Chapter 5

THE RISK ASSESSMENT METHODOLOGY

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5.1 INTRODUCTION

The objectives of the risk assessment methodology can be identified as:
1. Identify the initiating events and the event sequences that might contribute significantly to risk.
2. Provide realistic quantitative measures of the likelihood of the risk contributors.
3. Provide a realistic evaluation of the potential consequences associated with hypothetical accident sequences.
4. Provide a reasonable risk based framework for making decisions regarding technological objects such as refineries or nuclear power plant design, operation and siting.

5.2 SHORTCOMINGS OF THE LINEAR RISK

The equation for the linear risk:

$$R = \sum_{i=1}^{M} p_i c_i \tag{1}$$

is unsatisfactory for the reason that in it, the risk from a large number of small accidents would be the same as from a small number of large accidents, if the total number of effects, such as fatalities, is the same for each case.

In it exists a hypothesis that:

> "The perceived risk of a large accident is greater than the equivalent risk from many small accidents, because of human nature and the emphasis of the news media on the unusual news worthy events."

For instance, 50,000 [traffic accidents/year] is not news worthy, whereas 1 single accident killing 50,000 persons is very news worthy. This introduces nonlinearity into the process of risk assessment.

A suggested modification to the risk equation is:

$$R = \sum_{i=1}^{M} p_i c_i^{\nu} \tag{2}$$

where: $\nu > 1$ is a number introduced to account for the effects of perception.

A value of $\nu = 1.2$ has been suggested by the Nuclear Regulatory Commission (NRC).

The perception problems can be eliminated if the risk is considered as an ordered pair composed of probability and consequence without a relationship between the numbers of the pair:

$$(p_i, c_i)$$

where the p_i's are probabilities associated with consequences c_i's, such as fatalities.

A composite risk curve would then envelop many low risk accidents, where each dot represents a single accident.

Two bounds would thus confine the risk space:

1. A curved line that envelops the risk points.
2. A straight line of the linear risk (if a log-log scale is used) defined as the curve of:

$$p.c = k \qquad (3)$$

where k is the constant risk curve.

One must note that there are uncertainties associated with both the probabilities p_i and the consequences c_i.

The uncertainties are presented as Gaussian, normal or bell shaped curves given different names:

a) Probability density functions (pdf)
b) Probability distribution
c) Distribution.

These could be either discrete or continuous distributions.

5.3 THE PRIMARY DEFINITION OF RISK

To formally define risk, we assume the existence of n potential outcomes in the doubtful future. Risk can then be defined as a collection of n pairs:

$$Risk \equiv \{(L_1, O_1), (L_2, O_2), \ldots, (L_i, O_i), \ldots\}, \forall i = 1, 2, \ldots, n \qquad (4)$$

where: O_i= Outcome i
L_i = Likelihood of i.

EXAMPLE 1

The risk of throwing a coin can be construed to be:

$$Risk \equiv \left\{ \left(\frac{1}{2}, H \right), \left(\frac{1}{2}, T \right), ..., (0, E) \right\}$$

with the possible outcomes:
H = Head
T = Tails
E = Edge.

EXAMPLE 2

The risk of throwing a single die becomes:

$$Risk \equiv \left\{ \left(\frac{1}{6}, 1 \right), \left(\frac{1}{6}, 2 \right), \left(\frac{1}{6}, 3 \right), \left(\frac{1}{6}, 4 \right), \left(\frac{1}{6}, 5 \right), \left(\frac{1}{6}, 6 \right) \right\}$$

EXAMPLE 3

The risk of a weather forecast could be expressed as:

$$Risk \equiv \{ (0.7, Clear\ sky), (0.3, Rain) \}$$

5.4 RISK PROFILE OR RISK CURVE

The risk profile is the distribution pattern of the likelihood-outcome pair. It can be a discrete distribution like in the three examples, or it could be a continuous distribution or probability density function in short, pdf

$$pdf : f(x) \tag{5}$$

The variable x could represent any random variable such as “monetary outcome.”

One also defines the cumulative risk profile as the cumulative distribution function (cdf):

$$cdf : F(x) = \int_{-\infty}^{x} f(x)dx \tag{6}$$

which is the probability of the outcome being less than x (<x).

