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The Weighted Risk Analysis Applied for Bos & Lommer

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Abstract: Safety and risk assessment are characterized by aspects, like subjectivity and objectivity. In this paper, relations between safety and risk are described. When a risk analysis is performed, it is important to realize 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 realized 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), since 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.

Key Words: *Decision-making ,Risk Analysis, Safety, Safety Measures, Weighted Risk Analysis*

1. Introduction

Safety is nowadays one of the main items on the agenda during the planning, realisation and management of most large-scale projects, particularly in infrastructure and building projects in intensively used areas such as multiple use of space projects. Buildings above roads and railways are examples of multiple use of space [1]. Some buildings in The Netherlands are realised above transport routes of hazardous materials. Therefore, it is vital to assess the safety aspects at an early possible stage of the project, since safety is one of the critical issues for such projects. In this regard, quantitative risk analyses (QRA) can be undertaken to investigate what safety measures are required to realise these projects. The results of these analyses can also be compared to risk acceptance criteria, if they are applicable.

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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 [2].

When a risk analysis is performed, it is important to realise that decision making about (accepting) 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. Sometimes, expensive safety measures are necessary to realise multiple use of projects above transport routes of hazardous materials.

However, there is not a proper methodology through which the effect of safety measures can be weighed with multiple decision aspects. Having this all in mind, the following question arises: Can different decision-making aspects compared quantitatively - preferably in the same (cost) units - with the effect of safety measures? This question contains implicitly whether investments of safety measures can be efficient in comparison with other non-safety related aspects. Moreover, it is surprising that most studies treat physical safety aspects separate from financial deliberations instead of discussing relations or comparisons between (non-)safety related aspects and economic consequences, all of which are strongly desired by decision makers. Additionally, comparison of effects of safety measures with non-safety related aspects, such as environmental and spatial quality aspects, are more difficult to find in literature*, e.g.* [2,3,4,5].

In this paper, this question is answered by proposing the ”Weighted Risk Analysis” methodology (WRA) as an additional tool in the decision-making process, in which the effect of safety measures is optimised with aspects, such as environmental, quality, and economical aspects. Furthermore, the approach of the optimisation is not only based on effects of economical and human risks of measures, but also a deliberation of non-safety related aspects. Finally, the weighted risk analysis methodology is applied in a case study of Bos en Lommer, Amsterdam.

2. Safety & Risk

To define and to judge the objective elements of safety, it is vital to link safety with risk (the combination of probability and consequences), since safety cannot be quantified. The advantage hereof is that risk can be quantified and judged whether it is accepTable or not, while safety itself cannot. According to Kaplan & Garrick [6], risk consists of three components; (1) scenario, (2) probability of that scenario and (3) consequence of that scenario. Kaplan & Garrick [6] suggest also that one has to take all hazards into account, which can be accomplished by summing up all possible hazards (scenarios) with their consequences for an activity, which is the most frequently used definition in QRAs. Therefore, as an obvious extension, multiple scenarios (indexed i) may be taken into account, as presented in the following formula:

$$R = \sum_{i=1} P_{f_i} \cdot C_{f_i} \qquad (1)$$

.

in which:

R	=	risk [fatalities per year or money per year];
P_f	=	probability of failure [year^{-1}];
C_f	=	consequence of the unwanted event [fatalities or money].

Consequences C_f to be taken into account include: (1) injury, or loss of life, due to structural collapse; (2) reconstruction costs; (3) loss of economic activity and (4) environmental losses. It should be noted that it is possible to weigh the consequences C_f more heavily by taking them to a second power. Most of the time, there is an inverse relation between the probability that a hazard will occur and the consequences of that hazard.

