Risk and Safety

in

Engineering

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Contents of Today's Lecture

- The organisation of the lecture – practical stuff
- Why risk and safety in engineering?
- Decision problems in engineering
- Examples
- The lecture program

Organisation of the Lecture

- **Course webpage address is: http://www.ibk.ethz.ch/fa/education/ws_safety/index**

- **Available on course webpage:**
  - Lecture notes for the entire course (non-printable version)
  - Exercises
  - Exercise Solutions

- **Print edition of lecture notes for the entire course is available for a cost of CHF 45.**

- **PowerPoint presentations for each lecture will be uploaded on the webpage the latest one day before the respective lecture.**

- **Support will be available – you are welcome to contact Prof. Michael Faber in room HIL E 23.3 or contact Harikrishna Narasimhan in room HIL E 13.1 or by email (harikrishna@ibk.baug.ethz.ch)**

Examination

- The exam for the course is an oral examination

  - the emphasis of the exam is to ensure that a fundamental understanding of the area of risk and safety in engineering is acquired by the students

- The confirmation (or “testat”) for admission to the examination is fulfilled by attending the lectures of the course.

- Doctoral students need to take the oral examination in order to get credit points for this course.

Why Risk and Safety in Engineering?

- What do engineers do ?
  - Plan, design, build, maintain and decommission

    <u>Infrastructure</u>
    Roads, water supply systems, tunnels, sewage systems, waste deposits, power supply systems, channels

    <u>Structures</u>
    houses, hospitals, schools, industry buildings, dams, power plants, wind turbines, offshore platforms

  - Safeguard
    people
    environment
    assets

SUSTAINABLE DEVELOPMENT !

from natural and man made hazards

Engineering Decision Making for Society

- What do engineers do?

Is what we are doing of any relevance for society?

Engineering Decision Making for Society

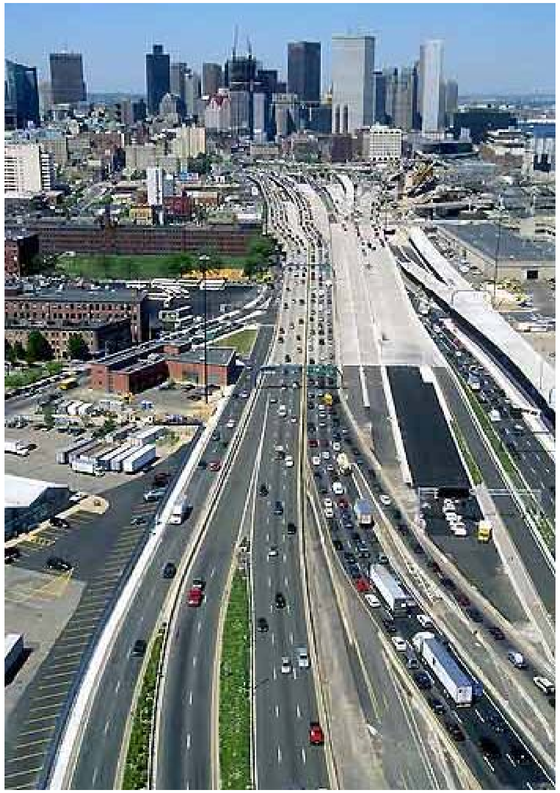
- **Examples of what we help to develop**

Golden Gate Bridge - USA

Øresund bridge - Denmark

Engineering Decision Making for Society

- **Examples of what we help to develop**



Big Dig Boston/USA

Engineering Decision Making for Society

- **Examples of what we help to develop**

Hoover Dam - USA

Engineering Decision Making for Society

- **Examples of what we help to develop**

Hong Kong Island - China

Engineering Decision Making for Society

- **Helping to control risks due to natural hazards**

Tornados and strong winds

Engineering Decision Making for Society

- **Helping to control risks due to natural hazards**

Earthquakes

Engineering Decision Making for Society

- **Helping to control risks due to degradation**

Corrosion

Fatigue

Engineering Decision Making for Society

- **Helping to control risks due to accidents**

Fires

Explosions

Engineering Decision Making for Society

- **Helping to control risks due to lack of knowledge**

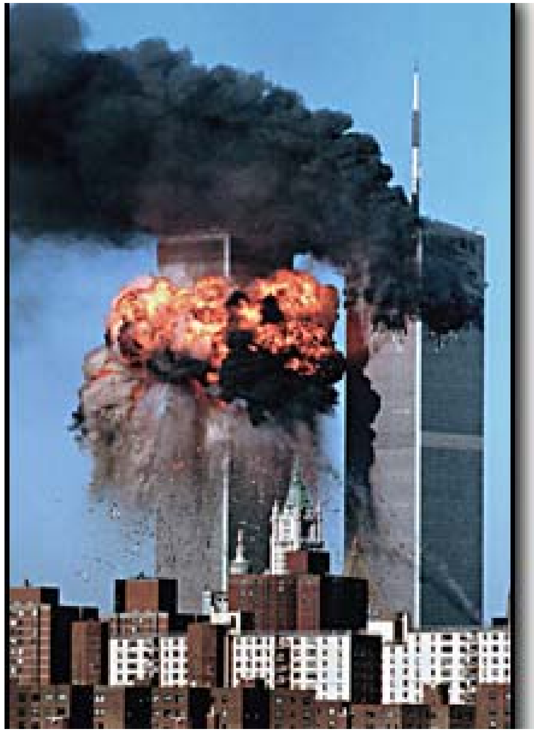
Over load

Design error

Engineering Decision Making for Society

- **Helping to control risks due to malevolence**

Bomb explosions



Airplane impacts

Why Risk and Safety in Engineering?