The probability of the outcome exceeding x (>x) is given by the complementary cumulative risk profile:

$$\bar{F}(x) = 1 - F(x) = 1 - \int_{-\infty}^{x} f(x)dx = \int_{x}^{\infty} f(x)dx \tag{7}$$

5.5 FARMER CURVES

Introduced by Farmer, Farmer's curves are complementary cumulative risk profiles of accident outcomes. As an example, the horizontal axis could display the variable: "Accident severity," or "Number of fatalities." The vertical axis would show the "Frequency of fatalities exceeding x" which is a complementary cumulative risk profile.

One should note the fatalities usually start at a value of unity in actual risk problems. The inclusion of a zero fatality in the Farmer curve requires the display of an unreasonably wide range of likelihoods, especially if a logarithmic curve is used.

Figure 1 shows an example of a Farmer's curve or risk profile.

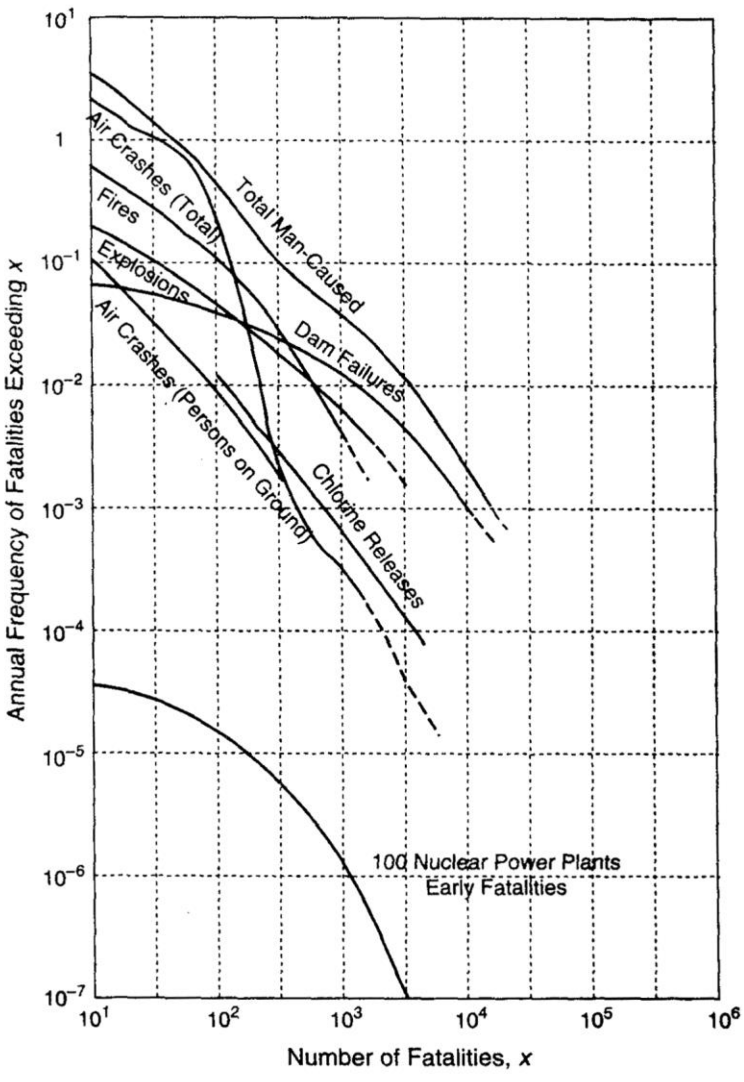

Figure 1. Farmer curve displaying the annual frequency of x or more fatalities from man made sources of risk, compared to the early fatalities risk profile of 100 operational nuclear power plants.

5.6 OBJECTIVE AND SUBJECTIVE LIKELIHOOD

The Likelihood concept is not always exact and is based on subjective evaluation. Table 1 shows a list of likelihoods and their associated outcome categories.

Table 1. Likelihoods and possible outcome categories.

Likelihood		Outcome Category
Measure	**Unit**	
Probability	Unitless	Physical
Percentage	Per demand or operation	Physiological
Density	Per unit outcome	Psychological
Frequency	Per unit outcome	Financial
Ratio	During time interval	Time, opportunity
Verbal expression	Per mileage	Societal, political

Examples of verbal expressions are: rare, possible, plausible, and frequent. These are examples of linguistic variables that cannot be described by probability theory but can be quantified using possibility theory concepts.

5.7 CONDITIONS FOR THE EXISTENCE OF RISK

The following conditions must exist for risk to be defined:

1. Existence of uncertainty

Risk must be represented by *plural* outcomes with positive likelihoods. Thus risk exists under a necessary and sufficient condition, or if and only if (iff) $n \geq 2$, or more than one outcome with positive likelihoods during a specified future time interval.

