The Introduction of the Weighted Risk Analysis

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Abstract: When a risk analysis is performed, it is important to realise that decision making about risks is very complex, and not only technical aspects but also economical, environmental, comfort related, political, psychological and societal acceptance are aspects that play an important role. In order to balance safety measures with aspects, such as environmental, quality, and economical aspects, a *weighted risk analysis* methodology is proposed in this paper. This paper also provides a theoretical background regarding the scope of safety assessment in relation to the decision-making in complex urban development projects adjacent to or above transport routes of hazardous materials. In Western Europe, such projects are realised due to shortage of space. The weighted risk analysis is an interesting tool comparing different risks, such as investments, economical losses and the loss of human lives, in one dimension (e.g. money), both investments and risks could be expressed solely in money. Finally, the weighted risk analysis approach is applied in a case study of Bos en Lommer, Amsterdam.

Keywords: Decision-making, risk analysis, safety measures,.

1. INTRODUCTION

The risk assessment of a system consists of the use of all available information to estimate the risk to individuals or populations, property or the environment, from identified hazards, the comparison with targets, and the search for optimal solutions [1]. When a risk analysis is performed, it is important to realise that decision making about risks is very complex and that not only technical and mathematical aspects, but also political, psychological, societal, moral and emotional processes play an important role [2,3,4].

2. THE WEIGHTED RISK ANALYSIS

2.1 The introduction of the weighted risk analysis

In some cases, especially scenarios with great consequences, *weighing factors* for all risk dimensions are used in order to make them comparable to each other and to relate them to the measures that must be taken for possible risk reduction [4,5,6]. It is, therefore, recommendable to compare and to integrate different decision making elements, such as political, social, psychological, environmental, and quality risks or benefits, in a "one-dimensional" weighted risk R_w, e.g. in terms of money, as following [7]:

$$R_w = \sum_{j=1} \alpha_j \sum_{i=1} P_{f_{ij}} \cdot C_{f_{ij}} \quad (1)$$

$$R_w = \sum_{j=1} \alpha_j \sum_{i=1} R_{ij} \quad (2)$$

in which:

R_w = weighted risk [year^{-1}];
α_j = (monetary) value per considered loss [cost unit].

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It has to be noted that the weighted risk R_w may consist of cost unities, which can be financial, but not necessarily. Bohnenblust & Slovic [8] introduced the so-called monetary collective risk, in which the marginal cost criterion is included. The weighted risk R_w can easily be extended into multiple decision-making elements, depending on the origin of the decision-maker. The formulas (1) and (2) can be specified into particular risk components [2,7]:

$$R_w = \alpha_1 \sum_{i=1} R_{human,i} + \alpha_2 \sum_{j=1} R_{enonomic,j} + \alpha_3 \sum_{k=1} R_{environment,k} + \alpha_4 \sum_{l=1} R_{quality,l} + ... \quad (3)$$

in which:

α_1	=	(monetary) value per fatality or injury [cost unit];
α_2	=	(monetary) value per environmental risk [cost unit];
α_3	=	(monetary) value per economical risk [cost unit] (mostly $\alpha_3 = 1$);
α_4	=	(monetary) value per quality risk [cost unit], and so on…

Note that elements related to the human risks may even contain risk perception aspects of human beings. According to Lind [9], safety criterions are not absolute. Cost-utility is only a part of the economic, social, cultural and political assessments that are required for responsible decision-making. Note that some α_j may also be negative (e.g. time). If these non-safety related aspects are quantified in the proposed weighted risk (analysis), and thus in one (monetary) dimension, safety measures can be balanced and optimised in respect of decision-making, shown as follows:

Minimise:

$$C_{tot} = C_0(y) + \sum_{j=1} \frac{R_{wj}}{(1+r)^j} \quad (4)$$

in which:

C_{tot}	=	total costs [money];
$C_0(y)$	=	the investment in a safety measure [money];
y	=	decision parameter;
j	=	the number of the year;
r	=	real rate of interest.

Equation (4) provides an overall mathematical-economic decision problem for balancing safety measures for all kinds of aspects by expressing both positive / negative risks and benefits of a project.

2.2 The monetary values of the weighted risk analysis

The elements of the weighted risk, considered in the case study of chapter 4, are the investments C_0, economical losses C_j, economic benefits $C_{benefits}$, human risks $E(N_d)$, quality risk $R_{quality}$ and environmental risk $R_{environmental}$. The components of the weighted risk can only be computed quantitatively, if the monetary value per considered risk α_j is determined. Some of these values can be found in literature. The monetary value per fatality or the valuation of human life depends on aspects such as Willingness To Pay (WTP), Willingness To Accept compensation (WTA), voluntariness and responsibility - all of which can be determined by e.g. a questionnaire - as discussed in [10]. More details on these monetary values of the weighted risk analysis can be found in thesis [2].

