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Social Risk Assessment of Large Technical Systems

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ABSTRACT

A probabilistic approach to engineering advances. Since risk adhering to a technical structure can be determined quantitatively easier and more accurately than before, criteria for decision making are becoming more important. If the structure is in the public domain, and benefits are not felt, the voluntariness of being subjected to the risk becomes low. Decisions become, in such a case, a political issue on the basis of considerations of ethics, law, and social justice. For a specific case, the comparison of the economic benefits with the total costs, including risk reduction in a worst case scenario, play a major role as we have seen over and over again in, for example, planning nuclear power generation. A criterion for individual risk of 10^{-5} per year for the purpose of "external safety" is generally accepted. For social risk assessment, however, a group risk criterion is essential and much more difficult to define. An analysis is made. Examples of inconsistency are given. Further dialogue is encouraged. © 2003 Wiley Periodicals, Inc.

1. INTRODUCTION

In the day-to-day practice of safety management and risk analysis at some point of time the question comes up, Is the remaining risk small enough? Do we have to think about further protective measures and risk reduction or do we have to abandon or to leave the activity altogether? In other words, how safe is safe enough?

In the past this question was already there, but with the further rapid development of science and technology and with the experience gained with large technical structures built, the question becomes more and more pressing. On the one hand, the structures become larger and contain larger quantities of toxic substances, energy, or both, and on the other hand the number of people at risk increases continuously. Moreover, the acceptability of being victim of an involuntarily taken risk decreases. Therefore, and because of the societal impact of a mishap, designers and producers of large structures, but also users, and governing authorities have to ask themselves the question, Is the risk acceptable?

In particular with the innovations made in the last century: the airship, airplane, large bridges, skyscrapers, large chemical plants, long tunnels, large passenger ships, tankers, hydropower dams, and nuclear reactors, we are used to accidents occurring that the original designers or producers of these systems did completely overlook. This now has changed and designers can tap from a wealth of information. A new scientific methodology named risk analysis developed. This systemic approach of the risks adhering to a structure starts with identification of possible mishaps. Several methods for hazard identification have been devised. Past experience has been condensed and put into data banks, and logic tree methods such as the fault tree and the event tree have been developed. The probability to identify all possible failures therefore has increased. Also the next step in an analysis, the estimation of the possible effects, has drastically improved. Computer modeling and simulation have created an extensive range of possibilities to determine given a certain scenario, how many will be killed and injured, and what will be the damages to the structure itself and the environment, including the ecosystem. Even the failure probabilities can be estimated reasonably accurately. Of course, in some disciplines such as aerospace and civil engineering, knowledge about possible incidents is much more complete and precise than in, for example, chemistry and biotechnology. Chemical process safety analysis has gone through a tremendous evolution in the last 30 years. However, information on specific material properties and the interaction of physics and chemistry is still lacking, whereas the properties and performances of construction materials—steel, concrete, aluminum—have been mapped extensively. Biotechnology is a relatively young discipline, and the risks of gene manipulation, though being estimated as small by experts, may not have shown themselves all.

Only part of the risk is to be reduced by the design of a structure. The management and organizational structure during operation may also fail and lead to a lower performance standard than foreseen at the design stage. At the end of its life cycle, safety measures in operating and maintaining the structure may further weaken, thus introducing new risks. The thought of even disbanding it may worsen the situation even more. A powerful, yet relatively unexplored method of Management Oversight and Risk Tree (Johnson, 1975), including all organizational and management failure types besides the technical ones, is a potential tool for analysis. Although it should, in fact, be part of the design, it is mostly used in hindsight to investigate more efficiently the cause of an accident. Catastrophic accidents with a high death toll usually entail improved regulation. So, the Piper Alpha offshore platform fire and explosion in 1988 entailed the introduction in the process industries of safety management systems, which by the Seveso II directive were made obligatory. However, next will be the question of what quality these systems need to have. Who would judge that situation? Against what criteria would it be evaluated?