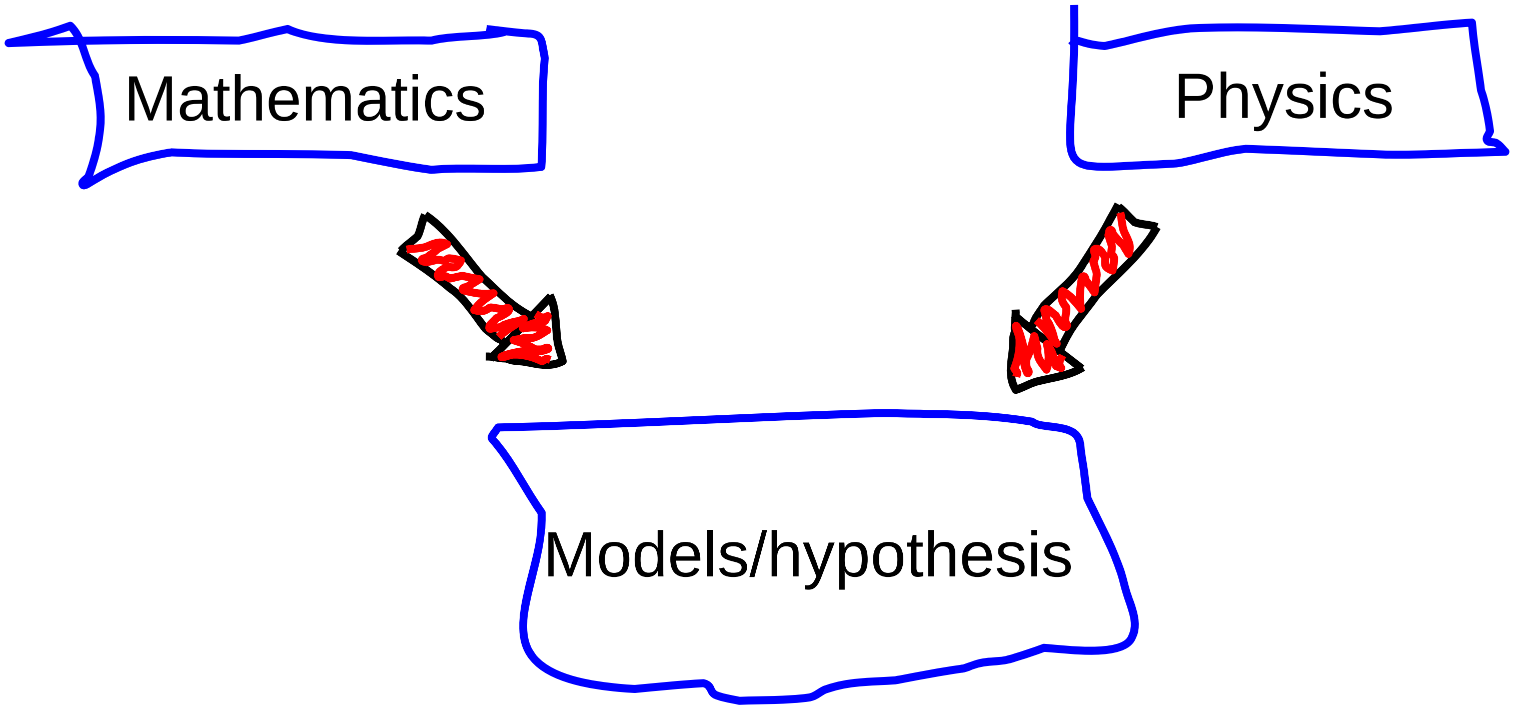
- **What are engineers working with ?**

  Real problems – the real world - nature

Gravity
Ice
Dynamics
Concrete
Waves
New materials
Snow
Soil
Temperature
Water
Rocks
Waste
Air
Chemicals
Electricity
Wind
Steel

Why Risk and Safety in Engineering?

- **How do engineers work with the real world ?**

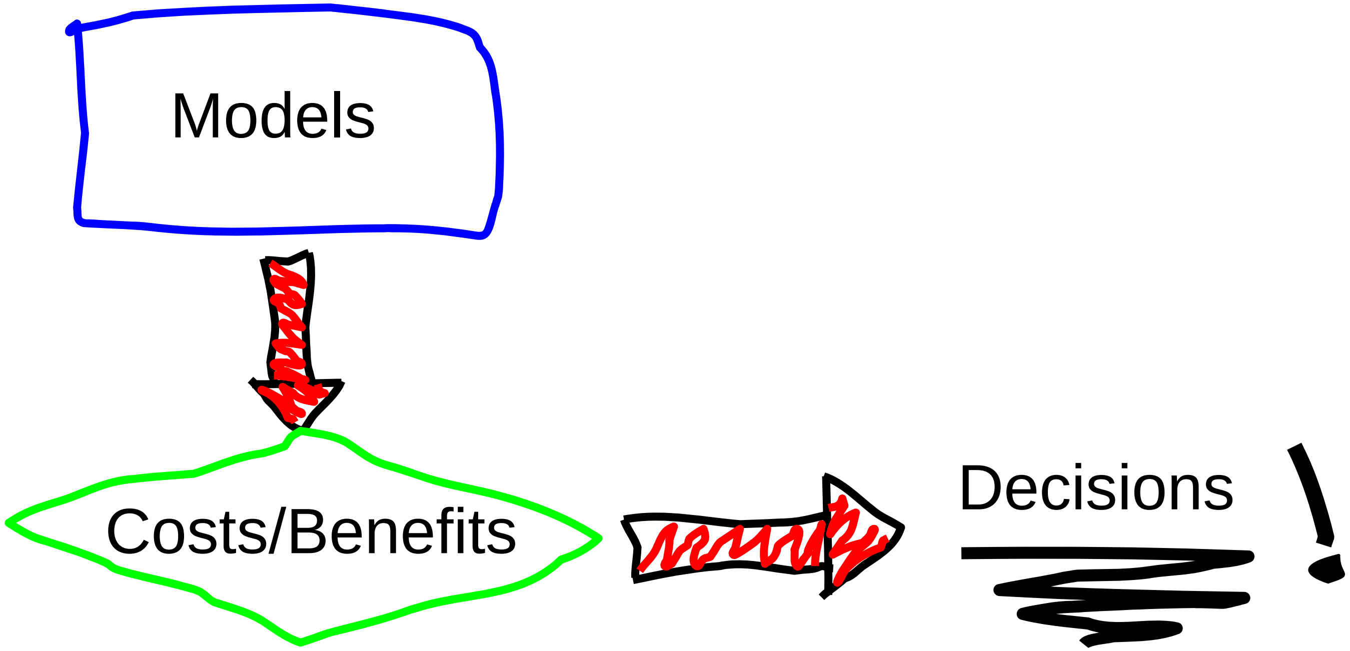


We model the real world to the “best” of our knowledge

Why Risk and Safety in Engineering?

