Risk Assessment
2. The Words of Risk Analysis

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(Version 0.1)

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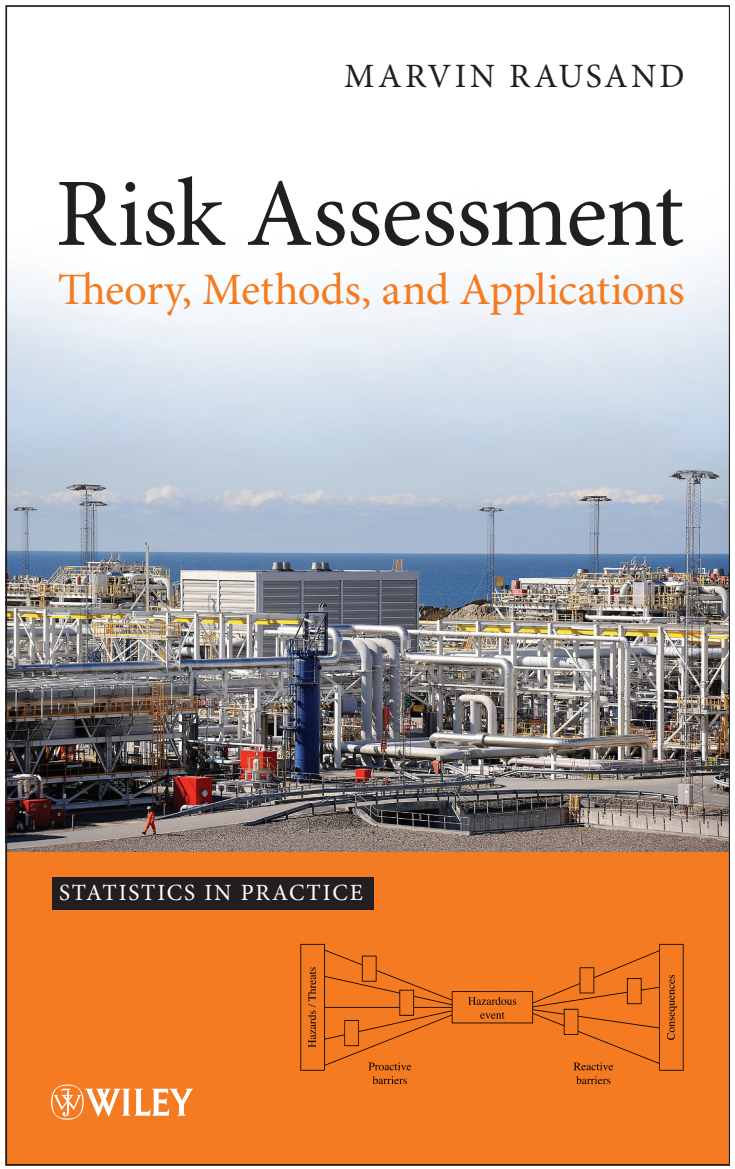
Slides related to the book

Risk Assessment
Theory, Methods, and Applications

Wiley, 2011

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



Objective

The objective of this presentation is to introduce some of the main concepts in risk analysis. Among these are:

- Risk
- Hazardous event
- Accident scenario
- Asset
- Consequence
- Severity
- Accident
- ...and so on

What is meant by risk?

- An expectation of loss?
- An element of uncertainty?
- Related to what may happen in the future?
- Covers both severity and likelihood of a loss?
- Refers to unwanted consequences?

What is risk?

The three fundamental questions

As a start, we define risk as the answers to the three questions:

1. What can go wrong?
2. What is the likelihood of that happening?
3. What are the consequences?

We will come back to a more thorough discussion later in the presentation.

What can go wrong?

The first question

The answer to the first question will be one or more *hazardous events* defined by:

☞ Hazardous event: The first event in a sequence of events that, if not controlled, will lead to undesired consequences (harm) to some assets.

Alternative terms:

Accident initiator, accident initiating event, accidental event, critical event, undesired event, unwanted event, initiating event, TOP event, process deviation, potential major incident (accident), process demand, and so on.