Summarizing, mankind has more and more knowledge about the nature and the magnitude of risks of the structures built and used. Also, insight has grown into the measures to reduce these risks. However each measure will require investment, running cost and so will take up resources. Increasingly, therefore, the decision maker will be confronted with the question, How safe is safe enough? Who will tell him? His intuition, or rather his conscience? His authorities? His management? A design standard? An economics textbook? A local politician?

2. RISK CRITERIA, TOLERABILITY

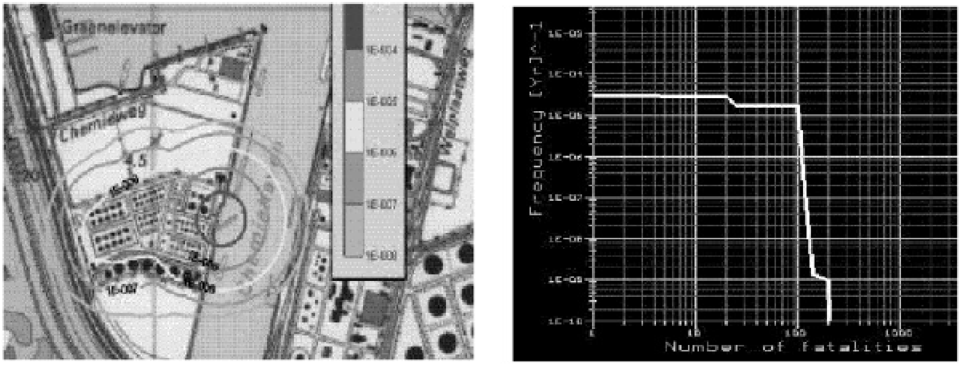
Risk of an activity is usually expressed by two measures: *individual* risk and *group* or *societal* risk. The first indicates the probability of an individual's losing his or her life due to a mishap occurring as a result of that activity. The second expresses the same for a group of persons. Distinction is often made between people who benefit from the activity and subject themselves to the risk more or less voluntarily and those who become a victim completely at random or who even had been against the activity taking place. In order of descending interest and involvement, one names employees, users, and third parties. In the private sector, an assessment of the risk run by employees and users is part of good business practice, on the other hand it is clearly also a societal concern if the effects of an accident project a threat onto the general public. Criteria for risk tolerability in this last sense are in the first place a public concern, and governments have to issue guidelines regarding the risks of planning and siting certain activities in relation to other land use. A certain risk level for third parties ought to be legally acceptable.

The Health and Safety Executive in the United Kingdom produced a shaded scale of criteria (LeGuen, 1999): From a broadly *acceptable* region, via a *tolerable* region, to an *unacceptable* region, in which risk cannot be justified. Between the tolerable and unacceptable regions, control measures to reduce risk must be introduced. In the acceptable region, risk should be minimized according to the As Low As Reasonably Achievable or As Low As Reasonably Practical principles. The first is used in connection with the risks of nuclear power; the second has a particular meaning in Anglo-Saxon law. We shall not dwell here on the subtle differences.

When the possibilities to calculate risk increase, a more quantitatively defined tolerability criterion will create more clarity in decision making. This will force a better handling of the uncertainties in the scenarios and the inaccuracies in the modeling. For example, even given the same scenario, the various gas and vapor dispersion models in use can produce outcomes of the range over which a toxic cloud is dangerous, which differ by several orders of magnitude (Amendola, Contini, & Ziomas, 1992). As already mentioned, in the course of time, this situation will certainly further improve. Inclusion of these uncertainties in risk estimates as proposed by Vrijling (Vrijling & van Gelder, 2000b) seems a way forward.

Once the so-called undesired event or danger occurs, there is the structure posing a *threat* on one side and *targets* vulnerable to effects on the other. Risk can therefore be determined as a function of the distance between a target and a threatening object/structure. The other way around, given a target density around the threatening structure, the number of potentially damaged targets can be determined. Since primary targets are people, one speaks of *individual risk* when addressing the first type of description. *Group, collective*, or *societal risk* indicates the second type. Individual risk gives the probability value of dying over an interval of time (1 year) of a person at a certain location, when permanently exposed. Individual risk can be presented as iso-risk contours on a map by drawing lines that connect locations with the same value of risk. It makes the measure suitable for land use planning. Group risk is expressed as a probability density function, $f(N)$, of the number of people, N, killed by the unwanted event or more commonly as the probability of exceedance or cumulative frequency, $F(\geq N)$, of N or more fatalities per year, where $F(\geq N) = \Sigma f(N)$, summed from N to $N_{\max}$. In Figures 1A and 1B, examples of a fictitious situation are presented.