Special case I: A situation with 2 opposite outcomes with equal likelihoods may me the most risky one.

Special case II: If future outcome is uniquely known, then n = 1, and hence guaranteed, then no risk exists.

2. Anonymity of victims

Assuming a USA population of 300 x 10^6 persons, over a lifetime or a 70 years period:

Risk of yearly fatal accident to the USA population over a 70 years lifetime=

$$\{(10^{-6}, \textit{fatality}),(1-10^{-6}, \textit{survival})\} \quad (8)$$

This expresses the lifetime likelihood of a type of fatal accident, e. g. motorcycle accident, accidental falls, etc., to an individual in the USA population as:

$$10^{-6}\left[\frac{death}{person.year}\right]$$

The additional deaths from this type of accident in the 300 million persons USA population becomes:

$$300\times10^{6}\times10^{-6}\left[persons.\frac{death}{person.year}\right]$$
$$=300\left[\frac{deaths}{year}\right]$$

The loss of 300 additional deaths is likely. This can be viewed as acceptable risk in comparison to the 2x10^6 [deaths/year] annual deaths in the USA.

Incidentally, the likelihood of death per year in the USA is:

$$Likelihood=\frac{2\times10^{6}}{300\times10^{6}}\left[\frac{deaths}{year}.\frac{1}{persons}\right]$$
$$=\frac{1}{150}\left[\frac{deaths}{person.year}\right]$$

The likelihood of the fatal accident per year over a 70 years lifetime is:

$$10^{-6}\times70=7\times10^{-5}\left[\frac{death}{person.year}.year\right],\left[\frac{death}{person}\right]$$

The total number of that fatal accident in the USA population is:

$$7x10^{-5}\times300\times10^{6}=21,000\left[\frac{death}{person}\ person\right],[deaths]$$

If 300 deaths by cancer of all workers in a factory are caused over a lifetime by some chemical totally confined to the factory and never released to the environment, then localization in the factory is not a risk in the usual sense.

Further, if the names of victims are known beforehand, it becomes a crime rather than a risk.

The USA population is not suitable anymore as a reference. It should be replaced by the group of people in the factory. Thus:

Risk of death by chemical exposure:

$$\{(1,\ fatality),(0,survival)\} \tag{9}$$

which is obviously unacceptable.

3. Prediction before realization

No risk exists after the time point when an outcome is realized. For instance, the risk of travel in an airplane ceases to exist after either a safe landing or a disastrous crash. Risk exists only at the predictive or anticipatory stage before its realization.

4. Risk is associated with meta-uncertainty

The risk profile has associated uncertainties that are called "meta-uncertainties." The range of uncertainty can span 3 orders of magnitude.

The error bands are a result of:

1. Uncertainty in the outcome levels O_i.
2. Uncertainty in the frequencies or likelihoods L_i.

The existence of meta-uncertainty makes risk management or decision making under risk difficult and controversial.

5.8 RISK ASSESSMENT AND MANAGEMNENT

The purpose of "risk assessment" is the derivation of risk profiles posed by a given situation. It enumerates the outcomes and quantifies the likelihoods.

As an example of risk assessment is the process of Probabilistic Risk Assessment (PRA) for nuclear power plants. This process of risk assessment involves:

1. Enumeration of the sequence of events that could lead to core meltdown.
2. Clarification of containment failure modes.
3. Estimate their probabilities and timings.
4. Identification of quantity and chemical form of radioactivity released if the containment is breached: the source term.
5. Modelling of dispersion of radionuclides in the atmosphere.
6. Modelling of emergency response effectiveness involving sheltering.
7. Evacuation and medical treatment.
8. Dose-response modeling in estimating the health effects on the population exposed.

On the other hand, in the process of "risk management," one gets involved in:

1. Proposing alternatives.
2. For each alternative, evaluation of the risk profile.
3. Make safety decisions.
4. Choose satisfactory alternatives to control the risk.
5. Exercise corrective actions.

Table 2 shows a comparison of Risk Assessment and Risk Management.

Table 2. Comparison of risk assessment and risk management.

Risk Assessment	Risk Management
Scientific	Value judgment
Technical	Uses heuristics
Formal	Subjective
Quantitative	Qualitative
Objective	Societal and political

Coupling risk assessment and risk management is designated as Risk Assessment and Management with the acronym: PRAM.