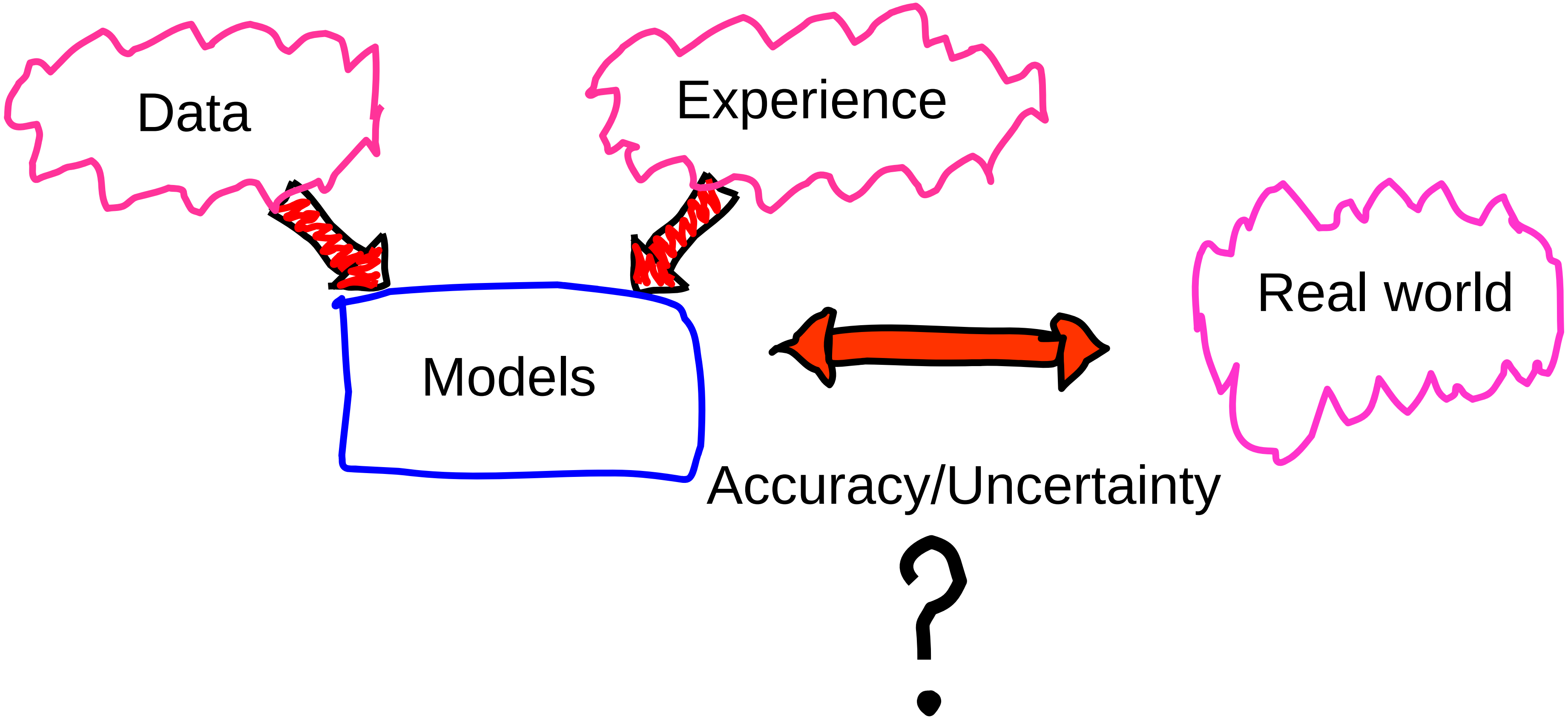
- **How do engineers use knowledge ?**

In a perfectly known world



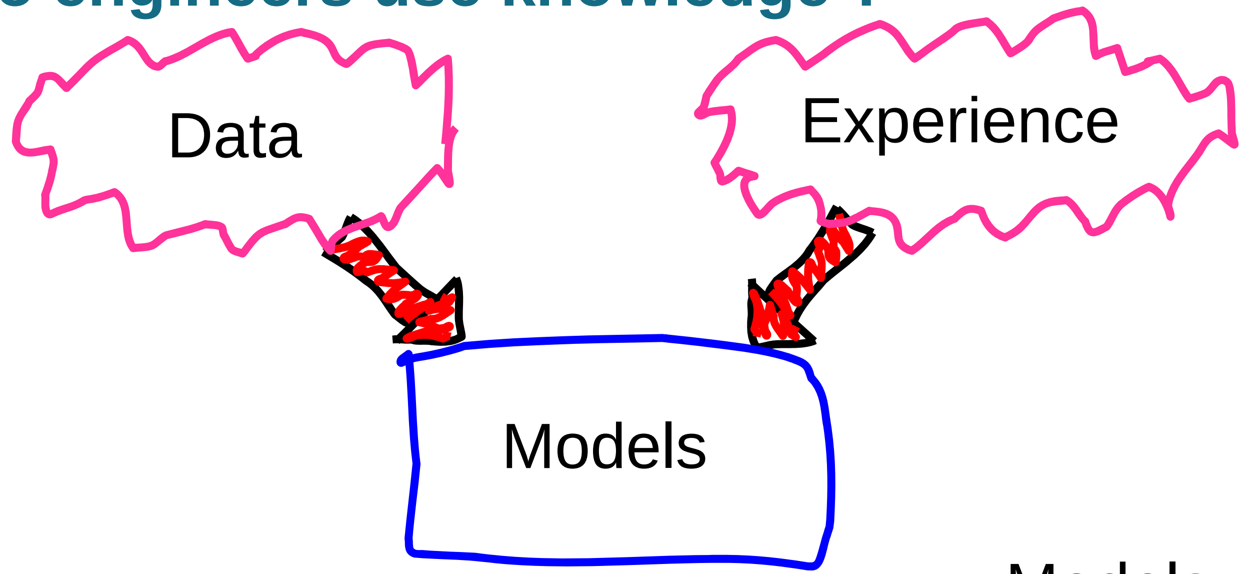
Why Risk and Safety in Engineering?

- **How do engineers establish knowledge ?**



Why Risk and Safety in Engineering?

- **How do engineers use knowledge ?**



Models are not precise

Uncertainty

Data are not sufficient

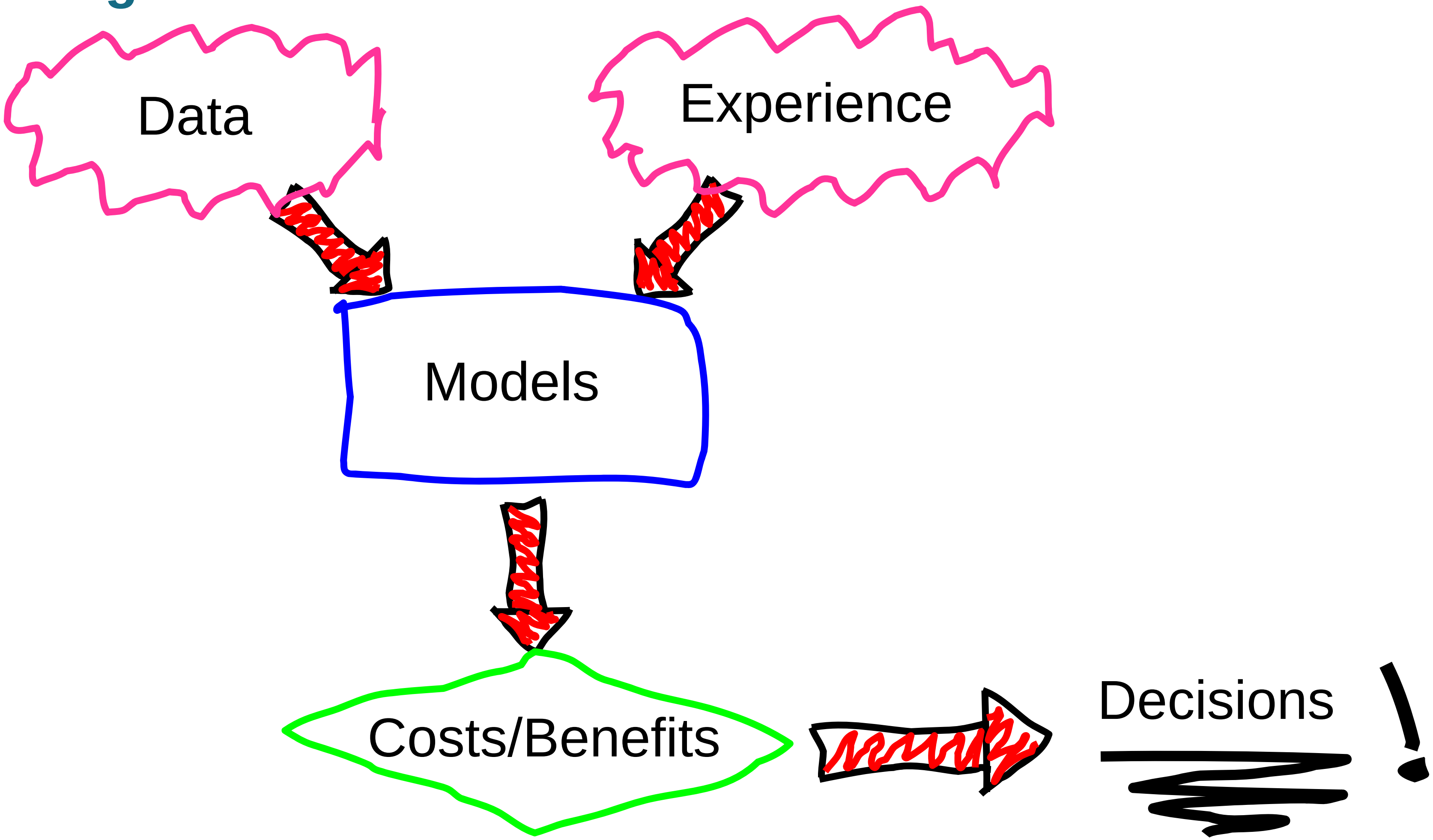
WHY ?