Next question is which values for individual and group risk can be considered tolerable. The Netherlands Ministry of the Environment (in full, Ministry for Housing, Land Use Planning and Environment, VROM) was probably the first to cast a criterion in law. In 1988, a law (Dutch Environmental Plan, 2000) was passed in which the tolerability limit for individual risk due to process industry hazards was set at 10^{-6} (year^{-1}). It means that external safety of a chemical plant shall be such that the chance of being killed outside the fence of a new plant's premises should at maximum have a value of once in a



(A) (B)

Figure 1 (A) Example of iso-risk-contours of individual risk generated by the TNO PC programme RISKCURVES: Outer contour (blue/grey) represents probability of being killed of 10^{-8}/year, most inner curve (red/black) 10^{-4}/year (PC programme RISKCURVES, 2002). (B) Example of an *F*, *N* curve or societal risk curve generated by TNO RISKCURVES. The frequency of 10 deaths or more is about $3 \cdot 10^{-5}$/year and 100 deaths $2 \cdot 10^{-6}$/year (PC programme RISKCURVES, 2002).

million years. For all activities combined, it shall be less than 10^{-5} (year^{-1}); this figure holds too for existing plant. Group risk tolerability limit was put at $F(\geq N) \times N^2 < C$ where criterion C has the value 10^{-3} for all $N \geq 10$. This means that an incident at the plant site with 10 fatalities in the public community outside the plant area may only happen once in 100,000 years and with 100 victims only once in 10 million years. It means that the tolerability limit quickly decreases when the number of deaths to be expected in an accident increases. In a log $F(\geq N)$ versus log N plot this criterion can be represented as a straight line, see Figure 2. The (negative) slope of the line (value of the exponent of N) represents the degree of aversion of larger accidents. A slope of -1 means risk neutrality, while a slope < -2 models risk aversion against larger accidents (Vrijling & van Gelder, 1997).

It should be noted that individual risk (IR) is a "property" of the location. The probability is calculated on the condition that a person is present. The IR does not change even if it is proven that nobody can be present at the moment of the accident. For a group risk distribution, however, the actual number of people at risk has to be known. Since population density usually varies with time and location, an average figure has to be applied. Group risk is sometimes expressed in one figure. Such figure is known under different names as the Risk Integral, Potential Loss of Life, Fatal Accident Rate[1] or Expected number of fatalities per year. It is defined as $\Sigma f(N) \times N$ or the summing of frequencies of all possible events times the consequences of these events in terms of fatalities from $N = 1$ to $N = N_{\text{max}}$. It can be expressed as a function of the expected value and/or the standard deviation of the number of fatalities as shown by Vrijling and van Gelder (1997).

In an analysis by Vrijling, Van Hengel, and Houben (1995), the risk a person will accept for himself results from a cost-benefit tradeoff and can be expressed as: $\beta_i \cdot 10^{-4}$ (year^{-1}). The policy factor β_i depends on the degree of voluntariness with which an activity, i, is undertaken and the benefit perceived:

[1]Fatal Accident Rate (FAR) is used specifically for workers and is expressed as a number per 10^8 working hours being the entire working life of 1,000 workers. A FAR-value of 1–2 is considered acceptable.