Initiating event

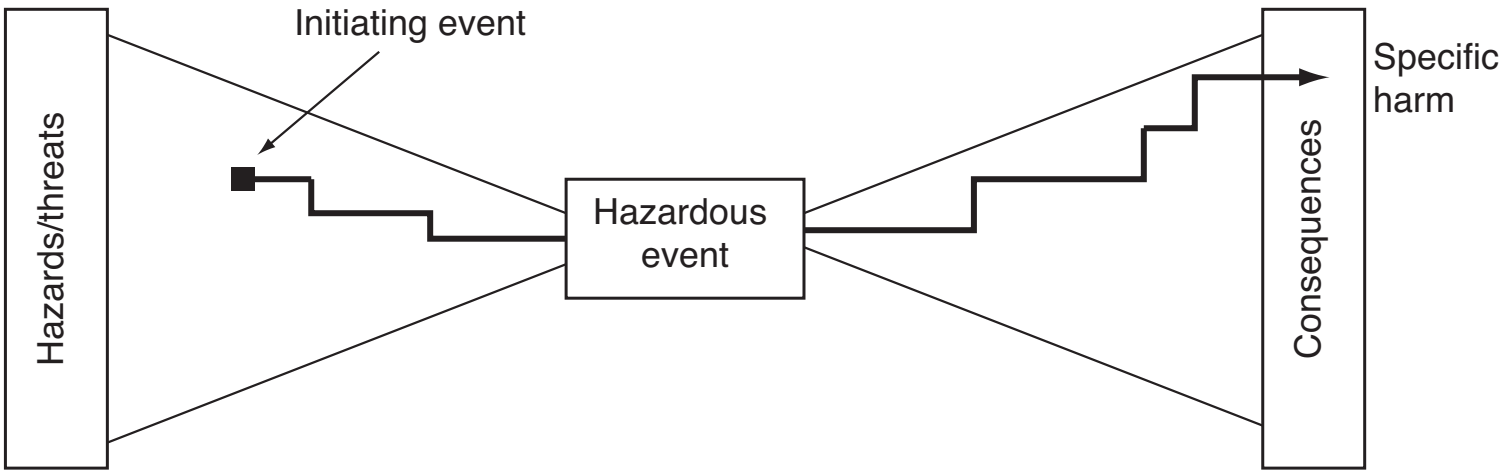
☞ Initiating event (or initiator): An identified event that upsets the normal operations of the system and may require a response to avoid undesirable outcomes.

- Analytical concept
- May be the same as a hazardous event but may also be a different point in the sequence of events.

Accident scenario

☞ Accident scenario: A specific sequence of events from an initiating event to an undesired consequence (or harm).

- The sequence is usually influenced by one or more safety barriers.
- May also be a single event (no barriers involved)



Accident scenario
Example

1. A gas leakage from flange A occurs (i.e., hazardous event)
2. The gas is detected and the alarm goes off (i.e., barrier works)
3. The process shutdown system fails to shut off the gas flow to the flange (i.e., barrier fails)
4. The gas is ignited and a fire occurs
5. The firefighting system functions as intended and the fire is extinguished within approximately 1 hour (i.e., barrier works)
6. No persons are injured, but the accident leads to significant material damage and a 20-days production stoppage (i.e., end event, unwanted consequence, specific harm)

Accident scenarios

Three important categories

☞ Reference accident scenario: A scenario that is representative for a set of accident scenarios that are identified in a risk analysis, where the scenarios in the set are considered likely to occur.

☞ Worst-case accident scenario: The scenario with the highest consequence that is physically possible regardless of likelihood.

☞ Worst credible accident scenario: The highest consequence accident scenario identified that is considered plausible or reasonably believable.

What is the likelihood of that happening?

The second question

The probability of an event E is a number between 0 and 1 (i.e., between 0% and 100%) that expresses the likelihood that the event will occur in a specific situation.

- $\Pr(E) = 1 \Rightarrow$ we know with certainty that event E will occur.
- $\Pr(E) = 0 \Rightarrow$ we are certain that event E will not occur.

Probability and likelihood

Probability and likelihood are not the same in statistical usage – however, they tend to be mixed in the context we are now, including in standards!

What is the likelihood of that happening?

Interpretations of the term probability

- Classical – repeatable experiments with a limited number of outcomes with same probability.
  - Limited applicability, mainly for gamblers!
- Frequentist – repeatable experiments which may give event E or not.
  - Implies that we need to repeat the experiment an infinite number of times to find the probability.
- Bayesian – probability is considered subjective, representing an individual's degree of belief about whether an event will occur or not.