Table 1: Monetary values of the weighted risk analysis

Aspects of the weighted risk analysis	Monetary values of α_j	Literature
Fatality	€ 1.000.000 - € 20.000.000 / person	[11]
A set of qualities	€ 100 / persoon / jaar	[12]
Environmental space saved	€ 4 / m^2	[13]

3. CASE STUDY BOS AND LOMMER

3.1 Introduction

The Bos en Lommer office development in Amsterdam is part of the development scheme, which centres on the Bos en Lommerplein and the surrounding area. The aim of this redevelopment programme is to span the gap between the eastern and the western flank of the A10 motorway and to provide the neighbourhood with a new heartbeat. The development lies close to the S104 exit on the A10 motorway to the west of Amsterdam. Accessibility by car, tram and train is excellent for this area. The buildings form a bridge between the eastern and the western side of the A10 ring road and comprise part of a plan for a new shopping centre with residential accommodation above. The focal point of the shopping centre will be the market square underneath, where an underground car park will be situated to serve shoppers and office workers. The buildings have a total floor space of 20,000 m² distributed over 2 buildings of 6 floors each of 9,000 and 11,000 m² respectively. The 5th floor has been designed as a set-back level with balconies. Commercial functions were planned for the ground floor of the building first (employment agency, travel agents, etc.). The buildings line the outside of the bridge such that the motorway is less apparent on the section in between the buildings, so doing justice to the commercial activities on the ground floor. Large entrance halls finished in natural stone are sited at either side of the bridge, designed primarily in glass. The depth of the buildings is approximately 15 metres (adapted from http://www.multivastgoed.nl). The construction of this project started in 2001 and was finished in end of 2003.

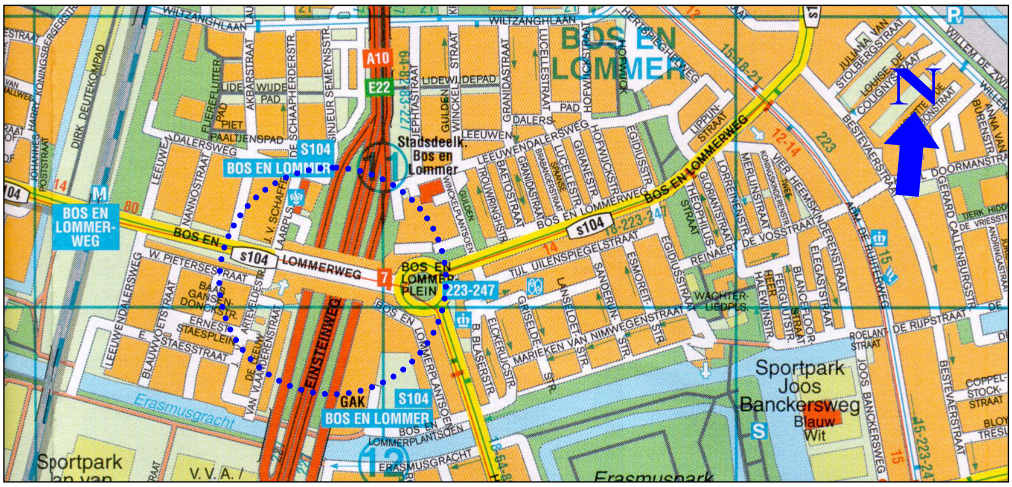

Figure 1: Map of Bos and Lommer.

Figure 2: An impression of the Bos en Lommer Office buildings with transport of hazardous materials.

3.2 Safety measures in the weighted risk analysis and different monetary values per fatality

Input parameters and results of the QRA, which were used to conduct a weighted risk analysis, can be found in [14]. The investigated measures can be divided into logistical measures and measures regulating transport of LPG.

Measures for regulation of transport of LPG

The effect of some measures is determined in the case Bos en Lommer. One of the measures is the ban of transport of LPG on roads. In The Netherlands, there is a strong recommendation to ban the transport of LPG on roads and rails, on a national level. Transporters could benefit from prohibiting urban development adjacent to transport routes. However, banning the transport due to urban planning or banning urban development due to the transport are both not the solution to the external safety problem in The Netherlands. Still, one may accomplish measures with similar effects; such as locally rerouting the LPG traffic through non-urban areas, or realising another transport types e.g. transport pipelines or even transport by ships. An advantage of transport of LPG on ships is that hardly any (densely) populated areas are established near the rivers. All these measures usually demand large investments of different parties or actors using the hazardous material. Logistic measures, such as (1) banning the transport of LPG, (2) rerouting the transport of LPG, (3) LPG through pipelines and (4) LPG transport during the night are taken into account. Investments, maximum economical risks and the number of people killed per year are considered in this part of the case. If we can calculate the risk reduction per measure, then the cost effectiveness of measures can be determined. Table 2 shows that the total costs depend upon the height of monetary value per human being α_{human}. So, the height of monetary value per human being α_{human} is very important for decision-making, because the α_{human} determines the total costs. Furthermore, this case also stresses the problem that the investments in safety measures are relatively high in contrast with their relatively low human risk reduction.