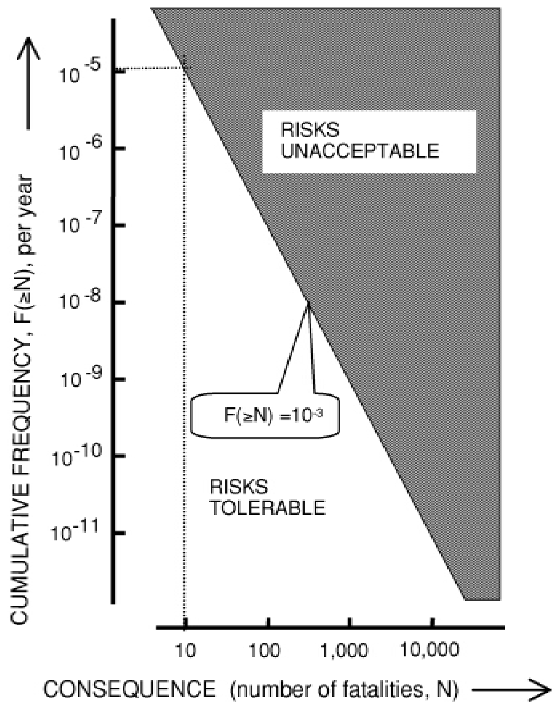


Figure 2 Group risk criterion $F(\geq N) \cdot N^2 < C = 10^{-3}$ for all $N \geq 10$, according to Dutch law of 1988 (Dutch National Environmental Policy Plan, 1988).

- β_i is 100 for voluntary high risk exposure for its thrill such as risky sports like mountaineering,
- β_i is 1 for high degree of self-determination with direct benefit, for example, car driving, and
- β_i is 0.01 for involuntary risk exposure due to a hazardous structure, as with spatial planning issues.

This scale can be further refined (see Vrijling, Van Hengel, & Houben, 1995).

VROM took another approach. Life expectancy in the Netherlands is highest for 14-year-old children at a minimum death rate of 10^{-4} per year. Exposure to a hazardous activity should be limited to only 1% of the already existing probability to die that year. This is equal to 10^{-6} per year and is equivalent with $\beta_i = 0.01$.

Vrijling, Van Hengel, and Houben (1995) made a further analysis of the socially acceptable value of group risk. In the Netherlands with a population of about 15 million the involuntary accident death rate is $1.5 \cdot 10^{-5}$ per year. This rate can be considered as tolerable. (In the circle of one's acquaintances of about 100 people, there will be only a chance of 10% that one of them will be killed by such accident over an entire lifetime of 70 years. Road accident death rate is 10 times as high!) The mentioned rate is the total over all kinds of activity. The number of different kinds of activity can arbitrarily be assumed to be 20. With $\beta_i = 0.1$ (involuntary, some benefit; e.g., worker at a plant) this leads to the outcome that for being tolerable for each activity the number of deaths should remain below:

$$\beta_i \cdot 1.5 \cdot 10^{-5} \cdot 15 \cdot 10^6/20 \approx \beta_i \cdot 100.$$

Risk aversion can be represented mathematically by the expression of the expected total number of annual deaths, N_i due to the activity, i, to which is added a confidence requirement by a multiple, k, of the standard deviation, σ: $E(N_i) + k \cdot \sigma(N_i) < \beta_i \cdot 100$. This is called a normative *nationally* acceptable level of risk. Here k is called the aversion index, for example, set at $k = 3$.

Obviously the degree of aversion has also a relation with the radius of the circle in which the news of the accident and its horrible result has an impact. Therefore, the criterion, C, in $F \cdot N^2 < C$ has to be related to such radius. Vrijling (Vrijling et al., 1995) assumes first as the region, the country. The total number of installations of a certain sector (e.g., process industry), N_{Ai}, in the country is therefore an important parameter. Assuming a binomial or Bernoulli distribution, the number of fatalities at each local installation is limited to 0 or N_{ij}, the expected number of deaths given an accident. The probability to get N_{ij} is p_i, the probability of an accident for this activity. The expected value of the annual number of deaths over all installations is $E(N_i) = N_{Ai} \cdot p_i \cdot N_i$, and the standard deviation for the distribution over all installations, $\sigma(N_i) = N_{Ai} \cdot p_i \cdot (1 - p_i) \cdot N_i^2 \approx N_{Ai} \cdot p_i \cdot N_i^2$.

