Some Basic Risk Concepts

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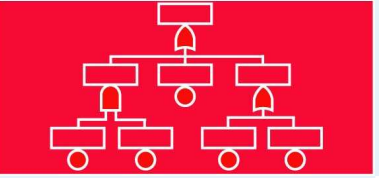

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- Hazard Categories
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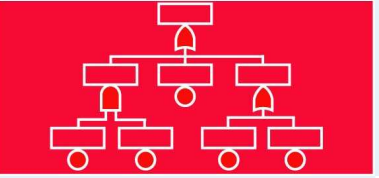
- Example
- Risk
- Risk Definition
- Consequence Categories
- Safety
- Consequence Spectrum
- Probability vs. Frequency
- Probability

Risk Measures

Acceptable Risk

Risk Prevention

Basic Concepts



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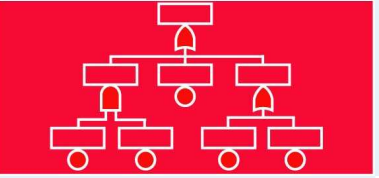
By *hazard* we mean any physical activity, situation or condition with the potential to cause harm, like:

- Human injury or death
- Damage to the environment
- Damage to physical assets
- Loss of production

Comments:

- In MIL-STD 882C, hazard is defined as “a condition that is a prerequisite to a mishap” (an accident)
- The words “threat” and “danger” are sometimes used with a similar meaning as hazard.



Hazard Categories

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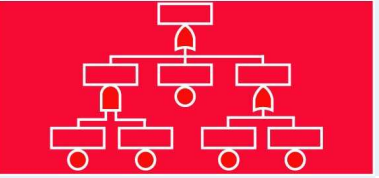
Hazards may generally be classified as:

- Natural hazards (e.g., flooding, earthquake, storm, lightning)
- Technological hazards (e.g., industrial facilities, structures, technical equipment, transportation systems, consumer products, pesticides, herbicides, pharmaceuticals)
- Societal hazards (e.g., assault, war, arson, terrorism, sabotage, communicable disease)



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Risk Prevention

- Threat (“deliberate”):

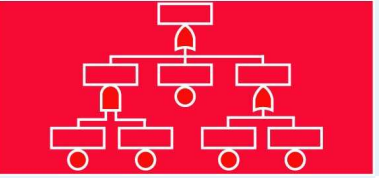
  A foreign or domestic entity possessing both the capability and the intention to make damage to a system. A threat mey be an individual, an organization, or a nation

- **Threat Agent**

  A person, organization, thing or entity that desires to or is able to trigger an event which can compromise the security of an asset or information

- **Threat Event**

  An event or occurrence that has the potential to compromise the security of an asset or information (synonymous to ‘attack’)



Vulnerability

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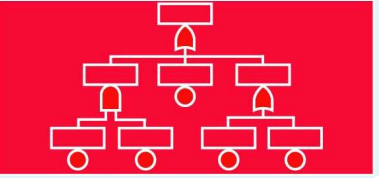
Acceptable Risk

Risk Prevention

A characteristic of a system which allows a successful threat event to occur



Information Security Concepts

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Risk Measures

Acceptable Risk

Risk Prevention

- **Availability**

  The accessability of systems, programs, services, and information when needed and without undue delay

- **Confidentiality**

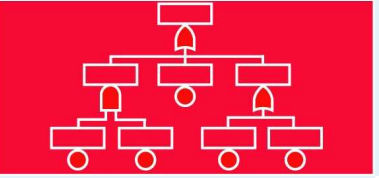
  The sensitivity of information or assets to unauthorized disclosure, recorded as classification or designation, each of which implies a degree of ‘loss’ should unauthorized disclosure occur

- **Integrity**

  The accuracy and completeness of information and assets and the authencity of transactions

- **Compromise**

  Unauthorized disclosure, destruction, removal, modification or interruption.



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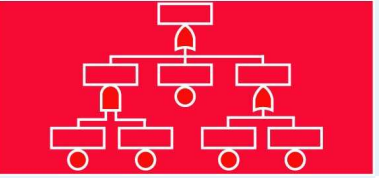
Risk Prevention

- An accidental event is an undesired event that may lead to loss of human life, personal injury, damage to the environment and/or loss of assets and financial interests.
  - The accidental event is usually defined as the first significant deviation from the normal situation (that may lead to an accident).
  - The accidental event is often used as a “starting point” for a risk analysis.



Accident

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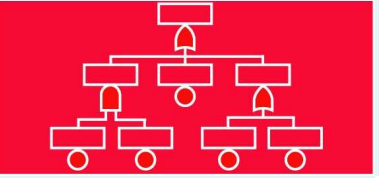
Risk Prevention

An accident may be defined as:

- 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 accurately predict 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) will not be considered as accidents in this context.

Comments:

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



Anatomy Of Accident

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Risk Measures

Acceptable Risk

Risk Prevention

Material/energy contained and controlled during normal operation
- Toxicity
- Flammability
- Reactivity
- Elevated pressure
- Etc.