3. Risk Management Process

3.1 Risk Assessment & Risk Evaluation

A quantitative risk analysis, which is a part of the risk assessment process, generally contains the steps: scope definition, hazard identification, modelling of hazard scenarios, estimation of consequences, estimation of probabilities and estimation of risks. Different stakeholders are involved in the risk management process. 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 [5]. If a risk analysis is carried out for only the qualitative part, the psychological and political aspects play a major role in risk acceptance and decision-making. Contrarily, when risk analysis is carried out until the quantitative part, limits for risk acceptance and economical criteria are considered for decision-making. Furthermore, 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 [4,7,8,9]. 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 [5,10]:

$$R_w = \sum_{j=1} \alpha_j \sum_{i=1} P_{f_{ij}} \cdot C_{f_{ij}} \tag{2}$$

$$R_w = \sum_{j=1} \alpha_j \sum_{i=1} R_{ij} \tag{3}$$

in which:

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

It has to be noted that the weighted risk R_w may consist of cost unities, which can be financial, but not necessarily [5]. Bohnenblust & Slovic [11] 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 (3) and (4) can be specified into particular risk components [5, 10]:

$$R_w = \alpha_1 \sum_{i=1} R_{human,i} + \alpha_2 \sum_{j=1} R_{enonomic,j} + \alpha_3 \sum_{k=1} R_{environment,k} + \alpha_4 \sum_{l=1} R_{quality,l} + ... \quad (4)$$

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 [10]. According to Lind [12], 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:

$$\text{Minimize:} \quad C_{tot} = C_0(y) + \sum_{j=1} \frac{R_{wj}}{(1+r)^j} \quad (5)$$

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 (5) 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. Since the proposed equation (5) is a multidisciplinary approach than decision-making on targets for risk acceptance, the WRA becomes a more justified supporting tool in decision-making. Note that ethical aspects are involved implicitly in such comparisons and should therefore be carefully considered. Only considering these ethical aspects is the proper way to validate decision-making about risks.

3.2 Monetary Values of Elements of the Weighted Risk

The elements of the weighted risk, considered in this paper, 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 (see Table 1). Most of these values can be found in literature, in which the monetary values per element are determined with various methods depending on the type of the considered value. Methods like Willingness To Pay (WTP), Willingness To Accept compensation (WTA), Life Quality Index (LQI), voluntariness and responsibility are used for the monetary value per fatality saved [13]. In the same manner, the WTP of employees working in a multifunctionally designed area is derived from questionnaires based on Stated Preference techniques, and implies that per year a person working in such an environment is willing to pay € 84.= let say € 100.= per year for the use of a specific (individually chosen) bundle of facilities [14]. An indicator for the green area preserved

(GAP), which is about € 4.= / m^2, is determined by Vogtländer [15]. More details on these monetary values of the weighted risk analysis can be found in thesis [5].

Table 1: Monetary Values of the Weighted Risk Analysis.

Aspects of the weighted risk analysis	Monetary values of α_j	Literature
Fatality (α_{human})	€ 1.000.000 - € 20.000.000 / person	[4,13]
A set of qualities ($\alpha_{quality}$)	€ 100 / person / year	[14]
Environmental space saved ($\alpha_{environmental}$)	€ 4 / m^2	[15]

3.3 The Weighted Risk Analysis Methodology

In order to compare risks with non-safety related elements, the traditional QRA approach can be extended with the Weighted Risk Analysis (WRA) methodology. This method provides sufficient elements to assess, integrate and evaluate physical safety in complicated projects for both the construction and the exploitation stage. In order to determine the weighted risk in a multiple use of space project, the methodological steps presented in figure 1 need to be taken, since the methodology is quite similar for any project. These steps will be demonstrated in the case study of the next chapter.

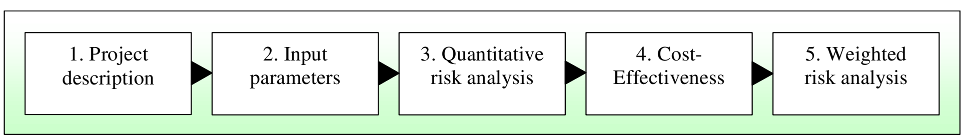

Fig. 1: Methodological Steps for Dealing with Physical Safety in Multiple Use of Space Projects.

