = \frac{V}{R}\sum_{j=1}^{R} WTP_j \qquad (3)$$

where WTP_j = willingness to pay of respondent j; R = number of respondents; V = relevant population

Subsequently the value of a statistical life ($VoSL_{CV}$) can be calculated according to:

$$VoSL_{CV} = \frac{V}{R}\sum_{j=1}^{R} \frac{WTP_j \cdot LE}{R \cdot \Delta LE} \qquad (4)$$

where WTP_j = willingness to pay of respondent j; LE = life expectancy; V = relevant population; R = number of respondents; ΔLE = change in life expectancy averaged over the age-distribution of the population

Contingent valuation includes risk perception in the valuation of life as the outcome is based on individual preferences. Risk perception depends on several characteristics of the hazard and risk under consideration [e.g. 12, 13, 14]. The method therefore values loss of life differently across a range of different hazards. One may consider this irrational but it expresses the importance of a fundamental aspect of the human condition: emotion.

Contingent valuation has received considerable criticisms [15]:

1. Contingent valuation surveys don't measure preferences correctly because respondents are not affected by budget constraints. Answers are given to hypothetical questions. Thus strategic and affective ('warm glow') behaviour confuse the results.
2. The results appear to strongly depend on context and phrasing [see also 16]. This is related to the strong cognitive demands that are paced on respondents. That temporal stability as a measure of the reliability of WTP is insufficient [11] supports this notion.
3. Studies have shown that WTP is rather insensitive to the quantity of the asset for which the value is to be determined. A study by Geurts et al. [11] shows that scope validity is ambiguous.
4. The willingness to accept appears to be considerably larger than the willingness to pay [see also 16]. The compensation a respondent would wish to receive for accepting a loss thus differs considerably from his willingness to pay for preservation of the same good.
5. A practical problem with contingent valuation is deciding on the size of the relevant market. Who should belong to the respondents? The willingness to pay for flood protection is likely to depend on the level of exposure of the respondent. However, non-exposed people could value the safety of others. If the number of respondents is enlarged, the aggregate willingness to pay will increase.
6. The non-neutral character of money can make the aggregation of individual preferences dependent on the choice of the numéraire. When the marginal rates of substitution between a public and a private good are not the same for all consumers, the outcome of a cost-benefit analysis is determined by the choice of the unit of aggregation. A change of sign of the sum of net benefits can occur when a different unit is chosen. The non-neutral character of money makes it questionable to aggregate costs and benefits of different involved parties in cost-benefit analyses without weighing [15]. A person that attributes relatively low value to money is systematically favoured when money is chosen as the numéraire in the cost-benefit analysis. The dependency on the choice of numéraire is the result of the fact that it not only normalizes prices but also marginal utilities [17].

4 BEHAVIOURAL VALUATION: REVEALED PREFERENCE

Revealed preference methods are based on the assumption that economic behaviour reflects the values implicitly assigned to intangibles. For instance, compensating wage differentials for more dangerous professions could be assumed to reflect people's willingness to accept (WTA) certain occupational risks.

In the field of industrial safety, property values in the vicinity of industrial hazards could be said to reflect willingness to accept. However, property values are probably mainly influenced by view, noise and other nuisances rather than the remote probability of catastrophic events. For industrial safety, a crude method could be to assume that accident statistics reflect acceptable levels of residual risk.

Then, the investment that has been made for the prevention of potential loss of life can be expressed as the cost of saving an extra statistical life (CSX). Past expenditures on life saving prospects can be used to calculate CSX-values. CSX-values indicate the apparent economic value attached to loss of life. The cost of saving an extra life year (CSXY) can be calculated by introducing the life expectancy. When calculating the value of a statistical rather than an actual life, the *CSXY*-values should be multiplied with the life expectancy at birth:

$$VoSL_{CSX} = CSX = CSXY \cdot LE \qquad (5)$$

where LE = life expectancy at birth

It is important to use net costs as material damages and other intangible losses than loss of life also influence economic behaviour [18]. For example, investments in the prevention of radionuclide-emissions not only reduce the probability of premature deaths but also the probability of injuries and severe pollution. It is now impossible to derive a unique solution for the cost of saving a statistical life.

CSX(Y)-values vary widely not only between but also within risk categories [19]. Sensitivity analysis is unlikely to provide a way out since the variance is in several orders of magnitude.