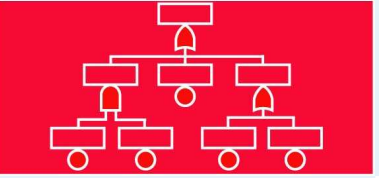
Initiating event of process upset; start of accident event sequence
- Mechanical failure
- Proceduiral error
- External force
- Fouling
- Etc.

Excursion beyond design/operating limits
- No flow
- High temperature
- Low level
- Impurities
- Wrong material
- Step omitted

Loss of containment of process material/energy
- Fire
- Explosion
- Hazardous material release, etc.
- Other energy release

Severity of consequences; losses
- Illnesses, injuries death
- Property damage
- Business interruption
- Environmental damage
- Etc.

– Adapted from DOE-HDBK-1100-96



Near Accident

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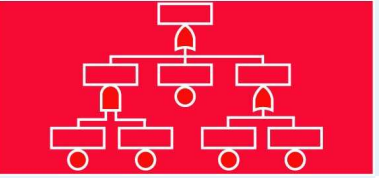
Risk Measures

Acceptable Risk

Risk Prevention

A near accident (near miss or incident) is defined as:

- An undesired event that, under slightly different conditions or circumstances, could have caused loss of human life, personal injury, damage to the environment and/or loss of assets and financial interests.



Mitigation Measure

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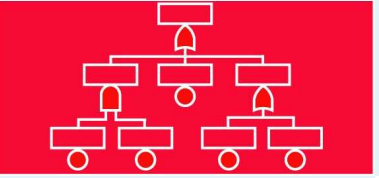
Risk Measures

Acceptable Risk

Risk Prevention

- A mitigation measure is an engineering or procedural control measure designed to reduce the severity of the consequences of an accidental event / incident.



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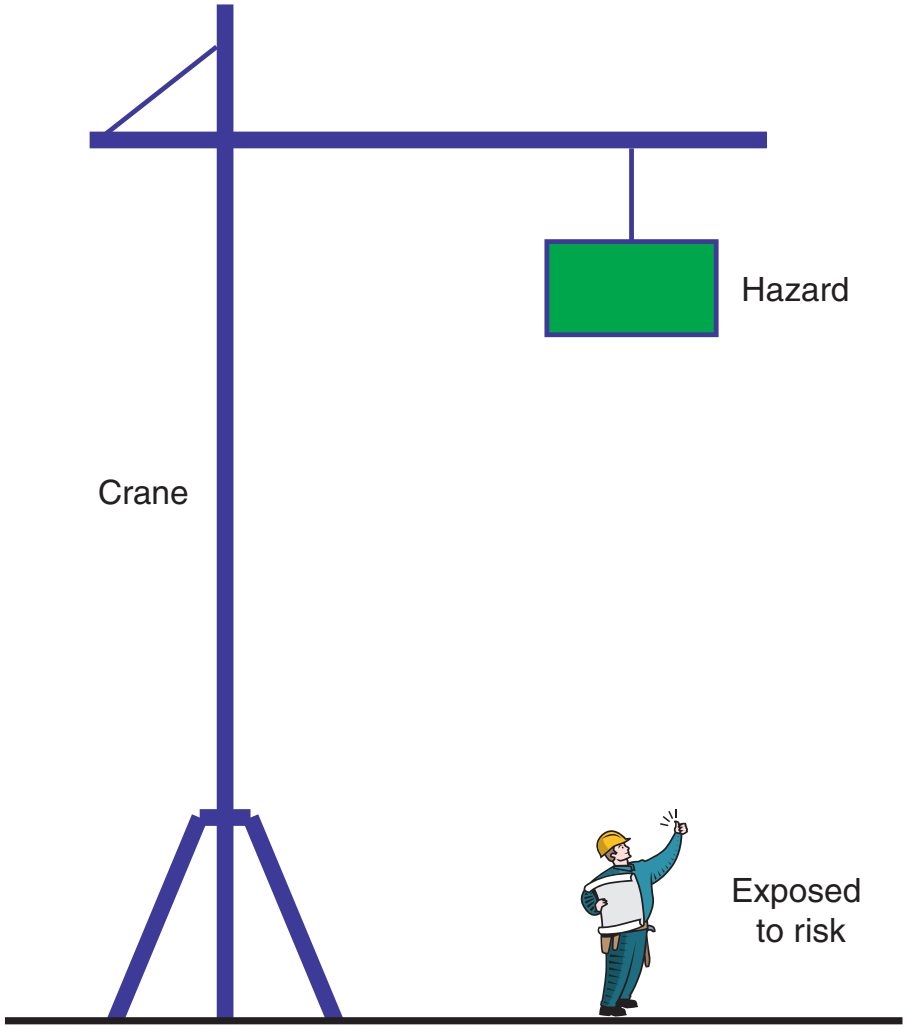