Natural variability

Experience is subjective

Why Risk and Safety in Engineering?

- **How do engineers make decisions**



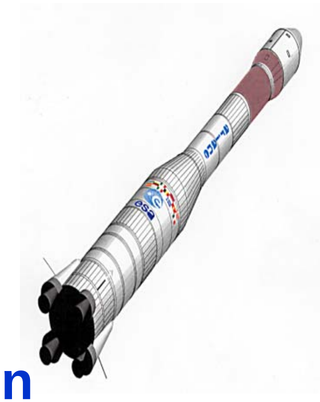
Why Risk and Safety in Engineering?

All activities are associated with uncertainties

Activities could be:

- **Transport**
- **Work**
- **Sport**

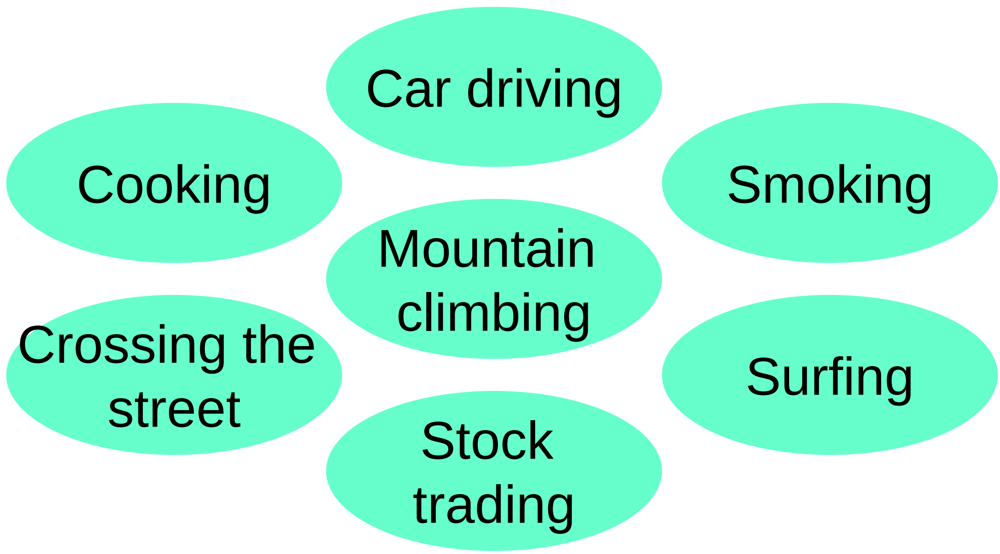
but also



- **Production of energy**
- **Exploitation of resources**
- **Construction and operation of production and infrastructure projects**
- **Research and development**

Why Risk and Safety in Engineering?

Every day we must make decisions in regard to activities associated with uncertainties



Every one of these activities is associated with uncertainties

We all have an opinion regarding the associated risks

We have gut feelings !

Why Risk and Safety in Engineering?

Disasters and accidents have always occurred

Some examples

Tacoma Narrows, Washington, 1940

Fort Mayer, Virginia, 1908

Open questions

- did we realise the risks ?

- are the consequences acceptable ?

Why Risk and Safety in Engineering?

Disasters and accidents have always occurred

Some examples

Kobe, 1995

Open questions

- did we realise the risks ?

- are the consequences acceptable ?

Why Risk and Safety in Engineering?

Disasters and accidents have always occurred

Some examples

Minneapolis, Minnesota, 2007

New York, 2001

Open questions
- did we realise the risks ?
- are the consequences acceptable ?

Why Risk and Safety in Engineering?

Disasters and accidents have always occurred

Some examples

Hurricane Katrina, New Orleans, 2005

Open questions

- did we realise the risks ?

- are the consequences acceptable ?

Why Risk and Safety in Engineering?

Risk assessment, within the framework of decision analysis, provides a basis for rational decision making subject to uncertain and / or incomplete information

Thereby we can take into account, in a consistent manner, the prevailing uncertainties and quantify their effect on risks

Thus we may find answers to the following questions

- **How large is the risk associated with a given activity ?**
- **How may we reduce and / or mitigate risks ?**
- **How much does it cost to reduce and / or mitigate risks ?**
- **What risks can we accept – what can we afford ?**

Definition of Risk

Risk is a characteristic of an activity relating to all possible events n_E which may follow as a result of the activity

The risk contribution R_{E_i} from the event E_i is defined through the product between

the event probability P_{E_i}

and

the consequences of the event C_{E_i}

The risk associated with a given activity R_A may then be written as

$$R_A = \sum_{i=1}^{n_E} R_{E_i} = \sum_{i=1}^{n_E} P_{E_i} \cdot C_{E_i}$$

Decision Problems in Engineering

Uncertainties must be considered in the decision making throughout all phases of the life of an engineering facility

Uncertainties

Traffic volume

Loads

Resistances (material, soil,..)

