Risk Assessment

Chapter 4

How to measure Risk?

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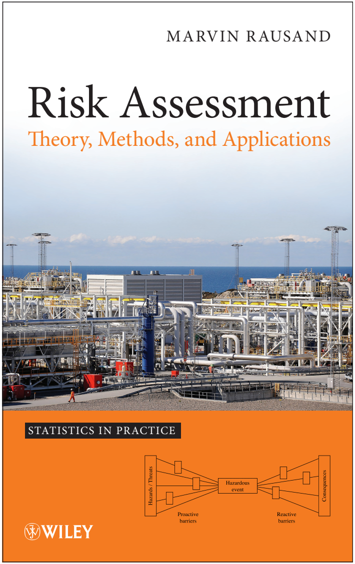
Slides related to the book

Risk Assessment
Theory, Methods, and Applications

Wiley, 2011

Homepage of the book:
http://www.ntnu.edu/ross/books/risk



Objective of the presentation

This presentation will focus on the following issues:

- How do we measure risk?
- Different consequence dimensions require different measures:
  - Life and health
  - Environment
  - Economical

Risk vs. safety performance

☞ Risk indicator: A parameter that is estimated based on risk analysis models and by using generic and other available data. A risk indicator presents our knowledge and belief about a specific aspect of the risk of a *future* activity or a *future* system operation.

☞ Safety performance indicator: A parameter that is estimated based on experience data from a specific installation or an activity. A risk performance indicator therefore tells us what *has happened*.

Measuring risk

Risk is measured at different stages of the accident sequence:

- Frequency of hazardous events
  - Frequency of red-light violations for trains (SPAD – signal passed at danger)
  - Frequency of gas leaks on offshore oil and gas installations
- Accident frequency
  - Frequency of aircraft crashes caused by ATM
- Statistically expected consequences
  - Direct measures, e.g., injuries or fatalities, damage cost
  - Indirect measures, e.g., loss of main safety functions

Individual risk per annum
IRPA

The individual risk per annum (IRPA) is defined as:

$$\text{IRPA} = \Pr(\text{Individual is killed during one year's exposure})$$

As safety performance measure:

$$\text{IRPA}^* = \frac{\text{Observed no. of fatalities}}{\text{Total no. of employee-years exposed}}$$

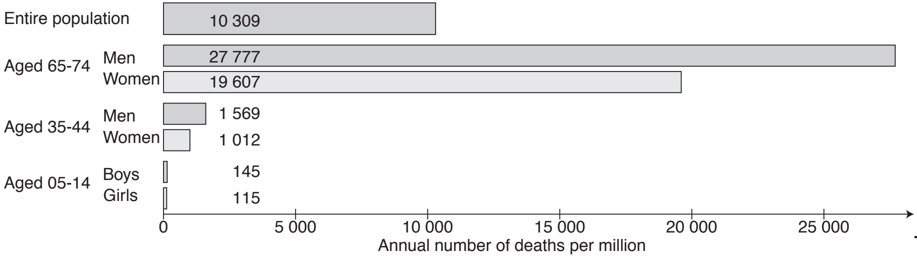
Individual risk per annum

Industry sector	Annual risk	Annual risk
Fatalities to employees	1 in 125 000	$8 \cdot 10^{-6}$
Fatalities to self-employed	1 in 50 000	$20 \cdot 10^{-6}$
Mining and quarrying of energy producing materials	1 in 9 200	$109 \cdot 10^{-6}$
Construction	1 in 17 000	$59 \cdot 10^{-6}$
Extractive and utility supply industries	1 in 20 000	$50 \cdot 10^{-6}$
Agriculture, hunting, forestry and fishing (not sea fishing)	1 in 17 200	$58 \cdot 10^{-6}$
Manufacture of basic metals and fabricated metal products	1 in 34 000	$29 \cdot 10^{-6}$
Manufacturing industry	1 in 77 000	$13 \cdot 10^{-6}$
Manufacture of electrical and optical equipment	1 in 500 000	$2 \cdot 10^{-6}$
Service industry	1 in 333 000	$3 \cdot 10^{-6}$

- Data from "Reducing risks, protecting people" (HSE 2001)

Deaths per million

The number of deaths per million (DPM) in a specified group is sometimes used as a safety performance measure.



The figure shows the DPM for various age groups in the United Kingdom based on deaths in 1999. The 'probability' that one person picked at random will die is $10309/10^6 \approx 1.03\%$

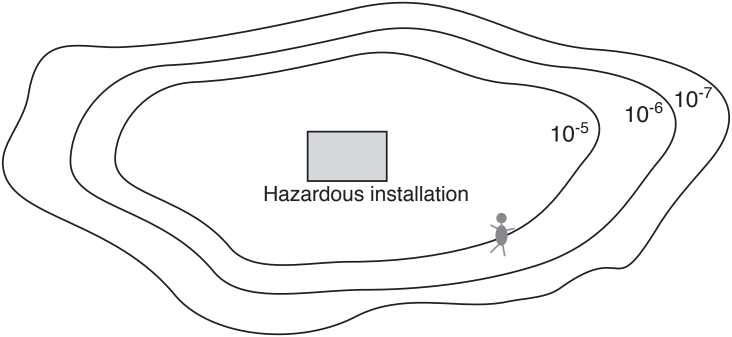
Individual risk index

The individual risk index (IR) is the probability that an average unprotected person, permanently present at a certain location, is killed in a period of one year due to an accident resulting from a hazardous activity. The IR is mainly used for land-use planning.