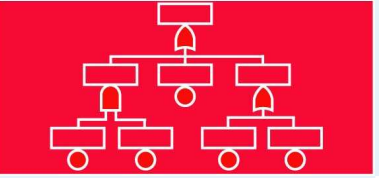

Accidental Event

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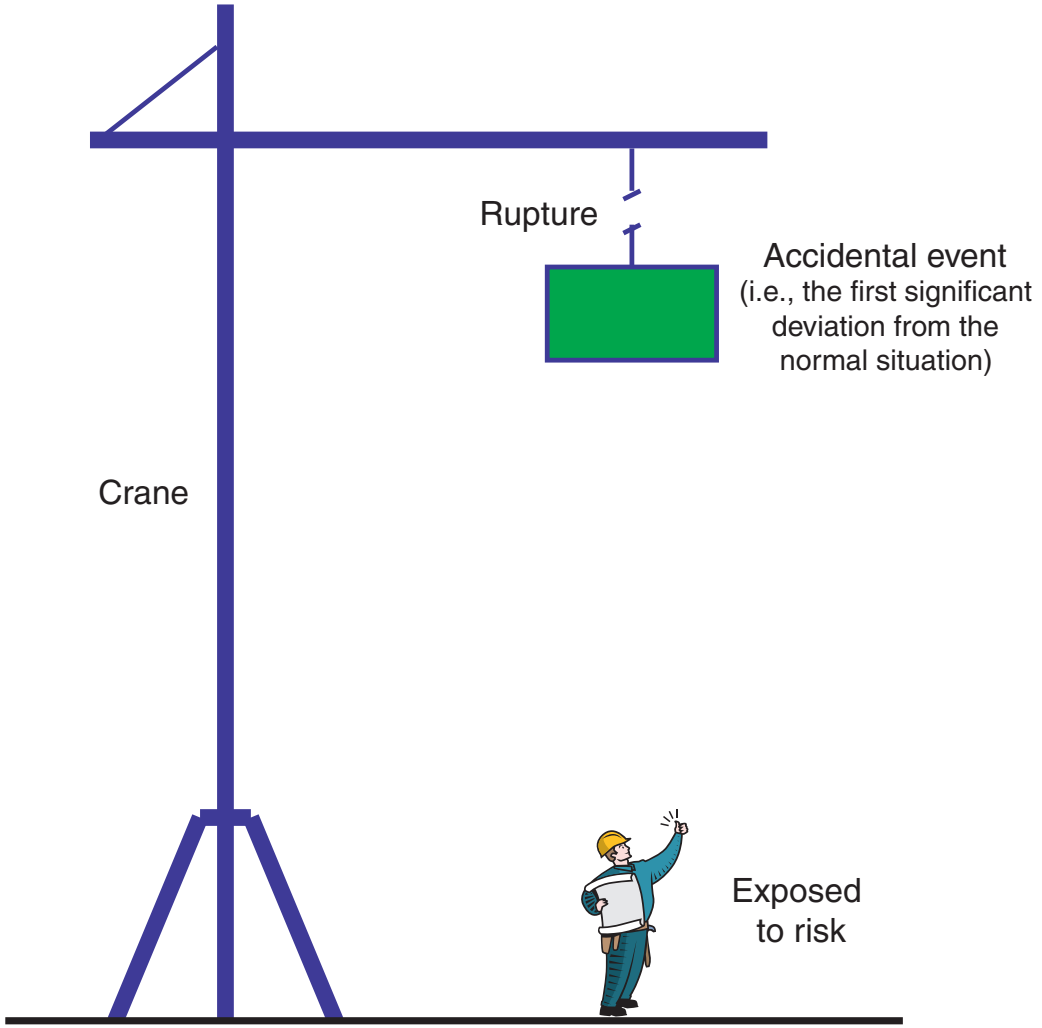