In this representation $E(N_i) = F_i \cdot N_i < C_i/N_i$ and $\sigma(N_i) \approx E(N_i) \cdot N_i < C_i$. Substituting the criterion parameter, C_i, in the equation proposed above for the national scale: $E(N_i) + k \cdot \sigma(N_i) < \beta_i \cdot 100$ and assuming $E(N_i) \ll \sigma(N_i)$, which is usually the case for calamities, $C_i = [\beta_i \cdot 100/(k\sqrt{N_{Ai}})]^2$. A similar result is obtained assuming an exponential distribution (Vrijling, Van Hengel, & Houben, 1995). Hence, to respect the national criterion, each single specific activity, structure, or installation shall obey this C_i-value as a *local* criterion. It increases with the square of the policy factor and the number of installations in the country. Here β_i is as above the degree of voluntariness, say 0.1 for workers and 0.01 for the public at large. For the 100 industrial process sites in the country coming under the Seveso directive regulating major hazard installations, this factor would become 10^{-3}, which is the value of the present criterion as defined in Dutch law for the process industry.

3. THE EXPERIENCE

Other countries than the Netherlands formulated criteria. In the United Kingdom (Health and Safety Executive [HSE]), Switzerland, California (Santa Barbara County), Western Australia, and Hong Kong, an individual risk criterion of 10^{-5} per year (Greenwood, Seeley, & Spouge, 1997) is common. For new installations, it is often a factor of 10 lower, and for workers relative to the public, a factor of 10 higher. For the group risk criterion, the situation is less clear. The equation used: $F \cdot N^k < C$ is mentioned in ISO 2394 (Vrouwenvelder, Lovegrove, Holicky, Tanner, & Canisisus, 2001). The slope, k, of the tolerable ($\log F$, $\log N$)-line differs. It is often -1 in stead of the Dutch value of -2. It should be noted that -1 only limits the expected number of fatalities, while -2 limits also the standard deviation. So -1 is risk neutral and -2 is risk averse. Also the minimum number of fatalities where the line starts differs. The group risk concept is found to have the disadvantage that the relative importance of the installation is not taken into account nor the full extent of its hazard in terms other than fatalities (Seiler & Bienz, 2001).

A risk evaluation aid that is quite common is the risk matrix. It is used in many slightly different variations throughout the process industry. The matrix is presented in Figure 3. Because of the complexities of reality, a full analysis of all possible incidents and scenarios is, given limited resources, often impractical. Therefore an order of magnitude ranking of events is desired before any detailed work is to be carried out. A Risk Matrix approach is often the solution. The plant is sectioned and for the various parts estimates of the order of magnitude of the damage consequences due to an unwanted event and the expected corresponding frequency are made. Frequencies range from once in a year to once in 10 million years, while the event damage has been grouped in five classes. These classes have been specified in Table 1 in terms of injuries and fatalities, but also of damage to the environment and overall financial losses. The history of such a table goes back some 20 years (see, e.g., Bridges & Williams, 1997; Gillett, 1985), with some modification by the present authors. The financial part of the damage can range from € 10,000 to over 100 million.

The serious cases, either because of their high frequency or of their effect, are collected along the first rows and the right columns respectively. Cases in the right upper corner of the matrix require action without delay. These have to be analyzed in more detail and

