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Criteria for acceptable risk in the Netherlands

J.K. Vrijling[a], P.H.A.J.M. van Gelder[a] & S.J. Ouwerkerk[a]
[a] Delft University of Technology, P.O. Box 5048, 2600 GA Delft, the Netherlands;
E-mail: j.k.vrijling@ct.tudelft.nl, p.vangelder@ct.tudelft.nl,
sonjaouwerkerk@yahoo.com

Abstract
Risk criteria are reference levels that are set in order to protect people against natural and man-made hazards. In the Netherlands, discussion has risen about the current risk criteria for the field of external safety. Reason for the discussion can be found in the fact that risk has been customarily considered purely as the probability of the loss of life. Other aspects such as economical damage and the degree to which the exposure to the risk is voluntary are not taken into account. To judge risk in a wider context a set of rules for the evaluation of risk, which leads to technical advice in a question that has to be decided politically, is proposed.

1 Introduction

Like many countries, the history of the Netherlands is marked by numerous disasters. Our prehistoric ancestors were threatened by natural hazards like extreme weather, floods and wild animals. Since the industrial revolution man-made hazards such as industrial accidents, train derailments, tunnel fires and airplane crashes also disrupt society on a regular basis (Jonkman et al, 2003). One of the first signs of the man-made hazards of the industrial revolution in the Netherlands was the explosion of a powder tower in the centre of Delft in 1654, resulting in the destruction of two hundred houses and the deaths of about hundred citizens. But also today the inhabitants of the Netherlands are frequently startled by the occurrence of both natural and man-made hazards. For example in 1953, a large part of the Netherlands was flooded due to a severe northwestern storm and over 1800 people lost their lives. Almost 40 years later, in 1992, one of the most devastating man-made hazards occurred: an Israeli cargo plane crashed into a 12-story apartment block in the Amsterdam suburb of Bijlmer. At least 39 people (reported) on the ground and all 4 people aboard the aircraft were killed. In May 2000 the thinking about safety and risks in the Netherlands took a new direction. A disaster occurred in Enschede, a city in the east of the Netherlands, that nobody had thought possible. The explosion of a firework warehouse wiped out an entire residential area. Thousands of buildings were damaged and there were about 20 fatalities.

A risk-free society without risk is not possible and not desirable, as risky activities are an engine for economic growth, but in order to prevent that certain inhabitants are exposed to a disproportionately large risk, risk criteria are applied. The current risk criteria in the Netherlands are under discussion. On the one hand, risky activities on occasion do not comply with the risk criteria. An example is the expansion of the Dutch national airport Schiphol, where risk criteria have been adapted in order to facilitate growth of the airport. On the other hand, some activities satisfy the risk criteria, but are not allowed to take place. An example is the nuclear power plant at

Borssele. Many people want the plant to be closed down, disregarding the fact that the plant complies amply with both national and international norms. Apparently, no consensus exists about the acceptability of risk as laid out by De Hollander and Hanemaaijer (2003).

Today, large interest exists in the Netherlands in the responsible management of risks (Advisory Council for Transport, Public Works and Water Management and the Council for Housing, Spatial Planning and the Environment, 2003). This paper proposes a framework that can serve as a rational basis for technological design. Although its focus is on the Dutch situation the broad outline is generally applicable.

2 Risk policy in the Netherlands

In order to protect the inhabitants of the Netherlands against risk resulting from dangerous activities, risk criteria are set. Risk criteria are reference levels against which the results of a risk analysis should be assessed (Vrouwenvelder et al, 2001). The first risk criteria date back from 1810 when the emperor Napoleon issued a decree stating that a permit was needed to operate an industry (Ale, 2002). In the imperial decree, a distinction was made between activities that were allowed inside cities and activities that were only allowed at certain distances outside housing development. It was not until 1960 that probabilistic methods were introduced in the risk policy. Van Dantzig (1956) and Van Dantzig and Kriens (1960) used an economical optimization of the height of the flood defenses along the Dutch coast resulting in a minimum safety level of main sea dikes of 10^{-4}/yr. The external safety policy in its current form originated in the beginning of the 1980s, when it became clear that the use of LPG would increase considerably (Bottelberghs, 2000). In those years an evaluation system was developed that was based on quantitative assessment of risks and quantitative criteria for decisions on risk acceptability. Nowadays, risk assessment techniques are applied in policy and regulation for several fields, such as the use of airports or the transport of hazardous materials.