Other approaches

The likelihood p can also be determined based on fuzzy set theory, evidence theory, plausibility theory, and so on, but this is outside the scope of the current book.

Interpretation of probability

- ## Classical/frequentist

  The probability is an "objective" entity and is equal to the long-term (relative) frequency of an event.

  The probability of an event may be estimated on the basis of experience data, or based on symmetry arguments (e.g., for a dice)

- ## Bayesian/subjective

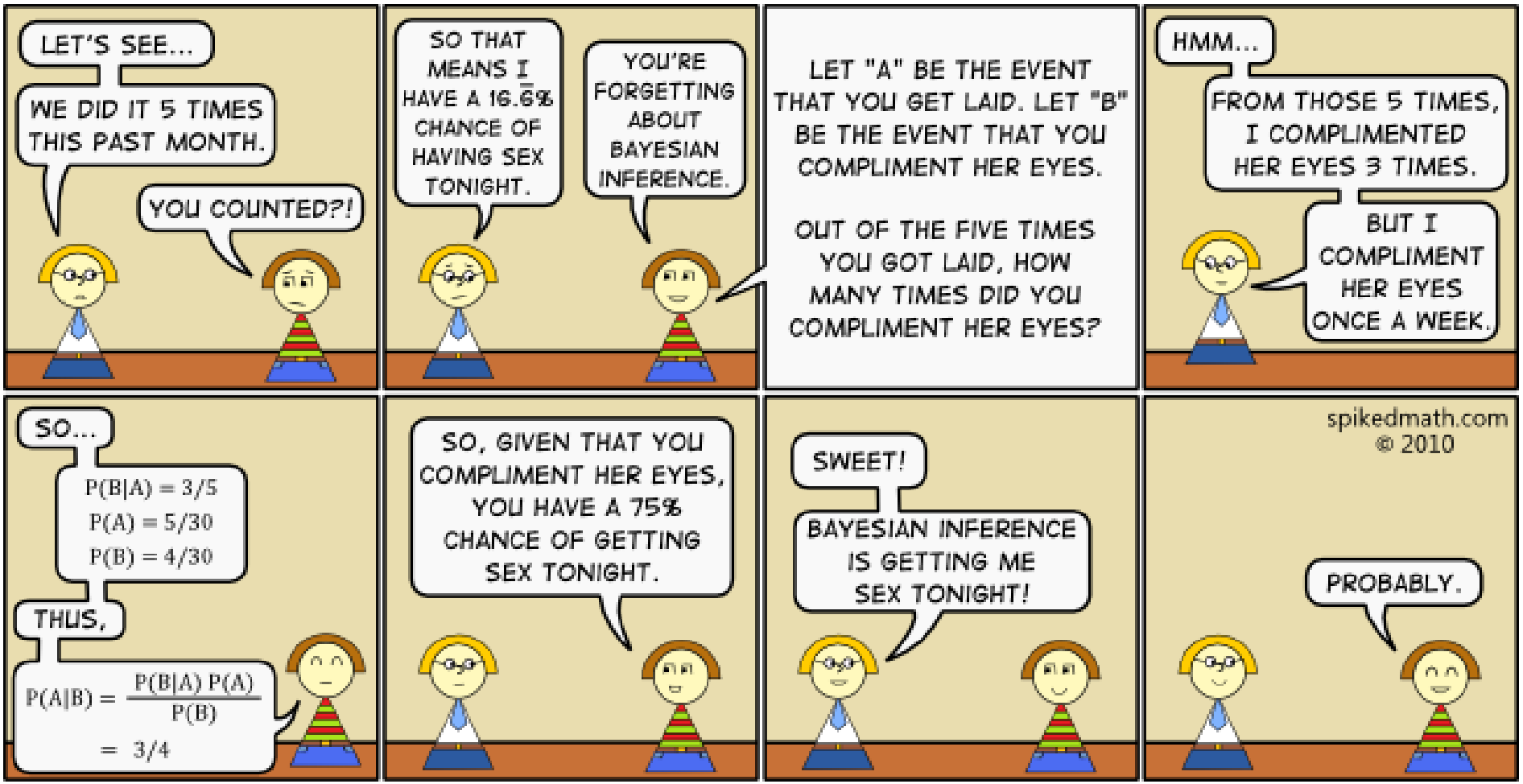
  The probability is a "subjective" measure of my belief about a situation, about the occurrence of an event, or about the truth of a statement.