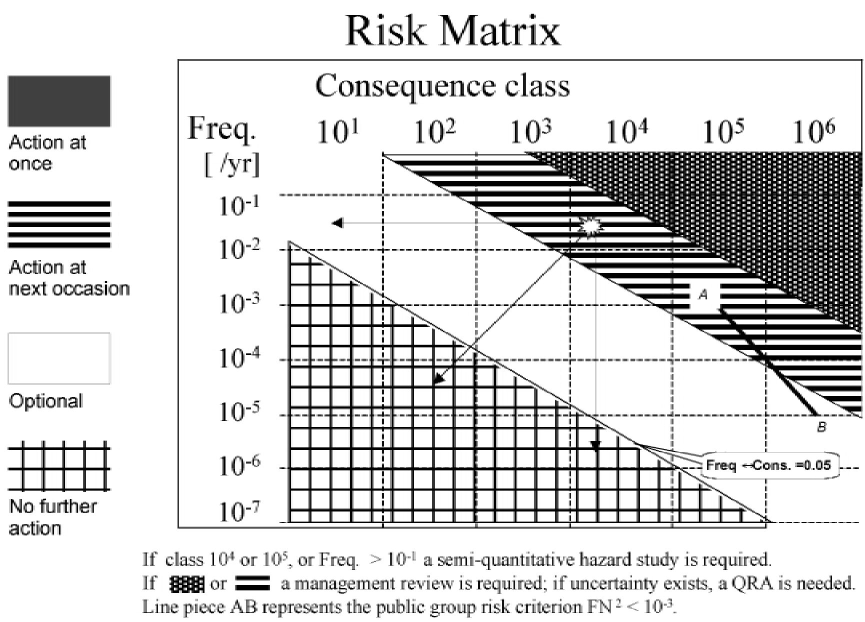


Figure 3 Risk matrix of consequence class (magnitude of effect, or severity) versus probability of occurrence (frequency, per year) enabling prioritization of actions to reduce risk. This can be realized by reducing consequence or frequency, or both (see arrows). Financial loss does *not* include business interruption loss. The latter can be 2–3 times higher than the direct damage costs. Reputation or image damage is not included either. The arrows give the direction of risk reduction: reduction of consequence, frequency, or both. The line piece *AB* in the "white," optional area represents the legal Dutch group risk criterion $FN^2 < 10{<}^{-3}$.

TABLE 1. Indication Consequence Classes of Risk Matrix

Consequence Class	Plant personnel	Community	Environment	Financial loss, k€
101	No lost time	No hazard	No notification	<100
102	Single injury	Odor/ noise	Permit violation	>100
103	1 Injury	Injuries; local news	Serious impact	>1000
104	Fatality	Injuries, regional news	Severe short term effects	>10,000
105	Multiple fatalities	Fatality; int'l news	Disastrous effects, long term	>100,000

have to be quantified. The area in which these cases are found is shaded dark (red) for immediate action. Light shade (orange) is for action at next occasion, and very light shade (green) for no further action needed; the white part is optional. Due to the low frequencies, the "green" area is quite a hard target to achieve. The slope of the diagonal lines in the logarithmic plot of Frequency, p, versus Consequence, D, in the risk matrix of Figure 3 is -1 and hence the product:

$$p \times D = \text{Frequency} \times \text{Consequences} = \text{constant}$$

If one takes Figure 3 as a basis and assumes the target value for risk reduction to be at or below the borderline of the very light shaded (green) area, then $p \times D \leq 0.05$. This requirement is tough. It means a frequency for the highest consequence class of being lower than 10^{-7} per year. However it will be a company's self-imposed policy and can pay off. As a consequence of a catastrophic accident a company may even cease functioning due to the bad reputation or image obtained, although the direct economic consequence of an accident may be overcome. The Dutch legal group risk criterion, $FN^2 < 10^{-3}$, for $N = 10$ and the extrapolation for $N = 1$, which are representing the two highest classes of consequence, produces tolerable frequencies of respectively $F < 10^{-5}$ and $F < 10^{-3}$. The line piece AB in the graph of Figure 3 just in the white "optional" region is representing these (F, N)-combinations. This finding is consistent with the fact that the criterion was developed for process industry accidents. However, the increase in number of fatalities is weighed more heavily than increase in financial damage and risk aversion is larger, hence the slope of the line becomes steeper.

In the Netherlands in 1993, a discussion has been held with respect to the safety of the national airport of Schiphol, Amsterdam. Noting that the probability of an accident at takeoff or landing is of the order of $5 \cdot 10^{-7}$ and the number of movements is about 200,000 per year, the probability of a crash would be 0.1 per year. In case of a crash the number of fatalities at the ground, let alone the passengers, would be 50. The probability the plane would hit an inhabited area is considerable. Clearly the simple group risk criterion for 50 fatalities ($4 \cdot 10^{-7}$) is not obeyed. The National Aerospace laboratory (NLR) developed a risk contour map and a full F, N curve, see Figure 4 (National Aerospace Laboratory [NLR], 1993). The 10^{-5} contour is outside the airport's perimeter and on the basis of the usual criterion the (F, N)-curve is unacceptable by several orders of magnitude.