In the current Dutch risk policy the specified level of harm is considered from two points of view. One is the point of view of the individual, who decides to undertake an activity weighing the risks against the direct and indirect personal benefits. The individual risk for a point location around a hazardous activity is defined as the probability that an average unprotected person (hypothetically) permanently present at that point location, would get killed due to an accident at the hazardous activity (Bottelberghs, 2000). Individual risk depends on the geographic position and can be presented as iso-risk contours on a map by drawing lines that connect locations with the same level of risk. The iso-risk contours give information about the risk at a certain location, regardless whether people are present at that location or not. The second point of view is the one of the society, considering whether or not an activity is acceptable in terms of the risk-benefit trade off for the total population. The societal risk for a hazardous activity is defined as the probability that a group of more than N persons would get killed due to an accident at the hazardous activity area (Bottelberghs, 2000). Societal risk is characteristic for the hazardous activity in combination with the population density in the surroundings. It can be presented in the form of a probability mass function: an fN-curve. In an FN-curve, however, the probability of exceedance or cumulative frequency, $F(\geq N)$, of N or more fatalities per year is plotted, where $F(\geq N) = \Sigma f(N)$, summed from N to N_{max}. Figure 1(a,b) shows an example of both a probability mass function and a frequency of exceedance curve.

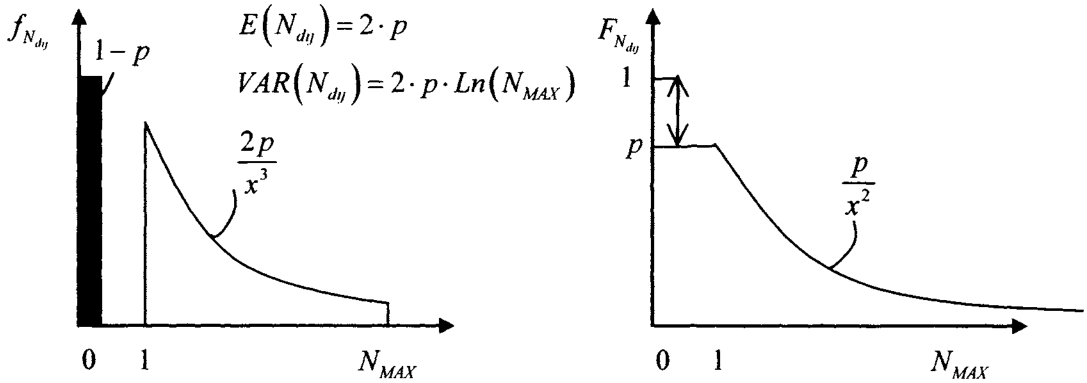

Figure 1 (a) probability mass function for the number of deaths by an inverse quadratic Pareto; (b) probability of exceedance curve for the number of deaths by an inverse quadratic Pareto.

For both risk criteria limits have been set (Ale and Piers, 2000). The present values of these limits for industrial activities are determined by the Ministry of Housing, Spatial Planning and the Environment (VROM). The individual risk limit is set to 10^{-6}/yr for new situations and 10^{-5}/yr for existing situations. These are limit values under the law, which means that they cannot be exceeded. The societal risk limit is set at $F=10^{-3}/N^2$, which serves as a guideline. In practice, not all activities comply with the current risk criteria. To illustrate the problems concerning the current risk criteria, they are applied below to a number of activities, namely the national airport Schiphol, LPG-stations and road safety.

Schiphol

At Schiphol national airport about 200,000 planes leave and arrive every year bringing the total number of movements to 400,000 per year. As Schiphol is surrounded by inhabited areas this leads to the exposure of a considerable amount of people to risks above the individual risk level (Ale and Piers, 2000). In 2001, almost 4100 people were exposed to risks larger than the VROM-limit of $1 \cdot 10^{-6}$/yr and about 50 people were even exposed to risks larger than $1 \cdot 10^{-5}$/yr. The societal risk criterion is exceeded as well. Figure 2 shows that the probability of an accident with 100 or more fatalities is equal to once in 70,000 years, while the limiting value according to VROM requires once in 1,000,000 years.