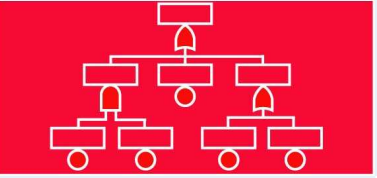

Accident

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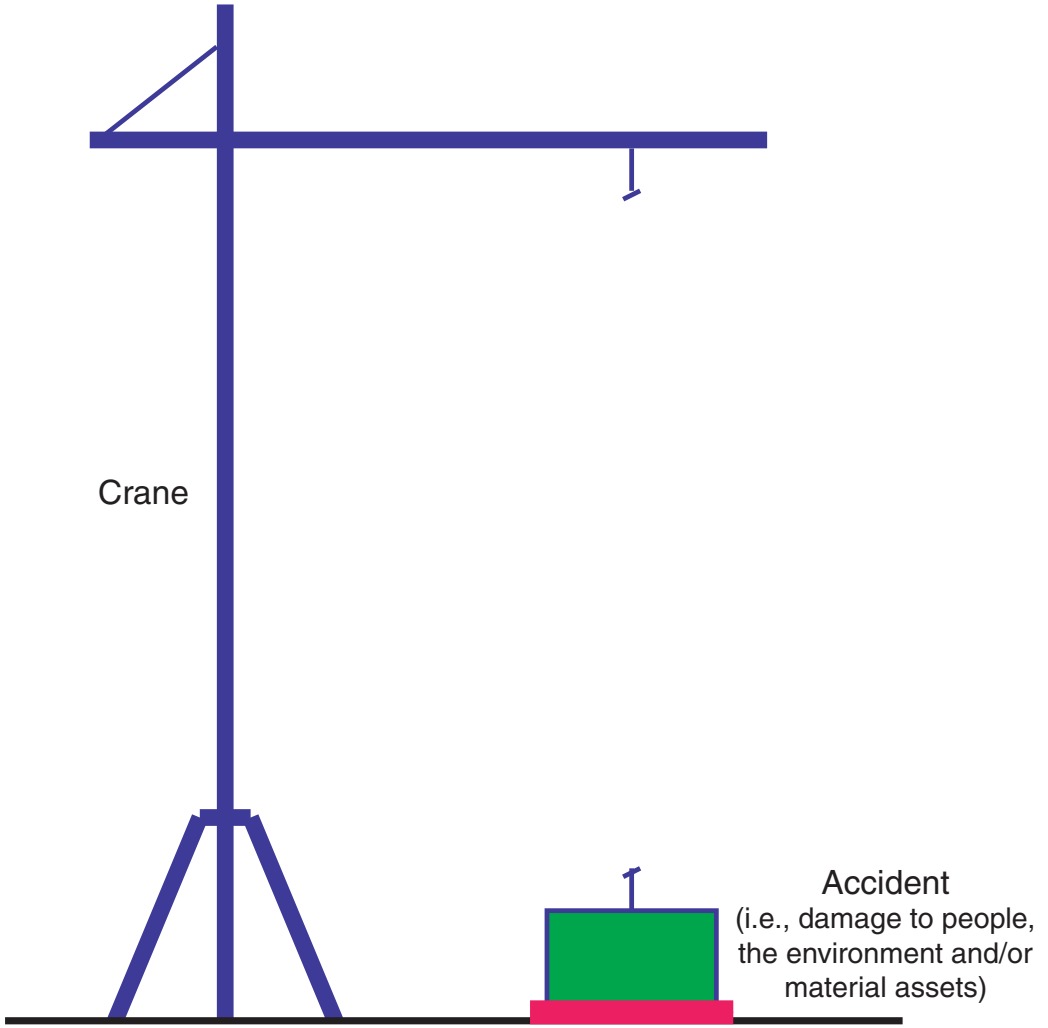
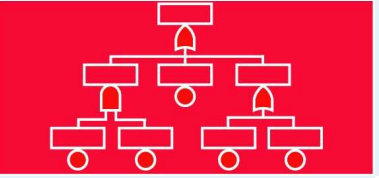
Acceptable Risk

Risk Prevention





What Is Risk?

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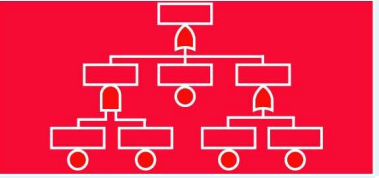
Risk Measures

Acceptable Risk

Risk Prevention

- An expectation of loss
- Always an element of uncertainty
- Always refers to to future
- Usually covers both severity and likelihood of a loss
- Usually refers to unwanted consequences



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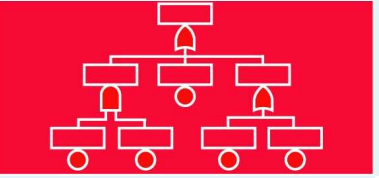
Risk Prevention

- An expression of the probability and the consequences of an accidental event
- Risk may be defined as a triplet $\{S_i, L_i, C_i\}$, for all i, where
  - $S_i =$ Scenario (accidental event) no. i
  - $L_i =$ The likelihood (probability or frequency) of S_i
  - $C_i =$ The potential consequences of S_i



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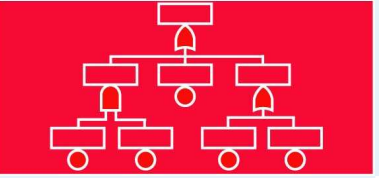
Acceptable Risk

Risk Prevention

"The words of risk analysis have been, and continue to be a problem . . .
When our Society of Risk Analysis was brand new, one of the first things it did was to establish a committee to define the word 'risk.' The committee labored for 4 years and then gave up, saying in its final report, that maybe it is better not to define risk."