Other objections to revealed preference methods are targeted at the assumptions underlying the method. First, the assumption that equilibrium has been reached and that this equilibrium is acceptable may be questionable [20]. The expected number of casualties in traffic in the Netherlands is approximately 1000 per year. The efforts of 3VO, a Dutch NGO concerned with safe traffic, indicate however that this level is not yet acceptable. Secondly, revealed preference methods have the questionable assumption that preferences are stable. Public investments in safety are highly influenced by actual calamities. The investments are then made when public concern is unusually high.

5 NON-BEHAVIOURAL VALUATION

When the economic value assigned to loss of life is only based on an individual's potential economic production, this method is referred to as a human-capital approach [21]. For determining a person's productivity, macro-economic indicators could be used. By Vrijling et al. [22] it is proposed to use the net national product per capita as a basis for the valuation of human life. According to that method, named here macro-economic valuation, the societal willingness to pay for a change in life expectancy would be:

$$SWTP_{MEV} = V \cdot d(NNP^*) \approx V \cdot NNP^* \cdot \frac{d(le)}{LE} \qquad (6)$$

where: V = population size; NNP^* = present value of net national product per capita averaged over the age-distribution of the national population; $d(le)$ = change in life expectancy averaged over the age-distribution of the national population; LE = life expectancy averaged over the age-distribution of the national population

The value of a statistical life depends on the age-distribution of the national population. As an approximation a uniform age-distribution is assumed. In the Netherlands, assuming a net national product per capita of 23.000 euros, a life expectancy of 78 years and a discount rate of 4% a value of a statistical life of about 400.000 euros is found. Due to the typical skewness of the age-distribution, this value is a lower limit. The upper limit of the value of a statistical life according to macro-economic valuation can be found by assuming the life expectancy at birth for the entire population. This upper limit is about 550.000 euros. The VoSL-estimate based on macro-economic valuation will thus be in the order of 0.5 million euros.

The introduction of economic growth would result in a higher value of a statistical life. Ramsberg [21] points out that a person's contribution to the national economy should be calculated by discounting the production minus consumption over the years the person had lived if he hadn't died. Then, even lower values than 0.5 million euros are obtained.

It might be considered unethical that the value assigned to human life by non-behavioural valuation depends on a nation's wealth. The purchasing power in wealthier and poorer countries varies considerably however. Moreover, it can be considered an advantage that the value of a statistical life depends on the net national product as it ensures that risk reduction measures are affordable in the context of the national economy [22]. Another advantage of macro-economic valuation is that macro-economic indicators are relatively stable. Stability over time of VoSL-estimates is a desirable property for cost-benefit analyses as investment projects generally have a life-span of many years. If the value would change considerably over time, the economic optimization would have to be repeated regularly.

A disadvantage of macro-economic valuation is that people are only seen as factors of production: life quality is not valued. A non-behavioural method for the economic valuation of loss of life that explicitly takes life quality into account is provided by the life quality index (LQI). The LQI is a social indicator of life quality [23]. It provides a rationale for the amount of money that can be considered reasonable for a certain amount of risk reduction. The results will be shown to be very similar to those of the previously described macro-economic valuation method. The LQI is equivalent to a utility function and has the following form [24, 25]:

$$LQI = G^q \cdot E \quad \text{where} \quad q = \frac{w}{1-w} \tag{7}$$

where: G = real gross domestic product per capita; q = ratio of average work to leisure time available; w = fraction of time spent working; E = discounted life expectancy averaged over the age-distribution of the national population

The basic thoughts underlying the LQI-methodology are that only leisure time and consumption provide utility and that available time and wealth are exchangeable [23]. Investments in risk reduction will have a negative impact on the gross domestic product but a positive impact on the life expectancy. A trade-off has to be made between consumption and life expectancy. The consumption rate is assumed constant and equivalent to the gross domestic product per year. The exponent q is the elasticity of marginal utility with respect to consumption. It is equivalent to the ratio of average work to leisure time available and assumed constant for all levels of consumption.

As the assumption is made that production equals consumption, the trade-off is essentially between the increase in life expectancy and the increase in work time required to pay for risk reduction. Years worked is thus a substitute for death, an extremely negative value judgment. A non-zero utility for years worked would imply that people are willing to work longer and thus pay more for the same risk reduction measure.