- Ad 1 Project description
In this stage, the specification or dimensions of the location, on which new urban development will be realised, are described in detail.
- Ad 2 Input parameters
Basic parameters, such as the number and the type of hazardous materials, are determined. These parameters form the basis of the QRA.
- Ad 3 Quantitative risk analysis
A QRA is needed to determine the economical risk C_j, the individual risks *IR*, the group risk *GR* and the expected number of people killed $E(N_d)$.
- Ad 4 Cost-effectiveness
Both costs and effects of safety measures are vital elements for taking cost-effective measures. Therefore, this stage is ineviTable in the risk analysis.
- Ad 5 Weighted risk analysis
The cost effectiveness of safety measures can now be deliberated and weighed with both non-safety and non-financial related aspects.

4. Case study of Bos en Lommer, Amsterdam

4.1 Introduction

The Bos en Lommer office development 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 (http://www.multivastgoed.nl). The construction of this project started in 2001 and was finished 2003.

Fig. 2: An Impression of the Bos en Lommer Office Buildings with Tansport of Hazardous Materials.

According to the QRA approach of Suddle [4], four interrelations (risk categories) of the different areas should be assessed, influencing the overall safety level and presenting both individual and group risk per risk category (see figure 3):

- Risk category [1]: External safety and risks from the building in relation to the infrastructure beneath (e.g. falling elements and fire);
- Risk category [2]: External safety and risks from the infrastructure towards the building (e.g. release of toxic gasses, fire, explosions and collisions against building structure);
- Risk category [3]: Internal safety and risks from the structures enclosing the infrastructure (e.g. explosions, fire, explosions and collisions against building structure);
- Risk category [4]: External safety and risks from the infrastructure towards the vicinity (e.g. release of toxic gasses, fire, explosions and collisions against building structure).

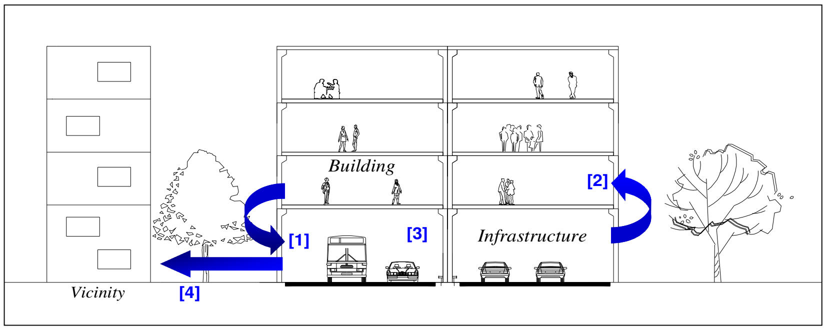

Fig. 3: The Four Risk Interaction Categories in Multiple Use of Space Projects [4].

4.2 Input Parameters

The input parameters for the QRA and WRA of Bos en Lommer are presented in Table 2. Details about the input parameters can be found in the thesis of Suddle [4].

Table 2: Input Parameters for the Case Bos en Lommer QRA.

Input parameters for case Bos en Lommer	
Characteristics of the road	
Type of road	3 x 2 lane motorway
Number of vehicles passed per day	159,000
Ratio of traffic type on the road	91% cars 8% truck traffic 1% busses
Transport of hazardous materials per year	36,501 LF trucks 3,664 GF trucks
Ratio transport of hazardous materials per year	0.122807 not hazardous traffic 0.729123 LF 0.14807 GF
Covering length	79.5 m
Frequency of an accident	$8.30 \cdot 10^{-8}$
Maximum people in the covered infrastructure	100
Characteristics of the building above the road	
Function of the building	Offices
Floor space of the buildings	20,000 m^2
Length of the building	79.5 m
Width of the building	85 m
Height of the building	20 m
Maximum people in the building	800
Characteristics of the vicinity	
Population density	50 persons/ha

4.3 Results Risk Analysis

- Individual Risk

The individual risk can be divided into IR for people present on the infrastructure and IR above the covered infrastructure, which is about $2 \cdot 10^{-5}$ and $2 \cdot 10^{-6}$ respectively (see figure 4). Table 3 presents the individual risk for the buildings above the infrastructure (per unit building), where the conditional probability of a person being killed due to an "average" scenario is presented.