Table 2 - Comparison of economical and human risk (per year) for LPG regulated safety measures in Bos and Lommer

Safety Measures	(Sub)total Costs C_{tot} if$_t$ α = € 0	$E(N_d)$	Total Costs if$_t$ α = € 1,000,000	Total Costs if$_t$ α = € 10,000,000
0. Starting situation	€ 300	$4.2\cdot10^{-3}$	€ 4,500	€ $420\cdot10^{3}$
1. Banning transport of LPG	€ 62,000,000	$2.9\cdot10^{-3}$	€ 62,002,900	€ $62\cdot10^{6}$
2. Rerouting transport of LPG (not through urban areas)	€ 55,300	$2.9\cdot10^{-3}$	€ 58,200	€ $345\cdot10^{3}$
3. Transport of LPG through pipelines	€ 62,500,300	$2.9\cdot10^{-3}$	€ 62,503,200	€ $63\cdot10^{6}$
4. Transport of LPG takes place during the night	€ 1,062,300	$2.9\cdot10^{-3}$ - $4.2\cdot10^{-3}$	€ 1,065,200	€ $1\cdot10^{6}$

Structural and Functional measures

Structural and functional measures are implemented in the building (structure) and the effect are determined on the weighted risk. Besides, it is interesting to see whether measures like regulating the LPG are cost efficient with respect to structural measures implemented in buildings. Structural and functional safety measures in this case can be divided into the following measures: (5) fire protection layer for building above the infrastructure, (6) explosion resistant building above the infrastructure, (7) dimensions of the building above the infrastructure with a small L/D (= implementing a big diameter (a high level for the lowest storey h_o and a bigger span l, and (8) fire protecting layer for the buildings above and in the vicinity (for 1 km). As before, we can calculate the number of people killed per year $E(N_d)$, the investments C_0 and the economical risks C_j. The results of these calculations are presented in table 3.

Table 3 - Comparison of economical risk (per year) for functional and structural safety measures in Bos and Lommer

Safety Measures	Investments C_o	Economical risk C_i	Total costs C_{tot}	$E(N_d)$
0. Starting situation	-	€ 300	€ 300	$4.2 \cdot 10^{-3}$
5. Fire protection layer for building above infrastructure	€ 720,000	< € 300	€ 33,750,000	$2.9 \cdot 10^{-3}$
6. Explosion resistant building above infrastructure	€ 11,000,000	< € 300	€ 11,000,300	$2.9 \cdot 10^{-3}$
7. Building above infrastructure with small *L*/*D*	€ 5,316,000	< € 300	€ 5,316,000	$2.9 \cdot 10^{-3}$
8. Fire protection layer for building above and in vicinity	€ 80,000,000	< € 300	€ 80,000,300	$2.5 \cdot 10^{-3}$

3.3 The weighted risk analysis for Bos en Lommer

Now, we can compare all these measures from non-human related perspectives with the weighted risk, in which the monetary values of section 2.2 will be used for the different components of the weighted risks (see table 4). In table 4, the 0-situation is also considered, which represents the situation if the project was not realised on that location, but on the boundary of a city centre. A positive value in table 4 presents an absolute risk (loss), a negative value in the table presents an absolute profit / benefit. First of all, it should be concluded from table 4 that the safety considerations hardly influence the weighted risk analysis. Even quality and environmental benefits of such a project vanish in the analysis. The reason hereof might be that the monetary values are assumed too low.

Table 4 - Comparison of weighted risk [€ per year] all safety measures in Bos and Lommer