$$\mathrm{IR}(x, y) = \sum_{i=1}^{m} \lambda_i \cdot \Pr(\text{Fatality at } (x, y) \mid \mathcal{A}_i)$$

where $\mathcal{A}_i$ denotes accident of type i, and λ_i is the frequency of $\mathcal{A}_i$

Risk contour plots



Lost time injuries

A lost time injury (LTI) is an injury that prevents an emplyee from returning to work for at least one full shift. The frequency of LTIs is often used as a safety performance measure:

$$\text{LTIF}^* = \frac{\text{No. of lost time injuries (LTIs)}}{\text{No. of hours worked}} \cdot 2 \cdot 10^5$$

An average employee is working around 2000 hours per year. A total of $2 \cdot 10^5 = 200\,000$ hours is therefore approximately 100 employee-years. If a company has an LTIF* = 10 LTIs per 200 000 hours of exposure, this means that on the average one out of ten employees will experience an LTI during one year.

Potential loss of life

The potential loss of life (PLL) is the expected number of fatalities within a specified population (or within a specified area A) per annum.

The PLL can also be expressed by the individual risk per annum (IRPA) as:

$$\mathrm{PLL}_A = \iint_A \mathrm{IRPA}(x, y)\, m(x, y)\, dx\, dy$$

where $m(x, y)$ is the population density at the location (x, y).

For a population where all n members of the population have the same risk per annum, we have:

$$\mathrm{PLL} = n \cdot \mathrm{IRPA}$$

Fatal accident rate

The fatal accident rate (FAR) is the expected number of fatalities per 10^8 hours of exposure:

$$\text{FAR} = \frac{\text{Expected no. of fatalities}}{\text{No. of hours exposed to risk}} \cdot 10^8$$

If 1 000 persons work 2 000 hours per year during 50 years, their cumulative exposure time will be 10^8 hours. FAR is then the estimated number of these 1 000 persons that will die in a fatal accident during their working life.

Fatal accident rate

Experienced FAR values for the Nordic Countries for the period 1980–1989.

Industry	FAR* (Fatalities per 10^8 working hours)
Agriculture, forestry, fishing and hunting	6.1
Raw material extraction	10.5
Industry, manufacturing	2.0
Electric, gas and water supply	5.0
Building and construction	5.0
Trade, restaurant and hotel	1.1
Transport, post and telecommunication	3.5
Banking and insurance	0.7
Private and public services, defense, etc.	0.6
Total	2.0

Societal risk

$$\text{Societal risk} = \text{Frequency} \times \text{magnitude}$$

- Risk (consequences/time)
- Frequency (events/time)
- Magnitude (consequences/event)

Example:
Road accidents in the United States:

$$\begin{aligned}(15 \cdot 10^6 \text{ accidents/year} \times (1 \text{ death/300 accidents}) \\ = 50\,000 \text{ deaths/year}\end{aligned}$$

Individual risk

$$\text{Individual risk} = \frac{\text{Societal risk}}{\text{Population at risk}}$$

Assume 200 million inhabitants in United States.

$$\frac{50\,000 \text{ deaths/year}}{200 \cdot 10^6 \text{ people}} = 2.5 \cdot 10^{-4} \text{ deaths/person-year}$$

that may be expressed as 25 deaths per 100 000 people.

When do we accept risk?

- When we do not know about the risk.
- When the risk is insignificant.
- When the benefit is high compared to the risk ("it is worth it").

Accepted risk

Activities with a fatality risk greater than $1 \cdot 10^{-3}$ deaths/year to the general public are generally not acceptable.

Cars	$\sim 3 \cdot 10^{-3}$ deaths/person-year
Falls	$\sim 1 \cdot 10^{-4}$ deaths/person-year
Fires	$\sim 4 \cdot 10^{-5}$ deaths/person-year
Drowning	$\sim 4 \cdot 10^{-5}$ deaths/person-year
Firearms	$\sim 1 \cdot 10^{-5}$ deaths/person-year
Poisoning	$\sim 1 \cdot 10^{-5}$ deaths/person-year
Lightning	$\sim 8 \cdot 10^{-7}$ deaths/person-year

Attitudes towards risk

- High risk activities are usually on the order of the Disease mortality rate:

$$10^{-2} \text{ deaths/person-year}$$

- Low risk activities are usually on the order of the Natural hazards mortality rate

$$10^{-6} \text{ deaths/person-year}$$

Issues of acceptable risk

- There is no practical definition
- Its perception varies among industries
- It is very hazard specific
- Even government agencies are not consistent
- There are contemporary comparisons that can be made

Attitudes towards risk

The acceptability towards risk depends on:

- Benefits of activity
- Voluntary nature of activity
- Consequence distribution
- Familiarity
- Frequency
- Control
- Media attention
- Suddenness of consequences
- Dread
- Personal versus societal

Risk tolerance limits

Methods:

- Formal analysis
  - Cost-benefit tradeoffs are rigorously evaluated
- Professional judgment
  - Subjectively based decisions are made by knowledgable experts
- “Bootstrapping”
  - Proposed new risks are compared to risks that already exist

– From Clemens and Mohr (2002)

Risk management options

Id.	Category	Description
R	Reduce	Impose countermeasure to suppress severity or probability
S	Segregate	Prevent one event from causing loss to the whole system
T	Transfer	Give the risk to others (e.g., insure)
A	Avoid	Quit - go into another line of work
A	Accept	Do it anyway

– Based on Clemens and Mohr (2002)

Accident prevention options

- Eliminate hazards
- Prevent initiating events (incidents)
- Add safeguards
- Make safeguards more reliable
- Reduce consequences
- Reduce effects