Degradation processes

Service life

Manufacturing costs

Execution costs

Decommissioning costs

Idea & Concept

Planning and feasibility study

Investigations and tests

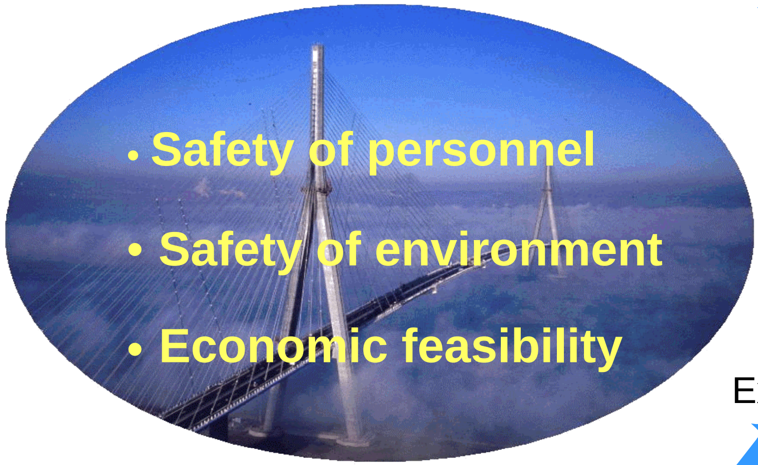
Design

Manufacturing

Execution

Operation & maintenance

Decommissioning



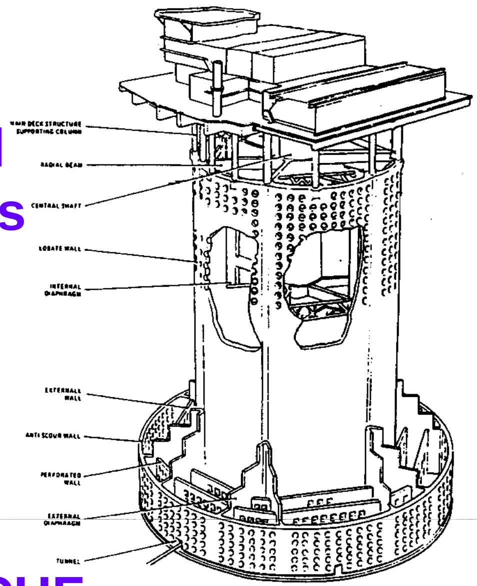
Example – Decommissioning of the Frigg Field

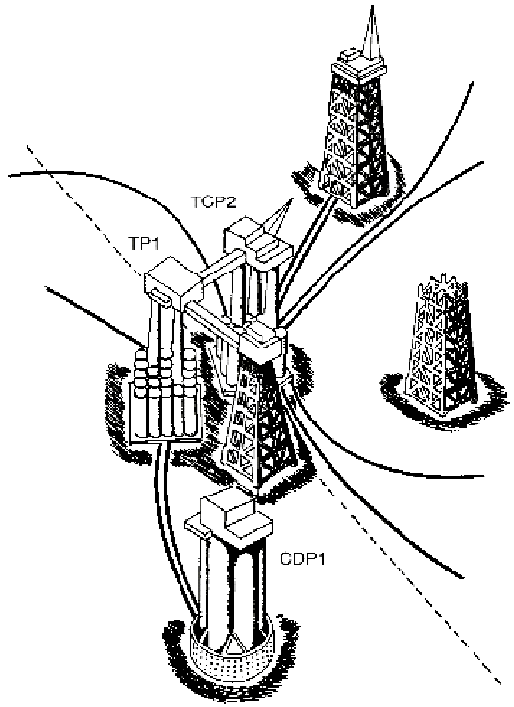
- The Frigg Field – built 1972-1978
  - TCP2
  - TP1
  - CDP1

According to international conventions the structures must be decommissioned

Each structure :

Weight : 250000 t
Costs : 200 – 600 million CHF





- None of the platforms were designed for decommissioning !

Decision Problems in Engineering

- **Structural Design**

Exceptional structures are often associated with structures of

"Extreme Dimensions"

Great Belt Bridge under Construction

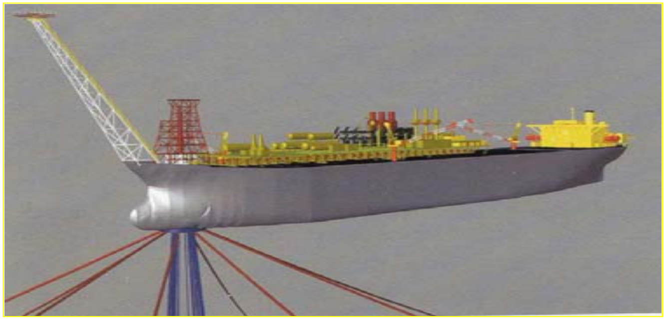
Concept drawing of the Troll platform

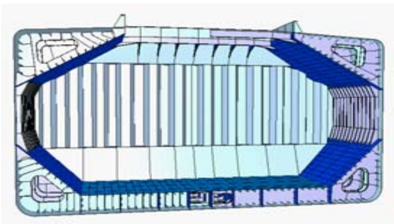
Decision Problems in Engineering

- **Structural Design**

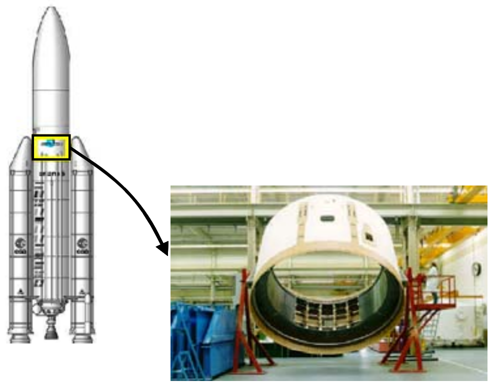
or associated with structures fulfilling

"New and Innovative Purposes"