– Stan Kaplan (1997)



Consequence Categories

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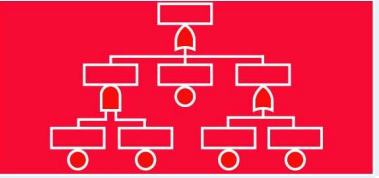
Risk Measures

Acceptable Risk

Risk Prevention

The consequences of an accident may be classified in different categories, as

- Personnel consequences
  - Fatalities
  - Impairment
- Environmental damage
- Economic loss
  - Damage to material assets
  - Production/service loss
- Information “loss”
- Image (i.e., damage to reputation)



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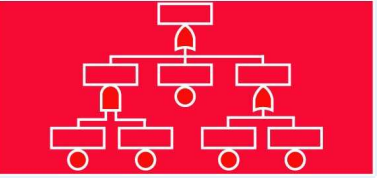
Acceptable Risk

Risk Prevention

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



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Risk Measures

Acceptable Risk

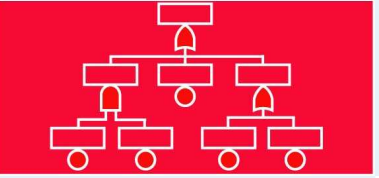
Risk Prevention

- The expectation that a system does not, under defined conditions, lead to a state in which human life is endangered

  – DEF-STAN 00-56

- 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



Consequence Spectrum

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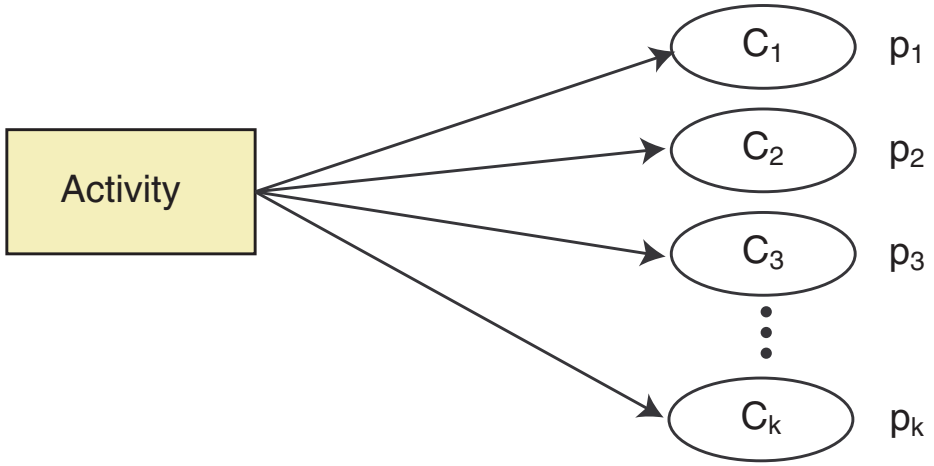
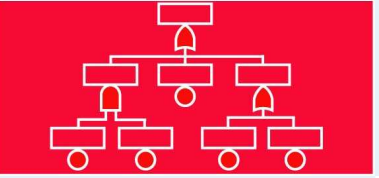
A *consequence spectrum* (or, *risk picture*) of an activity is a listing of its potential consequences and the associated probabilities (e.g., per year). Usually, only unwanted consequences are considered.



Risk is sometimes defined as:

$$\text{Risk} = C_1p_1 + C_2p_2 + \cdots + C_kp_k = \sum_{i=1}^{k} C_ip_i = \text{‘Mean consequence’}$$

This requires that all consequences may be measured with a common measure (e.g., as monetary value)



Probability vs. Frequency

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➤ Probability

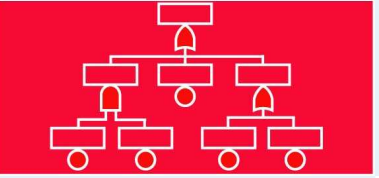
The probability that a specific event will occur in a specified context ($p =$ probability)

$$0.0 \leq p \leq 1.0 \quad \text{or} \quad 0\% \leq p \leq 100\%$$

➤ Frequency

The number of events per time unit (e.g., per year) ($f =$ frequency)

$$f = 5 \text{ events per year}$$



Probability

Basic Concepts
- Hazard
- Hazard Categories
- Threat
- Vulnerability
- Information Security Concepts
- Accidental Event
- Accident
- Near Accident
- Mitigation Measure
- Example
- Risk
- Risk Definition
- Consequence Categories
- Safety
- Consequence Spectrum
- Probability vs. Frequency
- Probability

Risk Measures

Acceptable Risk

Risk Prevention

➤ Classical

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

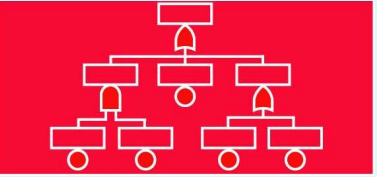
The probability of an event may be estimated on the basis of experience data, or based on symmetry arguments (e.g., for a dice)

➤ Bayesian

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).