  "What is the probability that San Fransisco is north of Madrid?" (This statement has no meaning for a classical statistician).

Frequentist or Bayesian?

- The frequentist assumptions are not valid in this context – we are left with the Bayesian approach.
- However, mathematical rules, methods and calculations are not affected by the approach that is taken.
- Interpretation and use of results are different:
  - Degree of belief versus a property of the situation.

Bayesian analysis



Frequency

- Frequency is often used instead of probability in calculations.
  - What is the frequency of fatal accidents in Norway (per year)?
  - What is the frequency of situations that can lead to hazardous events?
- When the frequency is small, e.g., less than 0.01 per year, the calculated probability and frequency will approach the same value.

What are the consequences?

The third question

☞ Asset: Something we value and want to preserve.

Important types of assets are:

- Humans
- The environment
- Material assets
- Production or service
- Performance
- Financial assets
- Historical monuments

Alternative terms:

Target, vulnerable targets, vulnerable assets, victim, recipients, receptor, risk-absorbing items.

Categories of assets

Railway industry

The railway industry sometimes classifies human assets in five categories:

1. Passengers
2. Employees
3. People on the road or footpath crossings of the line
4. Trespassers (who are close to the line without permission)
5. Other persons

Consequences and harm

☞ Harm: Physical injury or damage to health, property, or the environment.

- Consequence categories – classification related to the type of assets affected.
- Most common categories:
  - Loss of life and health
  - Environmental damage
  - Economic loss

Categories of human victims

1. First-party victims: People directly involved in the operation of the system.
2. Second-party victims: People associated with the system as suppliers or users, but exert no influence over it.
3. Third-party victims: Innocent by-standers who have no involvement in the system.
4. Fourth-party victims: Yet-unborn generations and people who will be contaminated in the future by residual substances – including substances that become concentrated as they move up the food chain.

Perrow (1984)

Consequences to people

1. Temporary harm: Injured person will be totally restored and able to work within a period after the accident.

2. Permanent disability: Injured person will get permanent illness or disability. The degree of disability is sometimes given as a percentage.

3. Fatality: The person will die from the harm – either immediately or because of complications. The fatality may sometimes occur a long time after the accident (e.g., due to cancer by radiation after a nuclear accident).

Consequence categories

- Loss of human life
- Personal injury
- Reduction in life expectancy
- Damage to the environment (fauna, flora, soil, water, air, landscape)
- Damage to material assets
- Investigation and cleanup costs
- Business-interruption losses
- Loss of information
- Loss of reputation
- ...and so on

Severity categories

☞ Severity: Seriousness of the consequences of an accident expressed either as a financial value or as a category.

Level	Description	Consequence types		
		People	Environment	Property
1	CATASTROPHIC	Several fatalities	Time for restitution of ecological resources > 5 years	Total loss of system and major damage outside system area
2	SEVERE LOSS	One fatality	Time for restitution of ecological resources 2-5 years	Loss of main part of system. Production interrupted for months
3	MAJOR DAMAGE	Permanent disability, prolonged hospital treatment	Time for restitution of ecological resources < 2 years	Considerable system damage. Production interrupted for weeks
4	DAMAGE	Medical treatment Lost time injury	Local environmental damage of short duration (< 1 month)	Minor system damage. Minor production influence
5	MINOR DAMAGE	Minor injury Annoyance Disturbance	Minor environmental damage	Minor property damage

What is risk?
Abstract definition

We return to the term risk and discuss some possible definitions and interpretations of this term.

An abstract definition of risk is:

☞ Risk: *Uncertainty* about possible, unwanted events that may occur in the future

Risk is always related to what may happen in the *future*. The term events is used since we have restricted our attention to discrete hazardous events, and not to risk related to continuous exposure to, for example, dangerous substances.