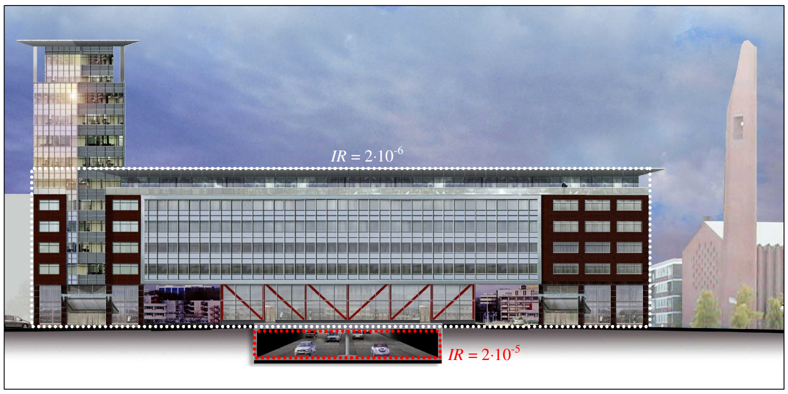

Fig. 4: The (schematic) IR Contours in the 3rd Dimension for Bos and Lommer Building (Source artist impression: www.multivastgoed.nl).

Table 3: The Individual Risk [death / year / km] for Bos and Lommer.

Covering Length	80 m		
Scenario i	P_{fi}	C_{fi}	R
1. Collisions with the structure of the building	$1{\cdot}10^{-6}$	0.1	$1{\cdot}10^{-7}$
2. Fires	$2{\cdot}10^{-5}$	0.07	$1{\cdot}10^{-6}$
3. Leak of toxic substances	0	0.5	0
4. Explosions	$3{\cdot}10^{-7}$	1	$3{\cdot}10^{-7}$
ΣIR *[year^{-1}·km^{-1}]*			$2{\cdot}10^{-6}$

- Group Risk

Likewise, the group risk can be determined for the Bos and Lommer buildings. The FN-curve for this project is presented in figure 5.

- Expected number of people killed

From the group risk, the expected number of people killed per year can be determined per risk category. The expected number of people killed per year $E(N_d)[1]$, $E(N_d)[2]$, $E(N_d)[3]$, $E(N_d)[4]$ are respectively $1.4{\cdot}10^{-4}$, $1.2{\cdot}10^{-4}$, $2.4{\cdot}10^{-3}$, $4.5{\cdot}10^{-4}$. The total expected number of people killed per year $E(N_d)_{tot}$ is thus equal to $4.2{\cdot}10^{-3}$. Note that the $E(N_d)_{tot}$ depends primarily on both risk category [3] and risk category [4].

- Economical losses

The economical risk for the Bos and Lommer building is approximately € 300 per year (Table 4). Suppose that the monetary value per fatality α is set to be € 1,000,000.=, then the value of $E(N_d)_{total} \cdot \alpha$ is equal to € 4,200.= which is higher than the expected economical loss for this case. This comparison will be made when different measures are implemented for this case.

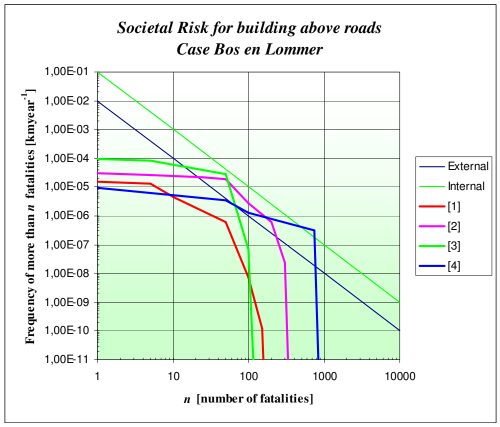

Fig. 5: The Group Risk for the Bos and Lommer Building and the Vicinity per Risk Categories [1], [2], [3] and [4] of figure 3.

Table 4: The Economical Risk for Bos and Lommer.