Thomas Bayes (1702 - 1761)



Certainty

Basic Concepts
- Hazard
- Hazard Categories
- Threat
- Vulnerability
- Information Security Concepts
- Accidental Event
- Accident
- Near Accident
- Mitigation Measure
- Example
- Risk
- Risk Definition
- Consequence Categories
- Safety
- Consequence Spectrum
- Probability vs. Frequency
- Probability

Risk Measures

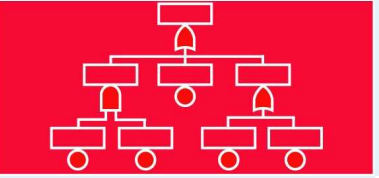
Acceptable Risk

Risk Prevention

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

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

of Philosophy at Columbia



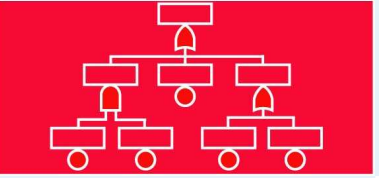
Basic Concepts

Risk Measures
- Individual Risk Per Annum
- Deaths Per Million
- Individual Risk Index
- Risk Contour Plots
- Lost Time Injuries
- Potential Loss Of Life
- Fatal Accident Rate
- Societal Risk
- Individual Risk

Acceptable Risk

Risk Prevention

Risk Measures



Individual Risk Per Annum

Basic Concepts

Risk Measures

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- Individual Risk

Acceptable Risk

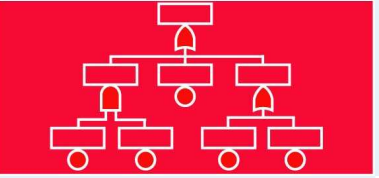
Risk Prevention

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

Basic Concepts

Risk Measures

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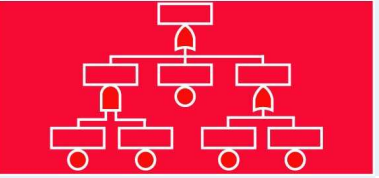
Acceptable Risk

Risk Prevention

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

Basic Concepts

Risk Measures

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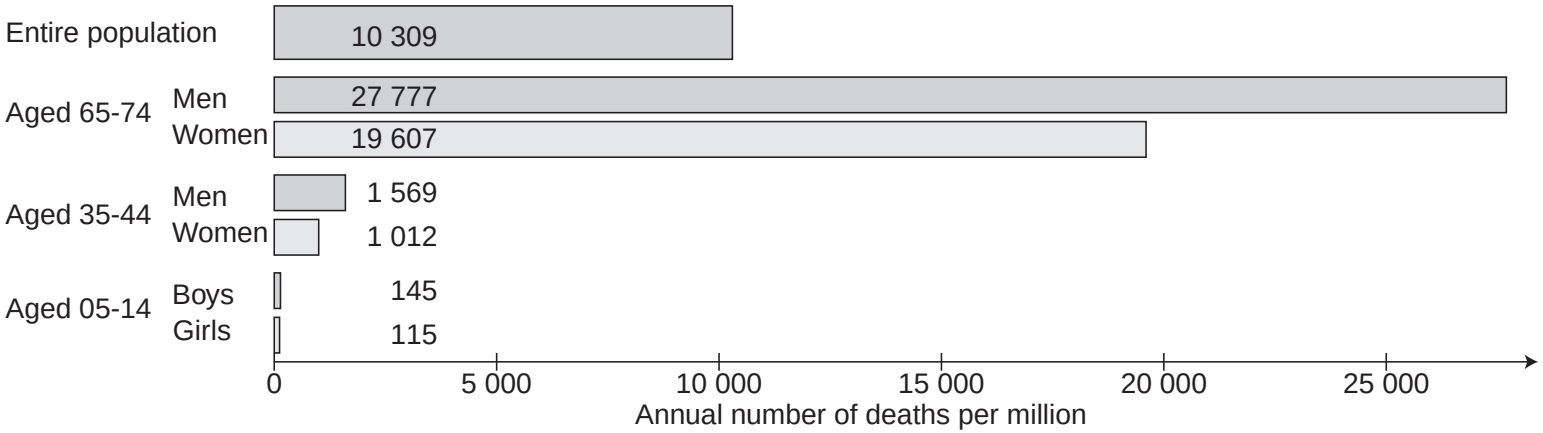
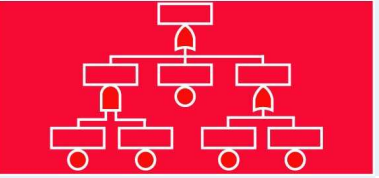
Acceptable Risk

Risk Prevention

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

Basic Concepts

Risk Measures

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- Societal Risk
- Individual Risk

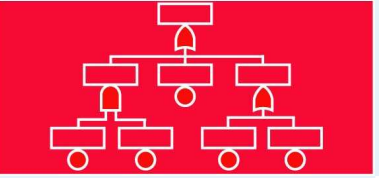
Acceptable Risk

Risk Prevention

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.