What is risk?
Operational definition (1)

The concept *risk* has two dimensions:

1. The probability that harmful events will occur
2. The consequences of these events

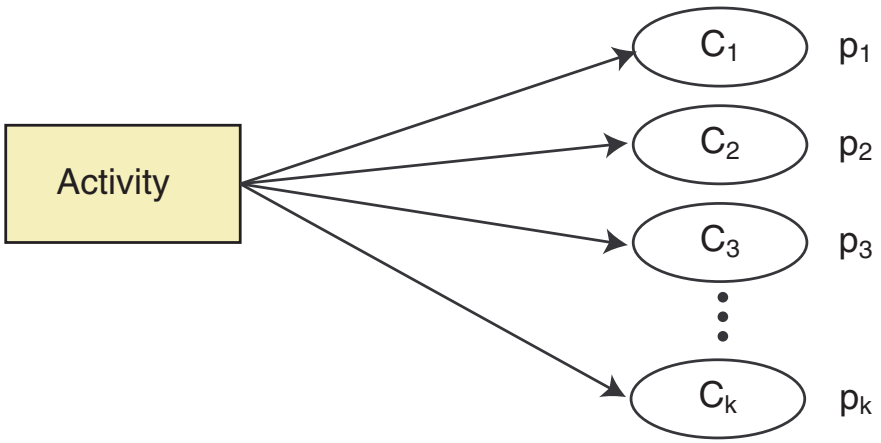
The probability (p) of a harmful event is most often quantified as a *degree of belief*, but p may also be specified by using fuzzy set theory, evidence theory (Dempster-Schafer), plausibility theory, etc.

The consequences (C) of a harmful event will usually be undesirable and may be quantified by the *magnitude of the harm* to one or more assets. The event may harm several types of assets (e.g., people, the environment, and material assets) and C will therefore be multi-dimensional.

What is risk?
Operational definition (2)

As several harmful events may occur, each with a degree of possibility p_i and a consequence C_i, for $i = 1, 2, \ldots$, the *risk spectrum* may be represented as

$$R = \{\langle p_i, C_i \rangle\}$$



☞ Consequence spectrum: A listing of potential consequences and associated probabilities (e.g., per year). Also called risk picture.

What is risk?

The three fundamental questions

A more operational definition of risk is to focus on intermediate events that are called *hazardous events*, HE. An example of such an HE is a gas leak that may or may not give harm to assets – depending on whether safety barriers are functioning or not. Risk is then defined by the three questions:

1. Which hazardous events (HEs) can happen?
2. What is the likelihood (p) that each HE will happen?
3. What are the consequences (C) of each HE?

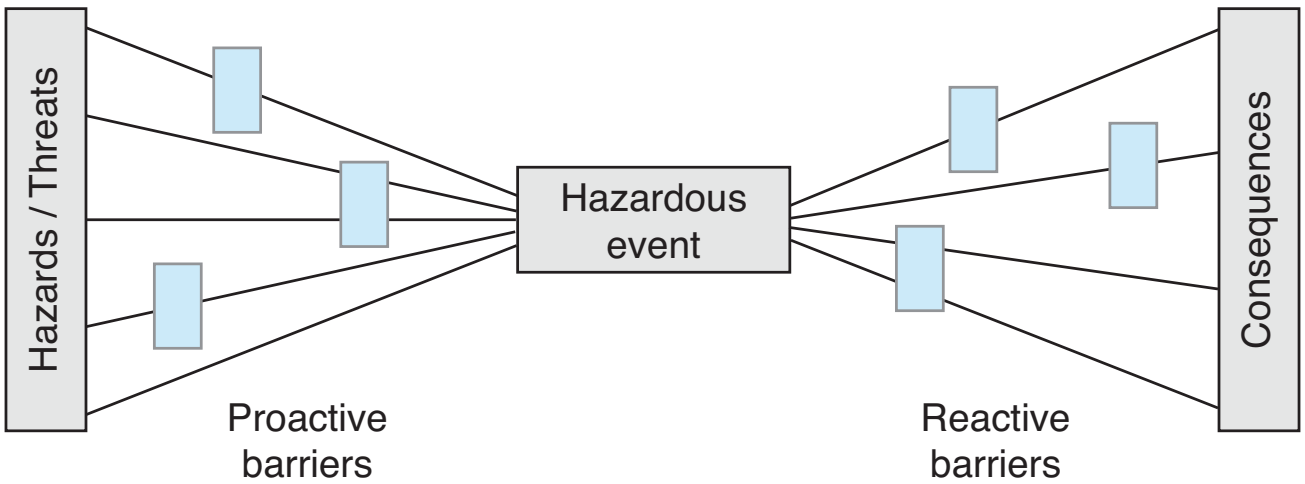
Since the consequence of HE_i depends on the correct functioning of one or more safety barriers, each will be a spectrum of possible consequences $C_{i,j}$ that will occur with certain probabilities $p_{i,j}$ such that

$$C_i = \left\{ \langle p_{i,j} C_{i,j} \rangle \right\}$$

Kaplan and Garrick (1981)

Bow-tie model

The operational definition of risk is in line with the *bow-tie model* for risk analyses.