Elements of the Weighted Risk R_w for year 1	Safety Measure								
	0	1	2	3	4	5	6	7	8
	Starting situatio n	LPG Ban	Reroute LPG	LPG through pipe line	LPG during night	Fire prot. building	Expl. Resist. building	Small *L*/*D*	Fire prot. vicinity
Investments C_0	0	-	$5.5 \cdot 10^3$	$6.3 \cdot 10^7$	$1 \cdot 10^6$	$7.2 \cdot 10^5$	$1.1 \cdot 10^7$	$5.3 \cdot 10^6$	$8.0 \cdot 10^7$
Economical risk C_i	300	$6.2 \cdot 10^7$	300	300	300	300	300	300	300
Human risk $E(N_d) \cdot \alpha$	$2.9 \cdot 10^3$	$4.2 \cdot 10^3$	$2.9 \cdot 10^3$	$2.9 \cdot 10^3$	$4.2 \cdot 10^3$	$2.9 \cdot 10^3$	$2.9 \cdot 10^3$	$2.9 \cdot 10^3$	$2.5 \cdot 10^3$
Quality risk $R_{quality} \cdot \alpha_{quality}$	$-8 \cdot 10^4$	$-8 \cdot 10^4$	$-8 \cdot 10^4$	$-8 \cdot 10^4$	$-8 \cdot 10^4$	$-8 \cdot 10^4$	$-8 \cdot 10^4$	$-1 \cdot 10^5$	$-8 \cdot 10^4$
Environmental risk $R_{env} \cdot \alpha_{environmental}$	$-1 \cdot 10^4$	$-1 \cdot 10^4$	$-1 \cdot 10^4$	$-1 \cdot 10^4$	$-1 \cdot 10^4$	$-1 \cdot 10^4$	$-1 \cdot 10^4$	$-1 \cdot 10^4$	$-1 \cdot 10^4$
Benefits	$-2 \cdot 10^6$	$-2 \cdot 10^6$	$-2 \cdot 10^6$	$-2 \cdot 10^6$	$-2 \cdot 10^6$	$-2 \cdot 10^6$	$-2 \cdot 10^6$	$-2 \cdot 10^6$	$-2 \cdot 10^6$
R_w [€·year^{-1}]	$-2 \cdot 10^6$	$6.0 \cdot 10^7$	$-2 \cdot 10^6$	$6.1 \cdot 10^6$	$-1.1 \cdot 10^6$	$-1.4 \cdot 10^6$	$8.9 \cdot 10^6$	$3.2 \cdot 10^6$	$7.8 \cdot 10^7$

If we consider table 4 in detail, it shows that, when considering the weighted risk R_w, the logistical safety measure 2 - rerouting the transport of hazardous materials - is the most effective and beneficial, because the value of the weighted risk R_w is minimised due to relatively small investments in the measure. This is followed by the safety measure ”protecting the building above the infrastructure against fire” (measure 5). Even another logistic measure scores well; transport of LPG, during the night (measure 4). It is therefore kindly appreciated that one should focus on logistical safety measures, such as allowing for a short time period (e.g. 10 minutes) the transport of LPG or other hazardous materials. Surprisingly, the weighted risk analysis shows that if the project was realised without measures (measure 0), even then the value of the weighted risk is negative. This means that according to the weighted risk, such a situation is beneficial as well. Banning the transport of LPG through infrastructure is strongly dissuaded, because the weighted risk is maximised. Measures such as the functional design of the building (measure 7) or explosion resistant building are rather costly and thus not efficient.

4. CONCLUSIONS

First of all, this case presents the fact that the proposed weighted risk analysis methodology is a well ordered, one dimensional quantified tool, which can compare different non-safety related elements. This methodology can support the decision-makers in a broader sense. Focussing on the treated safety measures, this case study accentuates the fact that taking the most progressive safety measure, banning or rerouting the transport of LPG, is not an apparent solution to the external safety problem in The Netherlands. Yet, when the LPG is not transported through urban areas, scenarios or disasters with large number of people killed can be minimised. This is exactly what the community desires; accidents with large number of fatalities are difficult to accept. Banning the transport brings out relatively high costs, while rerouting the transport of LPG is relatively cheap and should be paid by the transporters. Surprisingly, it appears from these cases that if the effect of safety measures is weighed and optimised with economical aspects, such as investments and benefits, the human risks vanish in the weighted risk analysis. Also environmental and quality aspects were less dominant in comparison with the costs / investments of a single safety measure and benefits of the project. For a single building above the infrastructure, the influence of the human risks with other mentioned aspects is negligible. Hence, it can be concluded that usually the costs and benefits are the most influential parameters for a go-no-go decision of either realising a project or taking a safety measure. In this paper, the value of a human life is assumed to be the commonly used € 1,000,000.=. Even though the upper limit of the monetary value of a human being is assumed to be € 20,000,000.=, the contribution and effect of human risks in the weighted risk vanishes. From this point, it can be stated that these monetary values for human beings must be higher in the future in the cost-benefit-analysis or even more aspects than presented in this thesis, are considered for decision-making. If a measure is still applied despite the high costs, it can be stated that the safety is in fact a boundary condition rather than a financial issue. Sometimes decisions on measures are taken on an intuitive basis or political interests, that can be totally unjustified or wrong, even though the purpose of the decision-maker is to guarantee a certain safety level to the society on the one hand and to provide a positive perception regarding safety issues on the other, rather than economical backgrounds. Therefore, one may expect that expendable commodities play an ethical role when taking safety measures. Finally, one should keep in mind that the proposed weighted risk methodology is a tool for comparing different measures with both financial and non-financial aspects for rational decision-making, rather than an exact expression of a cost-benefit analysis, since the monetary values of the considered weighted risk elements may vary largely.

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