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

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



Risk Contour Plots

Basic Concepts

Risk Measures

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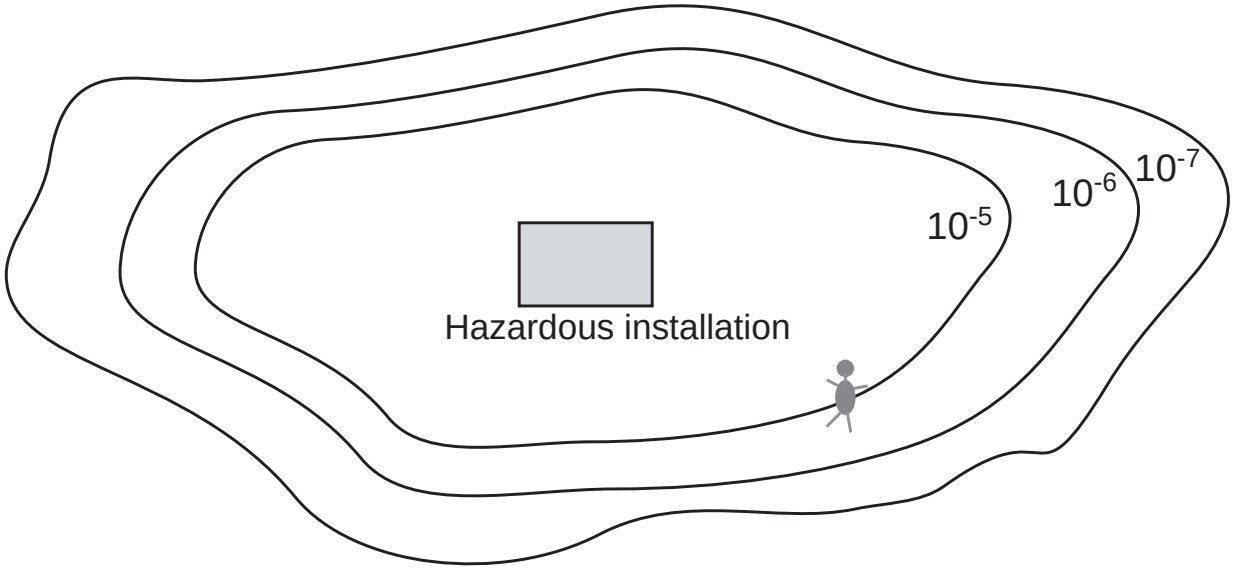
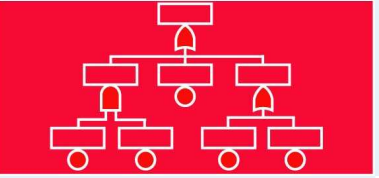
- Individual Risk

Acceptable Risk

Risk Prevention





Lost Time Injuries

Basic Concepts

Risk Measures

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- Individual Risk

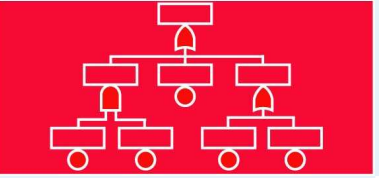
Acceptable Risk

Risk Prevention

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 $\text{LTIF}^* = 10$ 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

Basic Concepts

Risk Measures
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- Individual Risk

Acceptable Risk

Risk Prevention

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

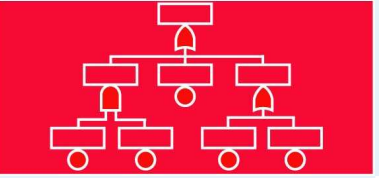
The PLL can also be expressed by the individual risk per annum (IRPA) as:

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

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:

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



Fatal Accident Rate

Basic Concepts

Risk Measures

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- Individual Risk

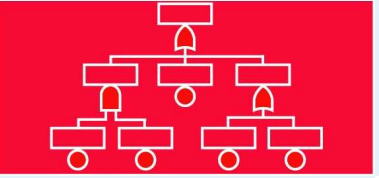
Acceptable Risk

Risk Prevention

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

Basic Concepts

Risk Measures
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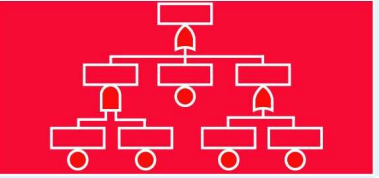
Acceptable Risk

Risk Prevention

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

Basic Concepts

Risk Measures
- Individual Risk Per Annum
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- Individual Risk Index
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- Fatal Accident Rate
- Societal Risk
- Individual Risk

Acceptable Risk

Risk Prevention

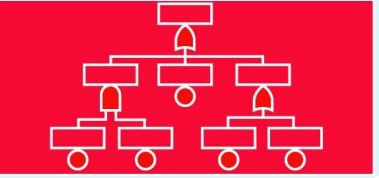
$$\boxed{\text{Societal risk} = \text{Frequency} \times \text{magnitude}}$$

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

Example:

Road accidents in USA

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



Individual Risk

Basic Concepts

Risk Measures
- Individual Risk Per Annum
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- Lost Time Injuries
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- Fatal Accident Rate
- Societal Risk
- Individual Risk

Acceptable Risk

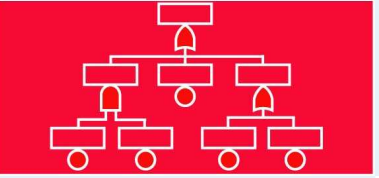
Risk Prevention

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

Assume 200 million inhabitants in U.S.