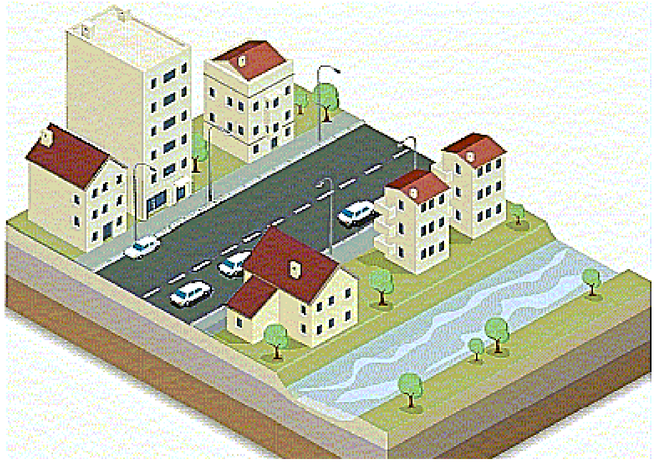


Concept drawing of
Floating Production, Storage and Offloading unit

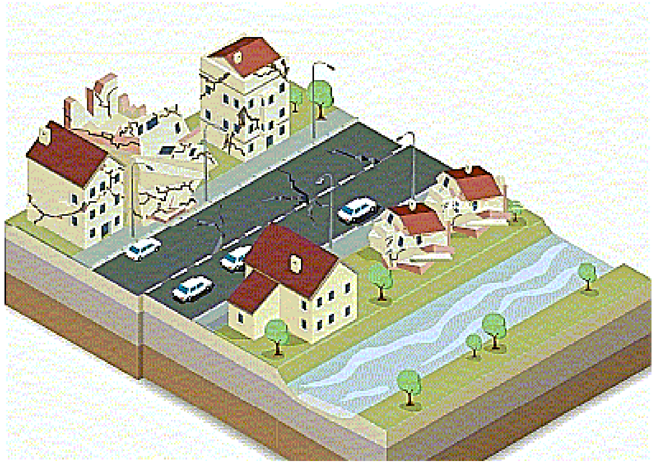


Illustrations of the ARIANE 5 rocket

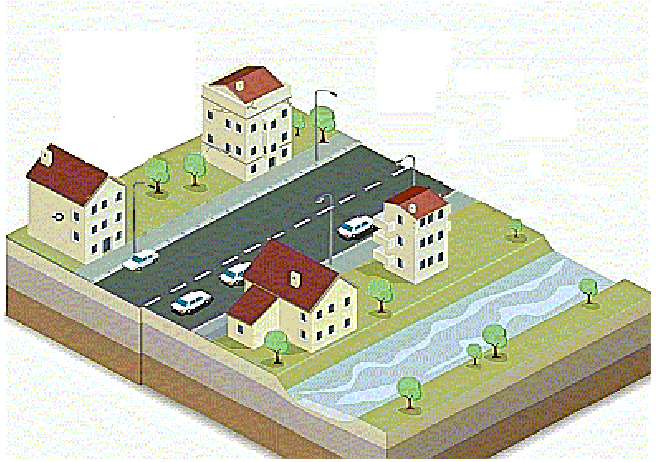
Decision Problems in Engineering



Before



During



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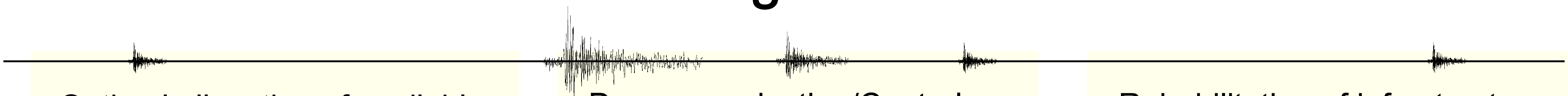


Optimal allocation of available resources for risk reduction

- strengthening
- rebuilding

in regard to possible earth-quakes

Damage reduction/Control

Emergency help and rescue

After quake hazards

Rehabilitation of infrastructure functionality

Condition assessment and updating of reliability and risks

Optimal allocation of resources for rebuilding and strengthening

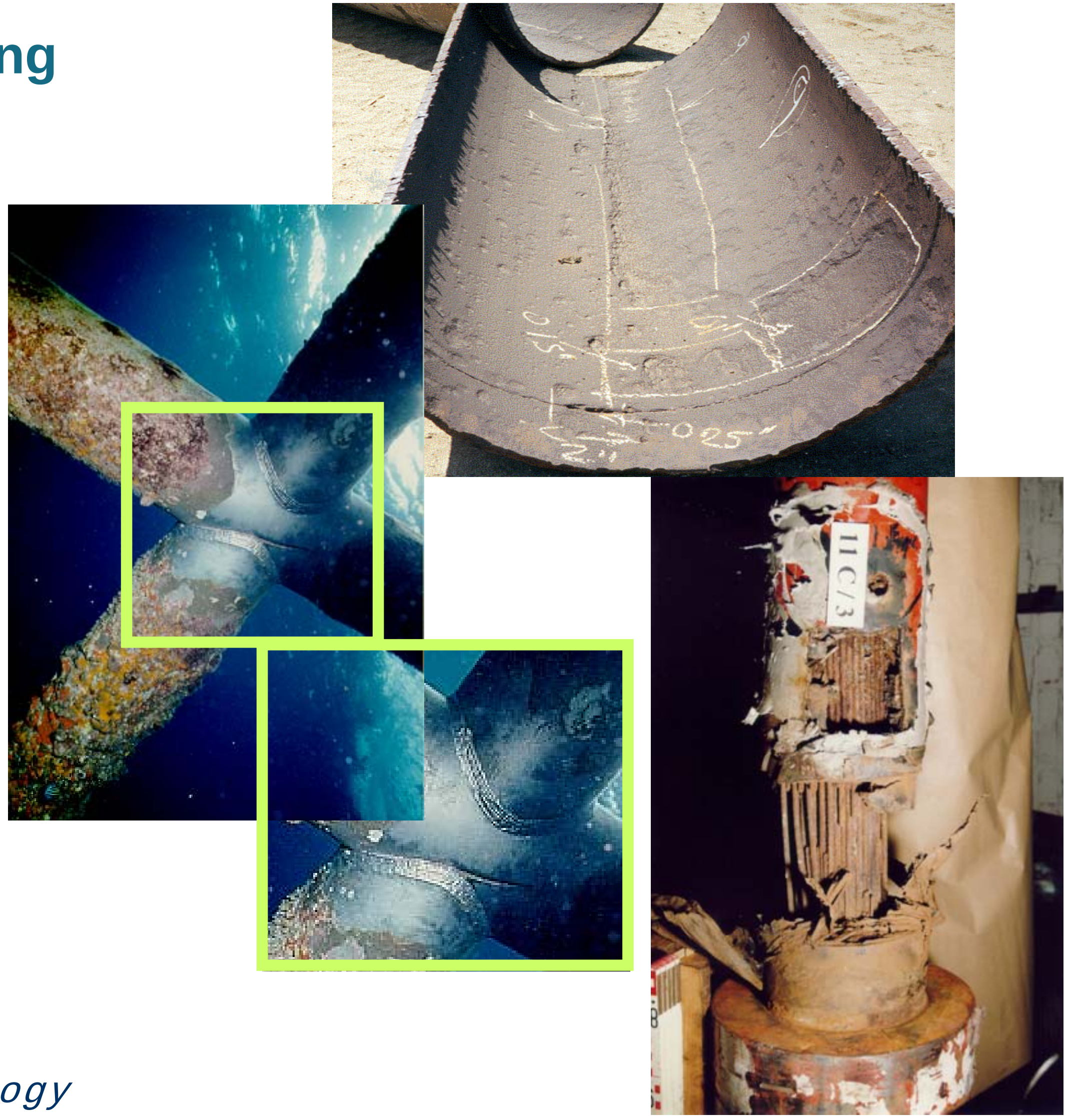
Decision Problems in Engineering

- **Inspection and Maintenance Planning**

  Due to
  - **operational loading**
  - **environmental exposure**

  structures will always to some degree be exposed to degradation processes such as

  - **fatigue**
  - **corrosion**
  - **scour**
  - **wear**



Decision Problems in Engineering

- **Inspection and Maintenance Planning**

  For industrial facilities inspection and maintenance is also an important issue with regard to:

  reduction of production downtime

  safety of workers

  safeguarding the environment

Decision Problems in Engineering

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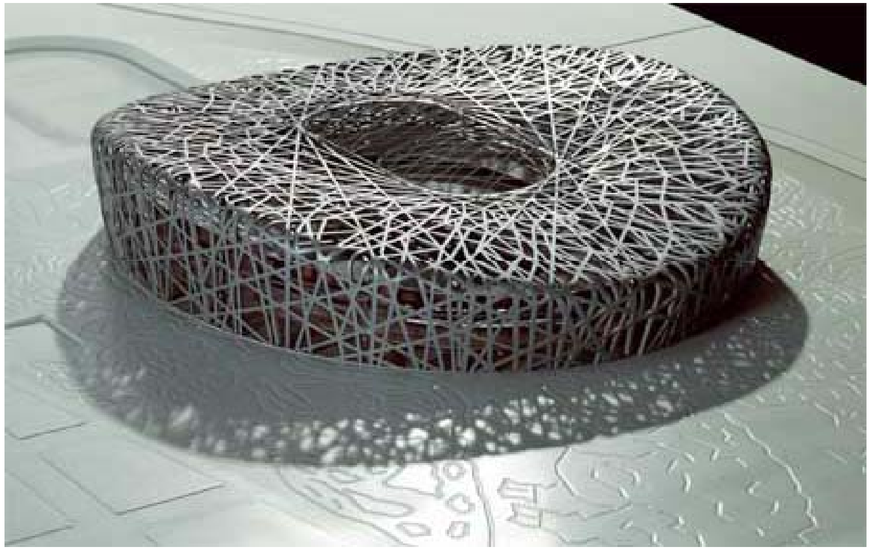
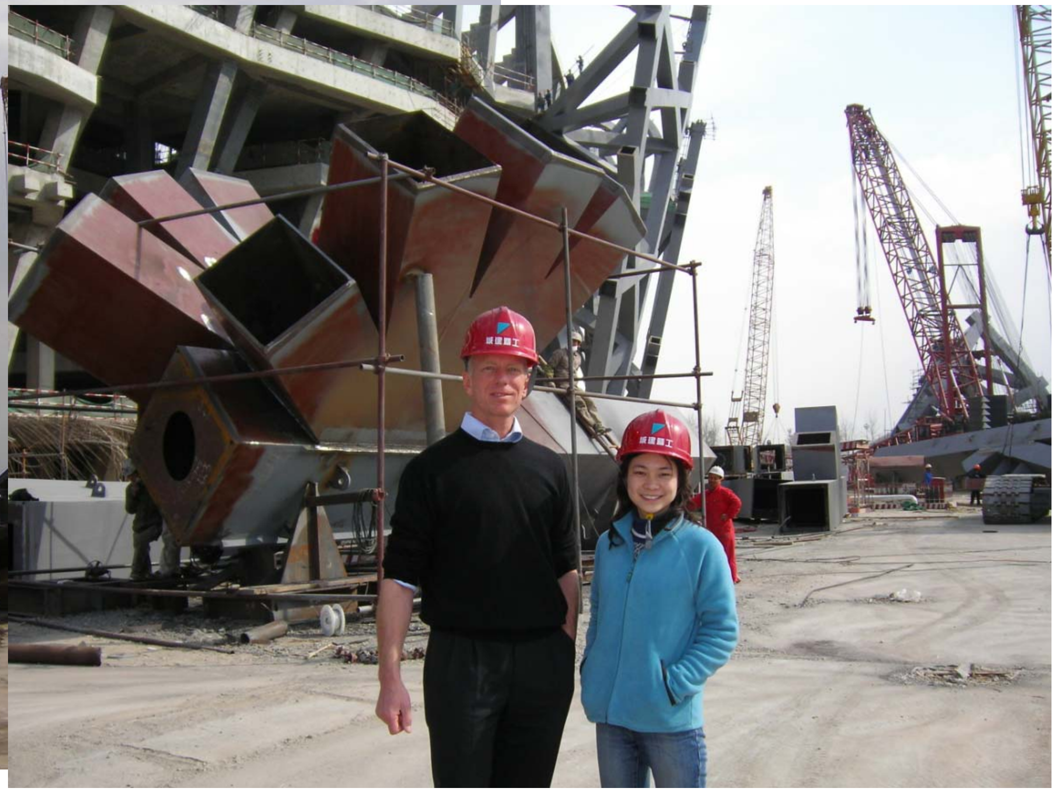
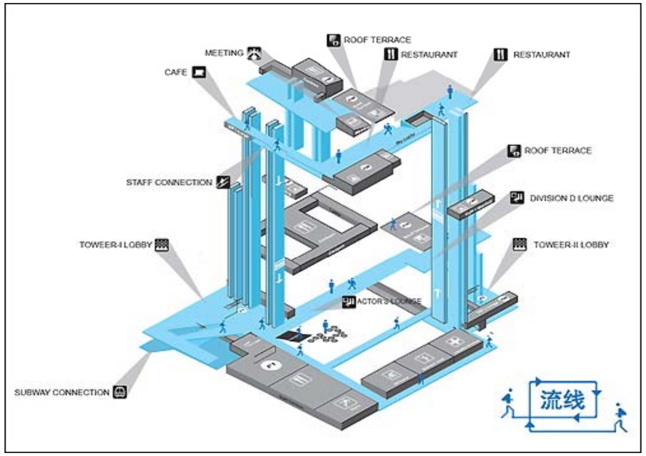
Decision Problems in Engineering