The discussion caused a slight modification of the criteria. The limits for individual risk are limit values under the law and thus cannot be exceeded. The limits for societal

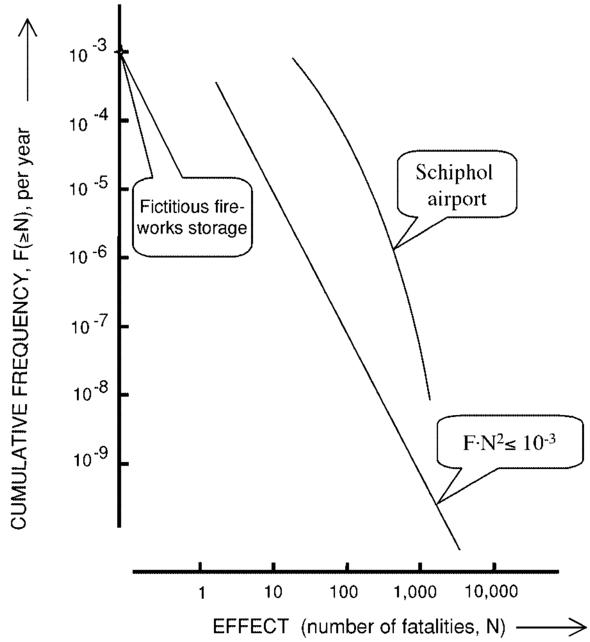


Figure 4 (F, N)-curves: Upper curve represents Amsterdam Schiphol airport calculated by NLR (1993); straight line is the Dutch legal criterion and the point represents the risk of a fictitious 10,000 kg fireworks storage at a distance of 800 m from a living quarter.

risk are set as guidelines. A general ordinance is in preparation, which will strengthen the legal status of these criteria. The current values of these criteria for industrial facilities have been described in a letter of the minister of VROM of 1993. For individual risk the limit is set to 10^{-6}/year for new and 10^{-5}/year for existing situations. The advised limit for societal risk is as before: $F \cdot N^2 < 10^{-3}$. New was that the limits for the transport of dangerous goods have been set in a document by the ministers VROM and of Traffic (V&W) in 1996. For individual risk the limit again is 10^{-6}/year. For societal risk the limit is set as a limit per kilometer route and is set at $F \cdot N^2 < 10^{-2}$.

When the line of reasoning of Vrijling et al. (1995) is followed and substituting the air crash accident values given before, it can be calculated that $E(N_i) = 5$ and mf$\sigma(\mathrm{N_i}) = 16$. Applying the formula proposed by Vrijling, Van Hengel, & Houben (1995) for the nationally acceptable level of group risk: $E(N_i) + k \cdot \sigma(N_i) \approx 50 < \beta_i \cdot 100$ yields a value of $\beta_i \geq 0.5$, which is too high on the scale of voluntariness and also leads clearly to the conclusion not tolerable. The discussion that weakened the $F \cdot N^2 < 10^{-3}$ criterion to a guideline was obviously under the pressure of the economic importance of the national airport. Vrijling et al. (1998) give other examples, such as the failing of dike rings of polders, that do not fulfill the group risk criterion. Further protective measures would require much of resources but seem economically warranted.

In May 2000, a severe explosion of heavy professional fireworks destroyed a living quarter in the city of Enschede with a death toll of 22 people. Emotions went high. As a result, the minister of VROM issued a fireworks decree, approved by Parliament in May 2001. This decree completely abandons the probabilistic risk criterion approach and goes back to an effect criterion. The distance between a fireworks storage and inhabited housing should be larger than 800 m. To test this criterion, a simple risk analysis has been carried out for a fictitious situation of a square storage place of width 1,600 m. In the middle of the square a quantity of fireworks is stored, producing in case of an accident a blast equivalent to 10 tons of TNT. Such quantity is already larger than permitted by the new decree. At one side along the border of the square a living quarter is present of 77 ($=11 \times 7$) dwellings, spaced 50 m from each other in width and 100 m in depth. Three persons inhabit each house. The assumed incident frequency is 10^{-3} per year, which for a storage place is rather high. The analysis results in a point[2] in the F, N graph as shown in Figure 4. The summed number of people killed in such incident is virtually zero. The point is far below the threshold set by the 1988 group risk criterion. The decree appears to be very stringent. The conclusion of the above is that economics and emotions produce much pressure, which results in significant deviations from the original criterion both to a more liberal and to a more stringent regime respectively. It is further clear that criteria for the purpose of land use planning and new structures are more stringent than for existing situations.