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

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



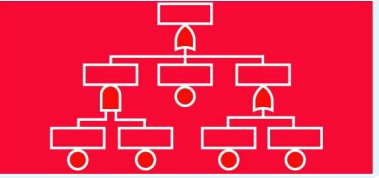
Basic Concepts

Risk Measures

Acceptable Risk
- When Do We Accept Risk?
- Accepted Risk
- Attitudes Towards Risk
- Issues of Acceptable Risk
- Attitudes Towards Risk
- Establishing Risk Tolerance Limits

Risk Prevention

Acceptable Risk



When Do We Accept Risk?

Basic Concepts

Risk Measures

Acceptable Risk

- When Do We Accept Risk?
- Accepted Risk
- Attitudes Towards Risk
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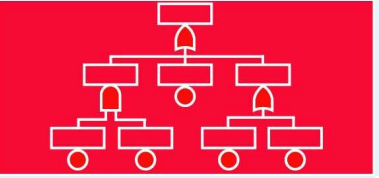
- Establishing Risk Tolerance Limits

Risk Prevention

- 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

Basic Concepts

Risk Measures

Acceptable Risk

- When Do We Accept Risk?
- Accepted Risk
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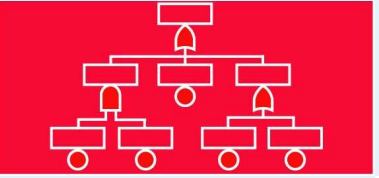
- Attitudes Towards Risk
- Establishing Risk Tolerance Limits

Risk Prevention

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

Basic Concepts

Risk Measures

Acceptable Risk

- When Do We Accept Risk?
- Accepted Risk
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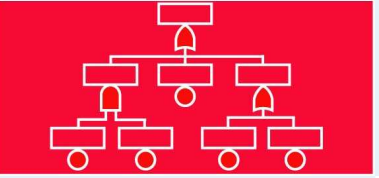
Risk Prevention

- 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

Basic Concepts

Risk Measures

Acceptable Risk

- When Do We Accept Risk?
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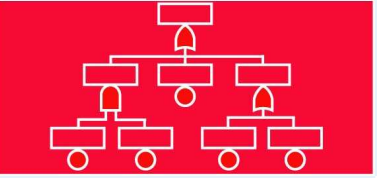
Risk Prevention

- 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

Basic Concepts

Risk Measures

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- When Do We Accept Risk?
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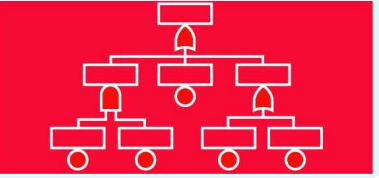
Risk Prevention

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



Establishing Risk Tolerance Limits

Basic Concepts

Risk Measures

Acceptable Risk
- When Do We Accept Risk?
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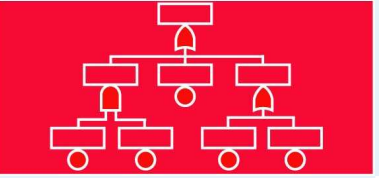
- Establishing Risk Tolerance Limits

Risk Prevention

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)



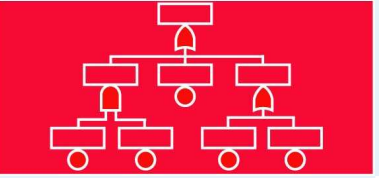
Basic Concepts

Risk Measures

Acceptable Risk

Risk Prevention
- Risk Management Options
- Accident Prevention Options
- Risk Prevention Criteria

Risk Prevention



Risk Management Options

Basic Concepts

Risk Measures

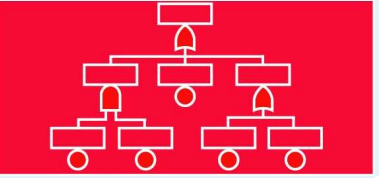
Acceptable Risk

Risk Prevention

- Risk Management Options
- Accident Prevention Options
- Risk Prevention Criteria

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

Basic Concepts

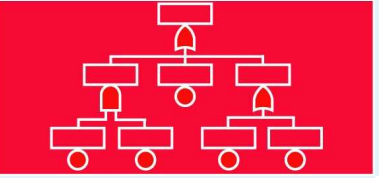
Risk Measures

Acceptable Risk

Risk Prevention

- Risk Management Options
- Accident Prevention Options
- Risk Prevention Criteria

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



Risk Prevention Criteria

Basic Concepts

Risk Measures

Acceptable Risk

Risk Prevention

- Risk Management Options
- Accident Prevention Options
- Risk Prevention Criteria

Criterion	Description
Efficacy	How much of the risk will be eliminated or minimized by the proposed action?
Feasibility	Is the proposed action acceptable (legally, physically, politically, socially, technically, etc.)?
Efficiency	Is the proposed action cost-effective? In other words, is the cost of implementing the action low compared to the loss that could occur if no action were taken?