Covering Length	**80 m**		
Scenario i	P_{fi}	C_{fi}	R
1. Collisions with the structure of the building	$1 \cdot 10^{-6}$	$1 \cdot 10^{6}$	$1 \cdot 10^{0}$
2. Fires	$2 \cdot 10^{-5}$	$5 \cdot 10^{6}$	$1 \cdot 10^{2}$
3. Leak of toxic substances	0	$2 \cdot 104$	0
4. Explosions	$3 \cdot 10^{-7}$	$5 \cdot 10^{8}$	$2 \cdot 10^{2}$
Expected economical loss [€·year-1]			$3 \cdot 10^{2}$

It should be noticed that the presented results are indications of amounts of several elements of the weighted risk, rather than an exact presentation of a cost-benefit analysis, through which results may vary considerably.

4.4 Cost-effectiveness of Safety Measures

- Measures for regulation of transport of LPG

The effect of some measures of the safety chain will be 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. A full overview of calculations of investments etc. is presented in thesis of Suddle [4]. If we can calculate the risk reduction per measure, then the cost effectiveness of measures can be determined. First, the group risk *GR* for the Bos en Lommer project without the transport of LPG is presented in figure 6, which is needed to determine the number of people killed per year $E(N_d)$.

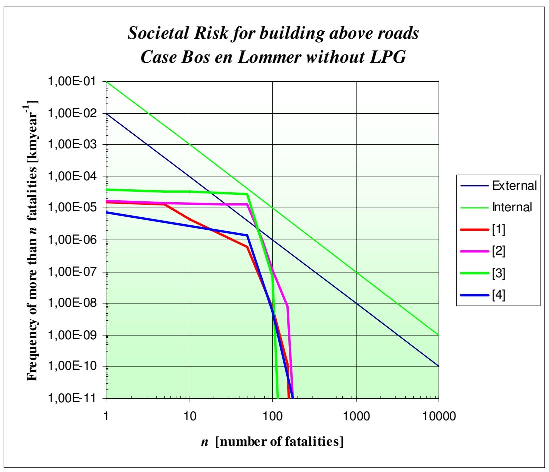

Fig. 6: The Group Risk for Measure 1, 2 and 3 of Table 5 per Risk Categories [1], [2], [3] and [4] of Figure 3.

From Table 5 it becomes evident that measures 1, 2 and 3 lead to the same effect regarding the number of people killed per year $E(N_d)$, where this value for the 4th measure fluctuates in the range of the other measures, because the number of people exposed to that risk will be the only difference. Therefore the risk analysis is not performed for the 4th measure, because the risk reduction of expected fatalities of measure 1, 2, and 3 compared with measure 0 (starting situation) is marginal. Hence, one can expect that the $E(N_d)$ of measure 4 lies somewhere between $2.9 \cdot 10^{-3}$ and $4.2 \cdot 10^{-3}$. The small reduction of the $E(N_d)$ is due to the fact that the probability of the number of fatalities more than 1000 decreases, while the probability of small accidents in which a relatively small number of people is killed, is relative constant. However, the reduction in disasters with large consequences is significant.

So, if the original FN-diagram of measure 0 (figure 5) is compared with the FN-diagram of figure 11, one sees that scenarios with large numbers of people killed per year decrease strongly. This large reduction, however, is not presented appropriately by the $E(N_d)$, this problem is also discussed by Bedford & Cooke [16].

The FN-diagram of figure 6 is valid for the measures 1, 2 and 3. When considering the measures, we see that measure 1 - totally banning the transport of LPG - leads to large economical losses (fired workers and sanitation).

Table 5: Comparison of Economical Risk (per year) for Different 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	$4.2 \cdot 10^{-3}$
1. Banning transport of LPG	-	€ 62,000,000	€ 33,750,000	$2.9 \cdot 10^{-3}$
2. Rerouting transport of LPG (not through urban areas)	€ 55,000	< € 300	€ 55,300	$2.9 \cdot 10^{-3}$
3. Transport of LPG through pipelines	€ 62,500,000	< € 300	€ 62,500,300	$2.9 \cdot 10^{-3}$
4. Transport of LPG takes place during the night	€ 1,062,000	< € 300	€ 1,062,300	$2.9 \cdot 10^{-3}$ - $4.2 \cdot 10^{-3}$