What is risk?

By considering the bow-ties for all relevant hazardous events, HE_i, for $i = 1, 2, \ldots, n$, we may represent the risk as the set of triplets

$$R = \{\langle \mathrm{HE}_i, p_i, C_i \rangle\}$$

This set may be rearranged to obtain the *risk spectrum* presented above.

"Risk is distinguished from uncertainty by postulating that risk is measurable, while uncertainty is not."

Knight (1921)

Population at risk

☞ Individual risk: Risk of fatality or injury to any identifiable (named) individual who lives within the zone impacted by the hazard, or follows a particular pattern of life, that might subject him or her to the consequences of a hazard.

☞ Societal risk: Risk of multiple fatalities or injuries in the society as a whole, and where society would have to carry the burden of a hazard causing a number of deaths, injury, financial, environmental, and other losses.

Risk-influencing factors

☞ Risk-influencing factor (RIF): A relatively stable condition that influences the risk.

- Not events, but conditions that influence the occurrence of hazardous events or performance of barriers
- May be classified as frequency-influencing or consequence- influencing

Desired risk and risk homeostasis

☞ Desired risk: Risk that is sought, not avoided, because of the thrill and intrinsic enjoyment it brings.

- Usually of limited relevance in the context of this course
- More relevant for recreational activities
- In relation to financial risk, risk may also be desirable

☞ Risk homeostasis: A theory that claims that if people feel unsafe, they are more cautious than if they feel safe.

- A tendency towards a constant risk level

Residual risk

☞ Residual risk: The risk that remains after engineering, administrative, and work practice controls have been implemented.

- Closely related to risk acceptance
- Residual risk is the risk we accept

Perceived risk

☞ Perceived risk: A perception of danger that individuals or groups of individuals can form as a result of various activities or situations in society.

The perceived risk is often influenced by:

- Familiarity
- Voluntariness
- Degree of control
- Potential for catastrophe(also called risk aversion)
- Dread

Perceived risk
– influenced by view on probability

- Classical approach versus Bayesian approach
  - Objective versus subjective risk
- As concluded earlier: The view on probability (and risk) will not affect the performance of risk assessment – only the interpretation and use of the results.

Safety

☞ Safety: Freedom from those conditions that can cause death, injury, occupational illness or damage to or loss of equipment or property, or damage to environment.

MIL-STD 882C

Since it is not possible to have zero risk, a more "realistic" definition is:

☞ Safety: A state where the risk has been reduced to a level that is as low as reasonably practicable (ALARP) and where the remaining risk is generally accepted.

Safety performance

☞ Safety performance: An account of all accidents that occurred in a specific (past) time period, together with frequencies and consequences observed for each type of accident.

The term "risk" is sometimes also used to describe the safety performance and some talk about

- "Historical risk" and "Experienced is level"
- Risk estimates are often based on safety performance

Vulnerability and resilience

☞ Vulnerability: The inability of an object to resist the impacts of an unwanted event and to restore it to its original state or function following the event.

- Influences the consequences should an unwanted event occur

☞ Resilience: The ability to accommodate change without catastrophic failure, or the capacity to absorb shocks gracefully.

- Opposite of vulnerability, but more general

Certainty

"Absolute certainty is a privilege of uneducated minds and fanatics"

C. J. Keyser
Mathematical Philosopher
of early 1900 and Professor

of Philosophy at Columbia

Accident

☞ Accident: A sudden, not intended, event that causes loss of human life, personal injury, damage to the environment, and/or loss of assets and financial interests.

- It is not possible to predict accurately when an accident will occur
- An accident may be caused by:
  – Random events, and/or
  – Deliberate actions
- Negative consequences caused by continuous influence (e.g., asbestos, toxic materials, radiation) are be considered as accidents in this context.

In MIL-STD 882C an accident is called a *mishap*

Near accident

☞ Near accident: An unplanned and unforeseen event that could reasonably have been expected to result in harm to one or more assets, but actually did not.

A near accident is also called a *near miss* or an *incident*.

Near accidents are sometimes referred to as *precursors*, as they often comprise hazardous events where the protecting barriers have functioned properly.