In 2003, the government adapted a new policy in order to control the further growth of the risk. The policy states that it is not allowed to build within the 10^{-5}-contours and that the current safety situation may not deteriorate. In 2010, no inhabitants will be allowed within the $5 \cdot 10^{-5}$-contours. Apparently, the economic importance of Schiphol allows a larger risk for Schiphol than for other industrial activities.

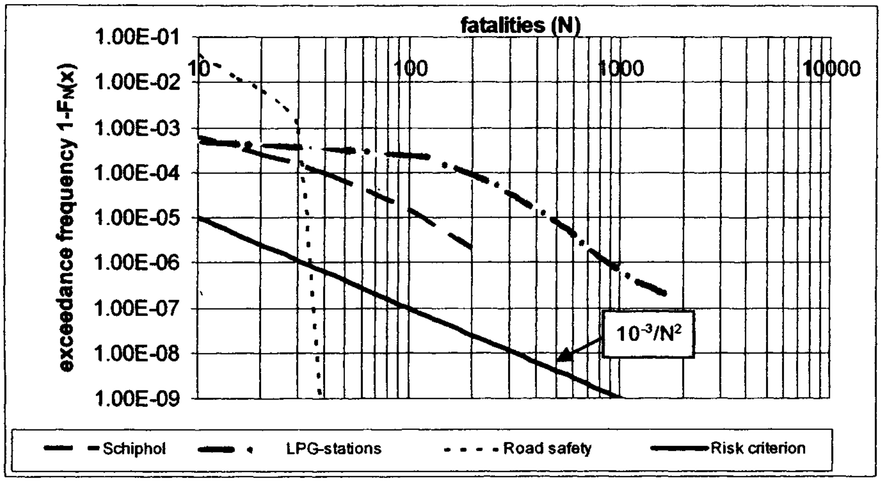

Figure 2 FN-curve (adapted from: National Institute for Public Health and the Environment, 2004).

LPG filling stations

About 2200 LPG filling stations are situated in the Netherlands. A part of these stations are located in inhabited areas, resulting in the exposure of 29,000 people to risks larger than 10^{-6}/yr of which more than 900 people were exposed to risks larger than 10^{-5}/yr in 2003. The presence of LPG-stations leads also to a large exceedance of the societal risk criterion (see figure 2): the probability of an accident with more than 100 fatalities is once per 5000 year.

The Dutch government has announced a three-year restructuring project involving approximately 200 LPG filling stations (Ministry of Housing, Spatial Planning and the Environment, 2004). EUR 15 million is earmarked to finance the removal of all LPG filling stations with facilities within the 10^{-5}-contours.

Road safety

In the Netherlands almost 1100 people die in the traffic every year. Given a population of 16 million people and assuming that every inhabitant of the Netherlands is exposed to risks resulting from traffic, this implies an individual risk of $1.4 \cdot 10^{-4}$ for each citizen, which exceeds amply the individual risk criterion of $1 \cdot 10^{-6}$ /yr. In view of societal risk, it is a smaller problem: most of the traffic accidents cost less than 10 fatalities. However, bus accidents can cost 20 or 30 lives. As can be seen in figure 2, the FN-characteristics of road safety result in a steep line.

The government wants the number of fatalities to be reduced to 980 in 2006 (Ministry of Transport, Public Works and Water Management, 2004). This would result in a reduction of the individual risk from $1.4 \cdot 10^{-4}$ to $1.6 \cdot 10^{-4}$ per year, which amounts to a large exceedance of the individual risk criterion set by VROM. Apparently, a daily activity with personal benefit and a relative high degree of voluntariness is more acceptable to society.

3 A framework for the acceptability of risk

In the Dutch risk policy, risk is narrowed down to the probability of the loss of life. However, the concept 'risk' involves many dimensions: it is characterized by a mixture of both technical and non-technical aspects. Technical scientists determine risk by measurement and calculation. In this approach, risk is frequently defined as 'the product of the probability of an event and its (monetary) consequences'. Probabilities and consequences of an event are quantified and combined in a risk number, which is used as the base for decision-making. Non-technical scientists attribute much value to the perception of risk. Risk perception deals with the judgments people make, when they are asked to characterize and evaluate hazardous activities and technologies. Vlek (1996) compiled a list of basic dimensions underlying perceived riskiness (table I).