According to the Ketenstudies [17][1)], banning the transport of LPG leads to large social losses, i.e. the loss of 4,700 labourers, which is approximately a loss of € 47,000,000.= (see [4]). This amount can also be considered as investments for the labourers losing their work. Furthermore, an important notice of applying measure 1 and 3 is that the investments are relatively high, while the risk reduction in terms of $E(N_d)$ is almost negligible. The costs of measure 3 are high, because new infrastructure has to be realised in order to make that measure practicable. In contrast, the costs of measure 2 are relatively low, because rerouting the traffic is taken into account locally. If the investments are computed for an overall rerouting of LPG in the Netherlands, the costs may be millions of euros. The costs of measure 4 are higher than those of measure 2. This case also shows that the economical risks are of minor relevance compared to the human risks. However, when the investments in safety measures are included in the risk picture, the improvement in human risks is marginal. This phenomenon is controversially emphasised when different monetary values α of human beings are taken into account. Table 6 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 (saved) 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.

- Structural and Functional measures

In this part, 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

1) Ketenstudies are performed on behalf of the Dutch Ministry of Spatial Planning, Housing and Environment (VROM) to map out the economical dis(advantages) of hazardous materials such as LPG, chlorine and ammonia.

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 larger distance between the infrastructure and the lowest storey and a bigger span, 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 (see [4]). The results of these calculations are presented in Table 7.

Table 6: 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	$4.2{\cdot}10^{-3}$	€ 4,500	€ $420{\cdot}10^{3}$
1. Banning transport of LPG	€ 62,000,000	$2.9{\cdot}10^{-3}$	€ 62,002,900	€ $62{\cdot}10^{6}$
2. Rerouting transport of LPG (not through urban areas)	€ 55,300	$2.9{\cdot}10^{-3}$	€ 58,200	€ $345{\cdot}10^{3}$
3. Transport of LPG through pipelines	€ 62,500,300	$2.9{\cdot}10^{-3}$	€ 62,503,200	€ $63{\cdot}10^{6}$
4. Transport of LPG takes place during the night	€ 1,062,300	$2.9{\cdot}10^{-3}$ - $4.2{\cdot}10^{-3}$	€ 1,065,200	€ $1{\cdot}10^{6}$

Table 7: 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	$2.5{\cdot}10^{-3}$

Table 7 also shows that the total number of people killed per year $E(N_d)$ does not change extremely, because, as mentioned before, this value is dependent of risk category [1], [2], [3] and [4], wherein risk category [3] is dominant over the other categories. Still, the risk reduction can be observed in the FN-diagrams (see figure 7). In reality, it does also mean that the $E(N_d)$ for risk category [1], [2] and [4] is much smaller than $2.9 \cdot 10^{-3}$, so, the effect of $\alpha_{human} \cdot E(N_d)$ in the weighted risk is almost negligible when an α_{human} of € 1,000,000.= is considered.

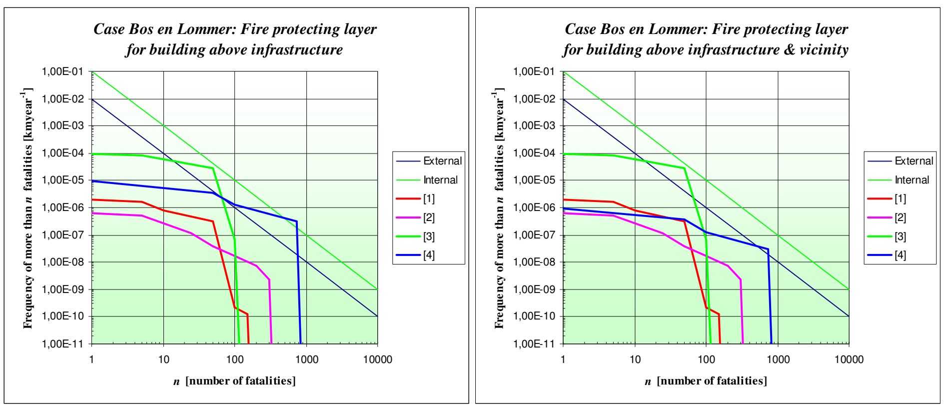

Fig. 7: The Group Risk for Measure 5 (left) and 8 (right) of Table 7 per Risk Categories [1], [2], [3] and [4] of figure 8.