Statistics as used in the foregoing are based on the laws of large numbers. When a (rare) accident happens, discussion with the general public in terms of probability is often fruitless.

4. ECONOMIC CONSIDERATIONS

As an alternative to a group risk criterion, economic optimization can be applied. The cost of loss of lives should be included. For the value of lives often the marginal cost to avert a fatality is used. However these values vary considerably, depending on the starting situation, economic strength, the marginal investments to save a life go up to several millions Euro. Fleischmann and Hogh (1989) specify the amounts in Pound Sterling as £ $2 \cdot 10^5$ and £ $3 \cdot 10^6$, respectively. A recent paper from Seiler and Bienz (2001) mentioned for the highest category of involuntariness (comparable with $\beta_i = 0.01$) an amount of 20 million Swiss franc, which is approximately \$$14 \cdot 10^6$. Vrijling and van Gelder (2000a) showed a possible reason for this variability and propose the present value of the net income as a more stable alternative.

Pasman (2000) has given a more extensive overview of the methodology to optimize measures of risk reduction. A recent systematic approach in the process industry is the so-called Layer of Protection Analysis, in which the contributions of independent risk reduction steps are determined to reach a target value of residual risk. The costs of the layers can be weighed against the benefit of the activity as a return on investment. Business interruption costs are important.

There is also the influence of economic benefits on a *macroscale* on the acceptability of the risk of a technical structure such as a tunnel, a dam, and so forth. Such infrastructure can boost the economy of a region or a sector. The benefits can often not make explicit with sufficient accuracy, however, the costs to further reduce the risk. It is interesting to note that such an economic optimization (Van Dantzig, 1956) provided the basis for

[2]Only one scenario has been considered: Full detonation. The number of people killed is the result of summation of all the probabilities times people present in the 77 dwellings. It is also summed over the various lethal mechanisms: direct blast, collapse of houses, tumbling of persons, impact of debris from the store (Van Dongen, Lodder, & Absil, 2000).

the design frequency of the Dutch dikes of 10^{-4} per year. In such cases the final decision becomes a political question.

5. APPEAL FOR A UNIVERSAL SET OF RISK CRITERIA AND GUIDELINES

Citizens have a right to know what risks are imposed on them by large technical structures that provide benefits to society. The examples vary from ro-ro ferries to large dams to chemical plants. In all cases the risks should be mapped and expressed in easy-to-understand figures like individual risk and the *F*, *N* curve. Engineers in various roles are confronted with the problem deciding what risks will adhere to a technical structure that affect life and death of the people using it or taking advantage of its benefits. It cannot be left to an individual engineer to do that on his own judgment. As a community, we shall need a dialogue and inputs from various sides to come to a universal set of risk criteria. From the foregoing it is clear that in particular, on the acceptability/tolerability of the group or societal risk further research is needed. Too many aspects are still unclear.

6. CONCLUSIONS

In recent years, some progress has been made in developing criteria for the social assessment of risks of large technical structures. Most straightforward is the criterion for individual risk. As a first approach worldwide, 10^{-5} per year seems generally acceptable as individual risk for third parties. In the article a flexible approach is proposed that takes the benefits and the voluntariness into account by $\beta_i \cdot 10^{-4}$ [year^{-1}] as a measure for individual risk for employees, users, and third parties.

A thorough analysis of the concept of group or societal risk has been made. Risk aversion has been quantified. It is, however, shown that the present criteria for group risk are not yet solid enough. They do not include the number of installations in the country and they miss the flexibility to withstand economic pressures. A proposal is made to include the number of structures and some flexibility (by means of the factor β_i). Moreover it is advised to pursue always additionally an economic approach of the optimal safety. A broad societal dialogue both at national and international level is needed in order to establish more clearly which factors play a role and which quantitative values are tolerable. The engineering community needs such guidance, because acceptable risk is a basis for design.

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