Table I basic dimensions underlying perceived riskiness (adapted from Vlek (1996)).

1. Potential degree of harm or fatality
2. Physical extent of damage (area affected)
3. Social extent of damage (number of people involved)
4. Time distribution of damage (immediate and/or delayed effects)
5. Probability of undesired consequence
6. Controllability (by self or trusted expert) of consequences
7. Experience with, familiarity, imaginability, of consequences
8. Voluntariness of exposure
9. Clarity, importance of expected benefits
10. Social distribution of risks and benefits
11. Harmful intentionality

It is assumed that acceptable risk should be seen in a wider context. Since it cannot be judged separately from other aspects of the activity. The acceptance can only be understood in a cost-benefit framework in the widest sense. Therefore, a set of rules is proposed, using two points of view: a personal and a societal. Personal gain, national gain, capital outlays, running costs, damage to the environment, and the risk play a part in the weighing process. As this complicated process cannot be adequately modeled, two crude approximations are proposed in this paper. The first is to accept the pattern of the accident statistics as the outcome of the cost-benefit weighing. The second is a risk-oriented technical cost-benefit model that expresses all consequences of failure in monetary terms.

Personally acceptable level of risk

The smallest-scale component of the social acceptance of risk is the personal cost-benefit assessment by the individual. Since attempts to model this appraisal procedure quantitatively are not feasible, it is proposed to look at the pattern of preferences revealed in the accident statistics. The fact that the actual personal risk levels connected to various activities show statistical stability over the years and are approximately equal for the Western countries indicates a consistent pattern of preferences. The probability of losing one's life in normal daily activities such as driving a car or working in a factory appears to be one or two orders of magnitude lower than the overall probability of dying. Only a purely voluntary activity such as mountaineering entails a higher risk (figure 3). This observation of public tolerance of 1000 times greater risks from voluntary than from involuntary activities with the same benefit was already made by Starr (1969).[1]

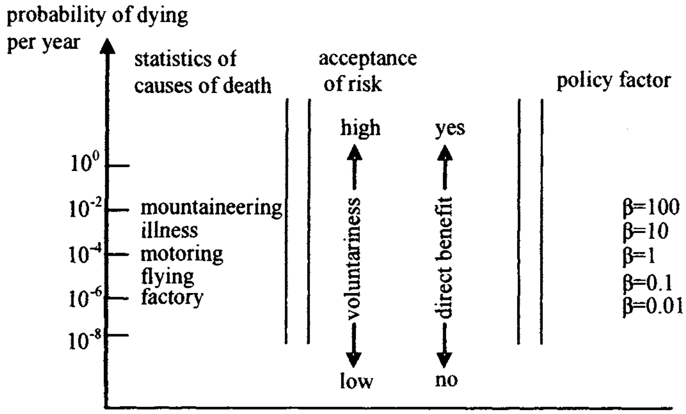

Figure 3 *personal risk in Western countries, deduced from the statistics of causes of death and the number of participants per activity.*

In view of the consistency and the stability, apart from a slightly downward trend due to technical progress, of the death risks presented, it seems permissible to use them as a basis for decisions with regard to the personally acceptable probability of failure in the following way:

$$P_{fi} = \frac{\beta_i \cdot 10^{-4}}{P_{d|fi}} \tag{1}$$

where P_{fi} is the yearly probability of dying and $P_{d|fi}$ denotes the probability of being killed in the event of an accident. In this expression the policy factor β_i varies with the degree of voluntariness with which an activity i is undertaken and with the benefit perceived. It ranges from 100, in the case of complete freedom of choice like mountaineering (P_{fi},= 0.1 = 100*$10^{-4}/10^{-1}$) to 0.01 in the case of an imposed risk without any perceived direct benefit.
A proposal for the choice of the value of the policy factor β_i as a function of voluntariness and benefit is given in table II. It should be noted that a β_i-value has to be chosen for each threatened group, that differs in relation to the activity. For instance, the pilots, passengers and people living under the flight paths each have a specific relation to air travel and consequently different visions on the acceptability of a certain level of risk.