The yearly societal willingness to pay for an increase in life expectancy of a person can be shown to be equal to [25]:

$$SWTP_{LQI} = \frac{V \cdot G}{q} \cdot \frac{d(e)}{E} \tag{8}$$

where: V = population size; G = gross domestic product per capita; q = ratio of average work to leisure time available; *d(e)* = change in discounted life expectancy averaged over the age-distribution of the national population; E = discounted life expectancy averaged over the age-distribution of the national population

In macro-economic valuation, the net national product was used instead of the gross domestic product. The gross domestic product is the total value of all goods and services produced domestically in a year. The net national product is equal to the gross national product after adjusting for the depreciation of capital. A national product also includes production by factors of production outside a state's borders whereas a domestic product confines itself to production within a state's borders. When the difference between net national and gross domestic product is disregarded a more insightful comparison of the macro-economic/human capital and life quality index valuation methods can be made. To do so the GDP is adopted as the measure of productivity in macro-economic valuation.

According to macro economic valuation, the societal willingness to pay for an increase of life expectancy would now be:

$$SWTP_{MEV} = V \cdot G^* \cdot d(le) \tag{9}$$

where: G^* = net present value of the total gross domestic product per capita in remaining life span averaged over the age-distribution of the national population

The societal willingness to pay according to macro-economic valuation appears to be somewhat similar to the yearly societal willingness to pay according to the LQI. Besides the fact that the LQI gives a societal willingness to pay per year, the results differ in two respects. First, in the LQI-method a factor ($q \cdot E$) is present that resembles the amount of discounted life years the person is expected to spend working. Secondly, in macro-economic valuation, discounting is applied to the gross national product, whereas discounting is applied to the life expectancy in the life quality methodology. It should be noted however that the discount operator in the LQI originally belonged to the utility of consumption and was applied to life expectancy for reasons of mathematical simplicity.

These two differences will now be evaluated. Consider a society of only one person that is 40 years old. Assume that this person has a life expectancy of 80 years. The maximum amount of money that would be spent on a risk reducing prospect that would result in an extension of this person's life expectancy with one year according to macro-economic valuation is:

$$SWTP_{MEV} = \frac{G}{(1+r)^{(81-40)}} = \frac{G}{(1+r)^{41}} \tag{10}$$

where: G = gross domestic product per capita per year; r = discount rate

According to the LQI-methodology, the societal willingness to pay can also be calculated. An important difference however is that this is a societal willingness to pay *per year*:

$$SWTP_{LQI} = \frac{1}{q \cdot E_i} \frac{G}{(1+r)^{41}} \quad (11)$$

where: G = gross domestic product per capita per year; r = discount rate; E_i = discounted life expectancy of the person under consideration

We could repeat this exercise for every person and derive the societal willingness to pay averaged over the age-distribution of the national population. For illustrating the differences between both methodologies this is however unimportant.

Whether discounting is applied to the change in life expectancy or productivity appears to be insignificant as was to be expected. The net present value of utility decreases similarly over time in both approaches because the discount rate is the same since 'we must discount future risk at the same rate as money' [23: 80]. The utility in terms of productivity (G) changes one unit per year, as does the utility in terms of life years. Besides the fact that the LQI-method gives yearly SWTP-values, the only difference between the macro-economic/human capital method and LQI-method appears to be the factor ($q \cdot E$) which resembles the amount of discounted life years the person is expected to spend working.

In developed countries, assuming a gross domestic product per person of about 28.575 euros, the value of a statistical life according to the LQI would be about 1-4 million euros depending on the discount rate (see [24: 72]). The fact that the LQI leads to higher VoSL-estimates than macro-economic valuation is due to the fact that in the LQI-method zero utility is attributed to life time spent working. Thus, more life years have to be saved to obtain a similar increase in utility.

6 COMPARISON OF VOSL-ESTIMATES

Comparing different VoSL-estimates that were obtained by either revealed or stated preference methods can be difficult. The initial risk level is important as the marginal willingness to pay is generally assumed to decrease with lower risk levels [4]. Only when the demand curve is horizontal is willingness to pay independent of the initial risk level and only then is a proper comparison of WTPs possible. At low risk levels, this may be the case [4]. The hazard type and context are important as risk perception influences the willingness to pay for risk reduction. Only VoSL-estimates based on non-behavioural methods are independent of initial risk level, hazard type and context . Non-behavioural valuations can thus more easily be generalized and compared.

Non-behavioural valuations are in the order of 1-4 million euros. As shown, macro-economic valuation yields a VoSL of about 0.5 million euros in developed countries. The life quality index methodology will result in values of 1-4 million euros. Behavioural valuation methods can produce much higher VoSL-estimates. Consider for example a CSXY-value of $1.2.10^6$ 1993-US dollars for a ban on chlorobenzilate pesticide on citrus [19: 377] indicating a VoSL of about 91 million 1993-US dollars. However, the VoSL-estimates obtained by these methods vary over several orders of magnitude, even within hazard categories, providing a poor basis for a robust cost-benefit analysis. Using a standard VoSL for industrial safety based on behavioural valuation seems problematic because of the contextual factors that determine people's willingness to pay for risk reduction measures.