4.5 The Weighted Risk Analysis

Now, we can compare all these measures from non-human related perspectives with the weighted risk, in which the monetary values of section 3.3 will be used for the different components of the weighted risks (see Table 8). In Table 8, 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 8 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 8 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.

If we consider Table 8 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.

Table 8: 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 situation	**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 [€$\cdot$year^{-1}]	$-2 \cdot 10^6$	$6.0 \cdot 10^7$	$-2 \cdot 10^6$	$6.1 \cdot 10^6$	$-1.1 \cdot 10^6$	$-1.4 \cdot 10^6$	$8.9 \cdot 10^6$	$3.2 \cdot 10^6$	$7.8 \cdot 10^7$

4.6 Conclusions

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 (see also studies of Vlek [18]).

Banning the transport brings out relatively high costs, while rerouting the transport of LPG is relatively cheap and should be paid by the transporters. It should be noticed that according to the study of NEI [19], the removal of LPG could even result in large profits, i.e. € 453,000,000.= savings in case of avoided redevelopment, which contradicts the Ketenstudies [17], while both are based upon opportunity costs. Rerouting the transport of hazardous materials can also be accomplished by transport of LPG on ships. Most chemical installations are situated near harbours or rivers. Hence, it is clear that rerouting the LPG through areas, which are not densely populated, is possibly the most effective and general measure to tackle the safety problem. In some cases, it could be interesting to set up a new chemical installation next to the place where the hazardous material is processed, if possible. Realising these options, one may accomplish that the transporters almost automatically pay for the investments of this measure. Furthermore, one should stand by the agreement that these transport routes will not be used in the future to establish new projects of urban development. In this case study, it is shown that for the building above infrastructure measures should be taken against fire (fire resistant layer), because these are very cost-effective and within the project budget.

Besides, if the proposed model of weighted risk (section 3.3) is considered, then the safety component safety may vanish in comparison with both financial and non-financial related aspects such as quality aspects, which may perhaps be the reason behind the realisation of such projects. Therefore one may assume that the monetary values of the considered elements of the weighted risk analysis might be much higher than used in this case. 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.

5. Conclusions and Discussion

First of all, this paper 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. In order to compare and integrate these aspects, from which economical, environmental and quality aspects are considered along with safety aspects, a methodology is proposed: the "weighted risk analysis", in which the extension of these aspects can be weighted and deliberated in one dimension, e.g. in terms of money. The main advantage of such an approach is that the basis of decision-making on projects or safety measures, which is usually based upon either optimisation of human risks or optimisation of economical risks and sometimes a combination of these two, becomes broader and the effects on several aspects can be shown quantitatively. This methodology supports decision-makers quantitatively to ponder on the effect of measures on different aspects, rather than only determining the risk reducing effect, which is provided by various methods and studies already. This is made clear by utilising the WRA methodology for the case Bos en Lommer.

Surprisingly, it appears from this case 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 paper, 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.

Other critical notes on the weighted risk analysis method should be considered carefully. These critical notes are related to future improvements and refinements of the proposed methodology, in order to reach an optimised methodology, for which several additional efforts need to undertaken. First, the case study indicate that the ultimate result of the weighted risk strongly depends on both the considered aspects and their monetary values. As far as possible, more non-financial aspects, like political issues, can be taken into account in the weighted risk analysis as well. In addition to this, sensitivity analyses should be performed for the height of these values. The monetary value of environmental space can be criticised, since large fluctuations prevail in that value: it ranges between € 4.= per m^2 to € 550.= per m^2.

By varying this value, the ultimate result of the weighted risk analysis will change completely. As mentioned before, the monetary value of a human being ranges between € 1,000,000.= and € 20,000,000.=. If we have a critical look at this value, an ethical decision-maker may estimate this value to be infinitely high, through which the optimisation followed by the decision after all becomes a minimum of human risks. It is questionable whether such large investments in safety measures are justified, since 100 % safety does not exist. Although these monetary values change along with time related aspects like the changing of the perception of people, the proposed weighted risk analysis methodology can still be used to evaluate safety measures.

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