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[1] It is noted that people tend to reject risks when asked directly (Fischhoff, 1990). However, in their more anonymous role as a citizen of the society they effectively accept it.

Table II the value of the policy factor β_i as a function of voluntariness and benefit.

β_i	Voluntariness	Direct benefit	Example
100	Completely voluntary	Direct benefit	Mountaineering
10	Voluntary	Direct benefit	Motor biking
1.0	Neutral	Direct benefit	Car driving
0.1	Involuntary	Some benefit	Factory
0.01	Involuntary	No benefit	LPG-station

Societal acceptable level of risk

The base of the framework with respect to societal risk in the Netherlands, is an evaluation of risks due to a certain activity on a national level. The risk on a national level is the aggregate of the risks of local installations or activities. Without mentioning it specifically, the risk criteria as developed by VROM in the Netherlands are meant to support a systematic appraisal by the local authorities of a single installation or activity.

If a risk criterion is thus defined on a local level the height of the national risk criterion is determined by the number of locations, where the activity takes place and by the probability mass function of the consequences of an accident. The acceptability of the resulting national norm has to be assessed separately, as it was not intentionally formulated.

It seems preferable to start with a risk criterion on a national level and to evaluate the acceptable local risk level, in view of the actual number of installations, the cost-benefit aspects of the activity and the general progress in safety, in an iterative process with, say, a 10-year cycle (figure 4).

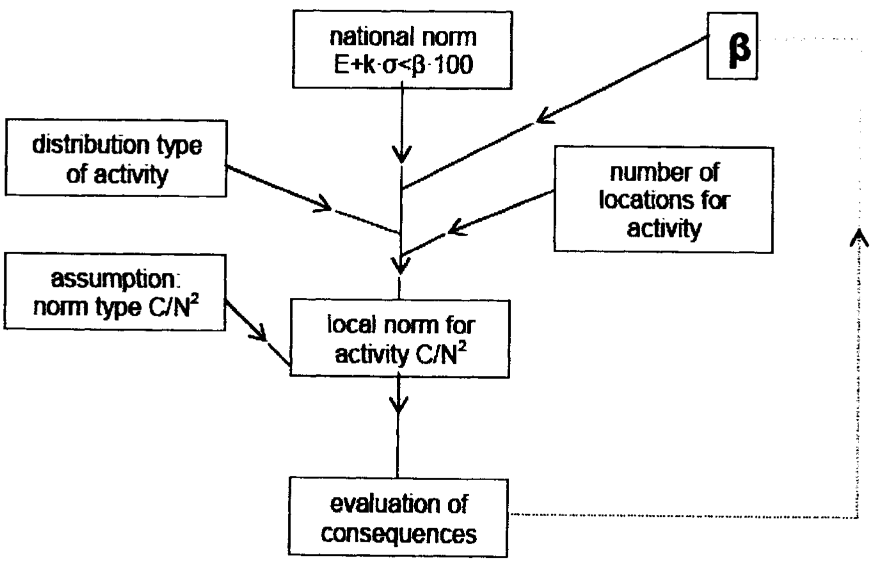

Figure 4 flowchart for risk management

Nationally acceptable level of risk
The determination of the socially acceptable level of risk starts from the assumption that the accident statistics reflect the result of a social process of cost-benefit appraisal. If these statistics reveal the preferences, a standard can be derived from them. It can be shown that the very low probabilities of a fatal accident, which appear socially acceptable, are perceptible using the concept of the circle of acquaintances as an instrument of observation. The recurrence time of an accident, claiming the life of an acquaintance from the circle, is of the order of magnitude of a human life span. To establish a norm for the acceptable level of risk for engineering structures it is more realistic to base oneself on the probability of a death due to a non-voluntary activity in the factory, on board a ship, at sea, etc., which is approximately equal to 1.4×10^{-5}/year, than on the number of casualties in the car traffic, which seems on the verge of acceptance. If this observation-based frequency is adopted as the norm for assessing the safety of activity i, then after rearranging the expression, and adopting a rather arbitrary distribution over some 20 categories of activities, each claiming an equal number of lives per year, the following norm is obtained for an activity *i* with N_{pi} participants in the Netherlands:

$$P_{fi} \cdot N_{pi} \cdot P_{d|fi} < \beta_i \cdot 100 \tag{2}$$

Note that the factor 100 is country-specific and based on: the value of the minimum death rate of the population, the ratio of the involuntary accident death rate (exclusive diseases) with the minimum death rate, the number of hazardous activities in a country (in average 20 sectors) and the size of the population of the country. Comparing this multiplication factor for the Netherlands (MF_{NL}) with the factor for South Africa (MF_{SA}), the factor for South Africa appears to be about 7 times higher than for the Netherlands:

$$MF_{NL} = \frac{10^{-4} \cdot 15 \cdot 10^6}{7 \cdot 20} \approx 100$$

$$MF_{SA} = \frac{10^{-3} \cdot 45 \cdot 10^6}{3 \cdot 20} \approx 750$$

Formula (2) states that an activity is permissible as long as it is expected to claim fewer than $\beta_i \cdot 100$ deaths per year. It does not account for risk aversion, which will certainly influence acceptance by a community or a society. Relatively frequent small accidents are more easily accepted than one single rare accident with large consequences, although the expected number of casualties is equal for both cases.[2] The standard deviation of the number of casualties will reflect this difference.

Risk aversion can be represented mathematically by increasing the mathematical expectation of the total number of deaths per year, $E(N_{di})$, by an appropriate multiple k of the standard deviation before the situation is tested against the norm:

$$E(N_{di}) + k \cdot \sigma(N_{di}) < \beta_i \cdot 100 \tag{3}$$

[2] It is noted that Slovic et al. (1994) shed doubt on this assumption, but here risk aversion is adopted.

where k = risk aversion index. To determine the mathematical expectation and the standard deviation of the total number of deaths occurring annually in the context of activity i, it is necessary to take into account the number of independent places N_{Ai} where the activity under consideration is carried out.

The norm with k = 3 is tested for several activities in the Netherlands by Vrijling et al. (1995). The agreement between the norm for reasonable values of N_{Ai} and $0.01 < \beta_i < 100$ and the actual risks accepted in practice seems to support the model.

Locally acceptable level of risk

The translation of the nationally acceptable level of risk to a risk criterion for one single installation or location where an activity takes place depends on the distribution type of the number of casualties for accidents of the activity under consideration. In order to relate the new local risk criterion to the present one proposed by VROM ($C_i = 10^{-3}$), a societal risk criterion of the following type is preferred:

$$1 - F_{N_{dij}}(x) < \frac{C_i}{x^2} \text{ for all } x \geq 10 \tag{4}$$

where x is the number of deaths.

Assuming a Bernoulli distribution (a distribution that limits the outcomes to zero or N fatalities) for the number of casualties at each of N_{Ai} independent locations, the expected value and the standard deviation of the casualties at national level are:

$$\begin{aligned} E(N_{di}) &= N_{Ai} \cdot p_{fi} \cdot N_{dij|f} \\ \sigma(N_{di})^2 &= N_{Ai} \cdot p_{fi} \cdot (1 - p_{fi}) \cdot N_{dij|f}^2 \approx N_{Ai} \cdot p_{fi} \cdot N_{dij|f}^2 \end{aligned} \tag{5}$$

where N_{Ai} is the number of independent locations, p_{fi} and $N_{dij|f}$ are the probability of failure at a location and the number of fatalities given failure, respectively.

If the Bernoulli distribution of the number of casualties at each location complies with criterion (4), it follows that for a location $E(N_{dij}) \leq C_i/N$ and $\sigma(N_{dij}) \leq C_i$. Substituting these values in equation (5) and subsequently in the national criterion (3), and solving the resulting quadratic equation in p_{fi}, gives for the value of C_i:

$$C_i = \left[\frac{-k \cdot \sqrt{N_{Ai}} + \sqrt{k^2 \cdot N_{Ai} + 4 \frac{N_{Ai}}{N} \cdot \beta_i \cdot 100}}{2 \frac{N_{Ai}}{N}} \right]^2 \tag{6}$$

If the expected value of the number of deaths is much smaller than its standard deviation, which is often true for the rare calamities studied here, the previous result reduces to:

$$C_i \approx \left[\frac{\beta_i \cdot 100}{k \cdot \sqrt{N_{Ai}}} \right]^2 \tag{7}$$