Behavioural methods produce VoSL-estimates that are influenced by risk perception, unlike non-behavioural valuation methods. Considerations about the acceptability of risks from an individual, societal and economic perspective are all reflected in the same VoSL-estimate. In industrial safety regulation, risk criteria are in use that consider industrial risks from an individual and societal perspective. When separate individual and societal risk criteria have already been put in place, one could consider it inappropriate to adopt this methodology to obtain VoSL-estimates: perspectives would blur and the added value of adopting a separate economic perspective would be low. An overview of the values of a statistical life according to the different valuation methodologies is presented in Table 1 for developed, industrialised countries.

Valuation methodology		*order of magnitude of VoSL (euros)*
behavioural valuation	*stated preference*	*no estimate*
	revealed preference	*$0\text{-}10^{10}$*
non-behavioural valuation	*macro-economic valuation*	*$0{,}5.10^6$*
	life quality index	*$1\text{-}4.10^6$*

Table 1 Valuations of loss of life in industrial safety

7 ECONOMIC OPTIMIZATION OR SOCIETAL COST BENEFIT ANALYSIS

Whether explicitly valuing loss of life will influence decision making depends strongly on the type of problem that is evaluated. In a societal cost benefit analysis for hazardous activities as a whole, valuing loss of life is unlikely to influence the net financial balance because the probability of harm to humans is generally low. In economic optimizations of risk control measures, valuing loss of life could however influence the optimal investments in safety.

Consider a chemical installation in the vicinity of a residential area. Assume that the expected value of the number of statistical lives lost due to accidents at the chemical plant is 10^{-3} per year. Considering the individual and societal risk criteria in the Netherlands, this is quite a high value. If the installation generates 1 million euros per year, the cost associated with one death would have to be in excess of 1 billion euros if the expected value of benefits is to become negative and the activity banned on economic grounds. Material losses and other intangible losses are likely to be correlated with loss of life. Still, a value in excess of 1 billion euros for all damages associated with the loss of 1 person indicates an extremely high value of a statistical life. The safety standards in the process industry as well as risk criteria have resulted in such low probabilities of harm to humans that loss of life has become a marginal cost item in the net financial balance for industrial activities as a whole.

Now consider the investment in a risk reduction measure. If an accident were to result in the loss of one statistical life and 1 million euros in damages, valuing loss of life at 1 million euros would strongly influence the optimal investment in risk reduction as potential damages are then doubled. Without valuing loss of life, a measure that could reduce the probability of an accident from 10^{-3} to 10^{-6} per year should cost less than 999 euros. When loss of life is valued in monetary terms, that measure should cost less than 1998 euros.

8 DISCUSSION AND CONCLUSIONS

Two distinct types of valuation methodologies have been discussed: behavioural and non-behavioural approaches. The valuation methodology has considerable influence on the value assigned to loss of life. None of the valuation methods is without ethical or methodological problems.

Only behavioural approaches provide measures of social preference. Applying these approaches for making investment decisions in the context of industrial safety regulation is however troublesome. Stated preference methods are time consuming and have some methodological difficulties. Revealed preference methods for industrial safety value loss of life based on past investments in risk reduction. However, statistics of the past provide little guidance for making new investment decisions since the values of saving a statistical life vary widely within and between hazard categories.

Non-behavioural valuation methods do not elicit social preferences; rather they assign an economic value to loss of life based on productivity. Because these valuations are based on rather stable macroeconomic indicators they lead to stable reference values for loss of life. In developed countries, macroeconomic valuation yields a value of a statistical life of about 0.5 million euros and the life quality index a value of about 1-4 million euros.

With these valuations, valuing loss of life in monetary terms will generally not be important in a CBA that is about a comparison of the costs and benefits of an entire activity (e.g. a CBA for a chemical plant in a populated area) because the probability of death is already very limited due to stringent risk regulations. However, for optimizations of investments in risk reduction (e.g. optimization of dike height) valuing loss of life can sometimes be important for the outcome.

It is suggested not to value loss of life in monetary terms in CBAs for industrial activities as a whole, because loss of life will otherwise be a marginal item in the decision-making process. For such CBAs, it is proposed to list potential loss of life separately as a PM-item together with all other intangible losses. These intangible losses then have to be weighed politically against the net financial balance. This method is in line with the recommendations of the guide for societal-cost benefit analysis on infrastructural projects that was developed for the Dutch government [26].

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