Decision Problems in Engineering

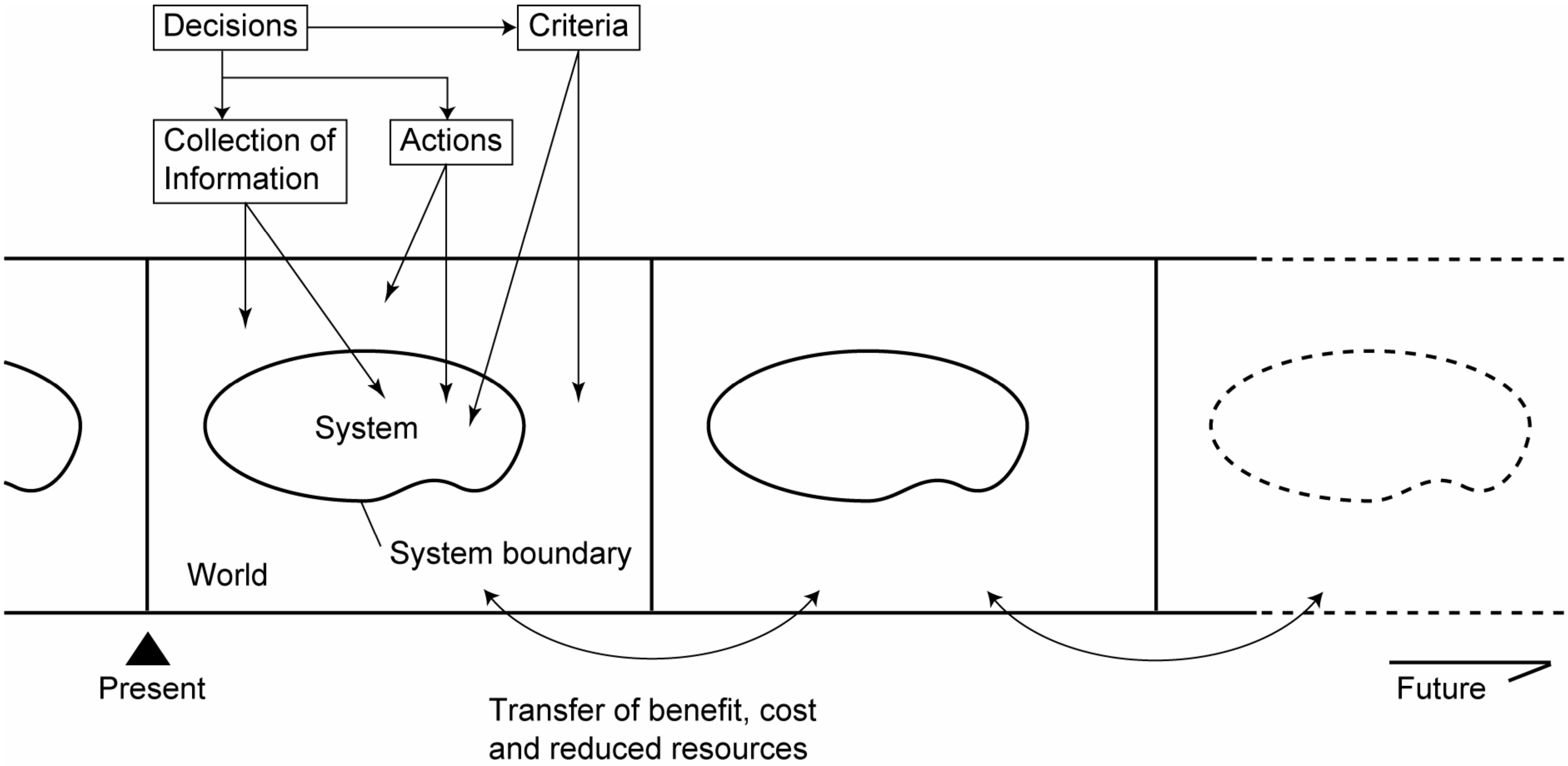


Decision Problems in Engineering



New emerging challenges have necessitated exceptional requirements with regard to construction management and safety

The Risk Based Decision Process

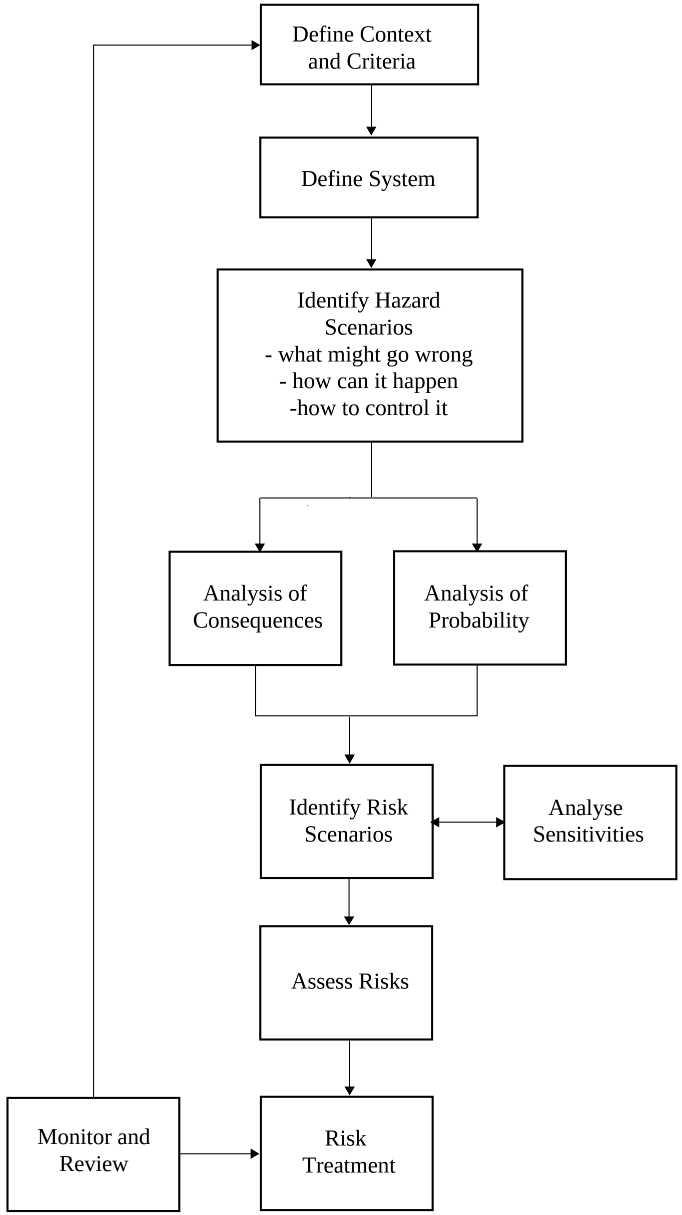


The Risk Based Decision Process

Risk assessment supports decision making subject to uncertainties

The theoretical basis for risk based decision making is the theory of decision analysis

The main task is to optimally manage risks in terms of life safety, economic losses as well as potential damages to the environment



The Risk Based Decision Process

The risk assessment can be categorized according to the degree of detail

Level 1 :
Analysis of the probabilities of occurence of critical events

Level 2 :
Analysis of the probabilities of occurence of critical events and the corresponding consequences

Level 3 :
As for level 2, but with consideration of human errors as well as potential loss of lives – if relevant

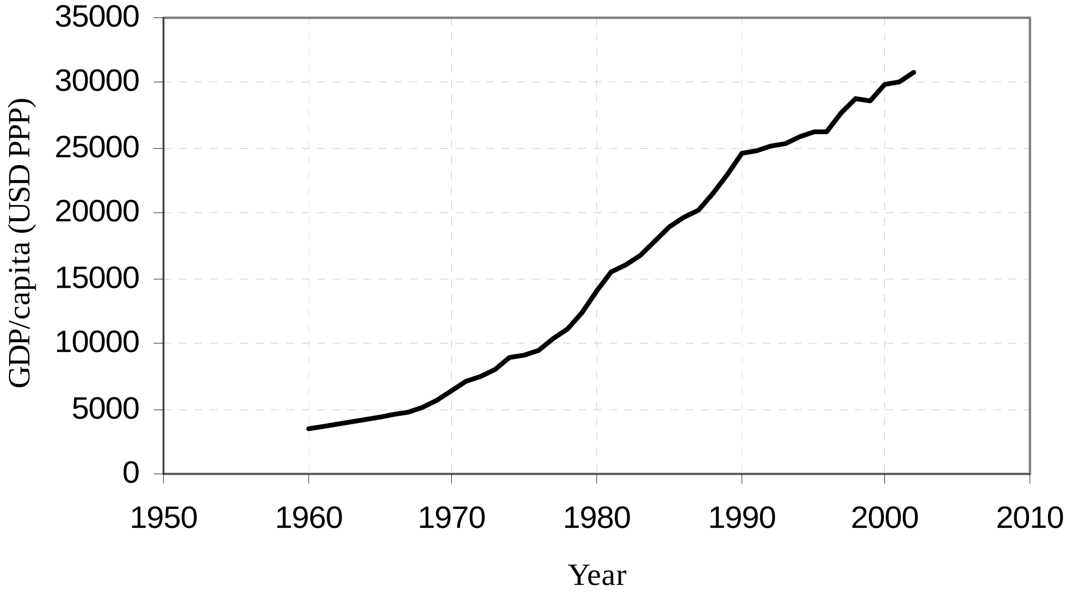
Categorization of risk assessments is usefull!

Documents to what detail the risk assessment was performed!

Life Quality

- **Demographical indicators**

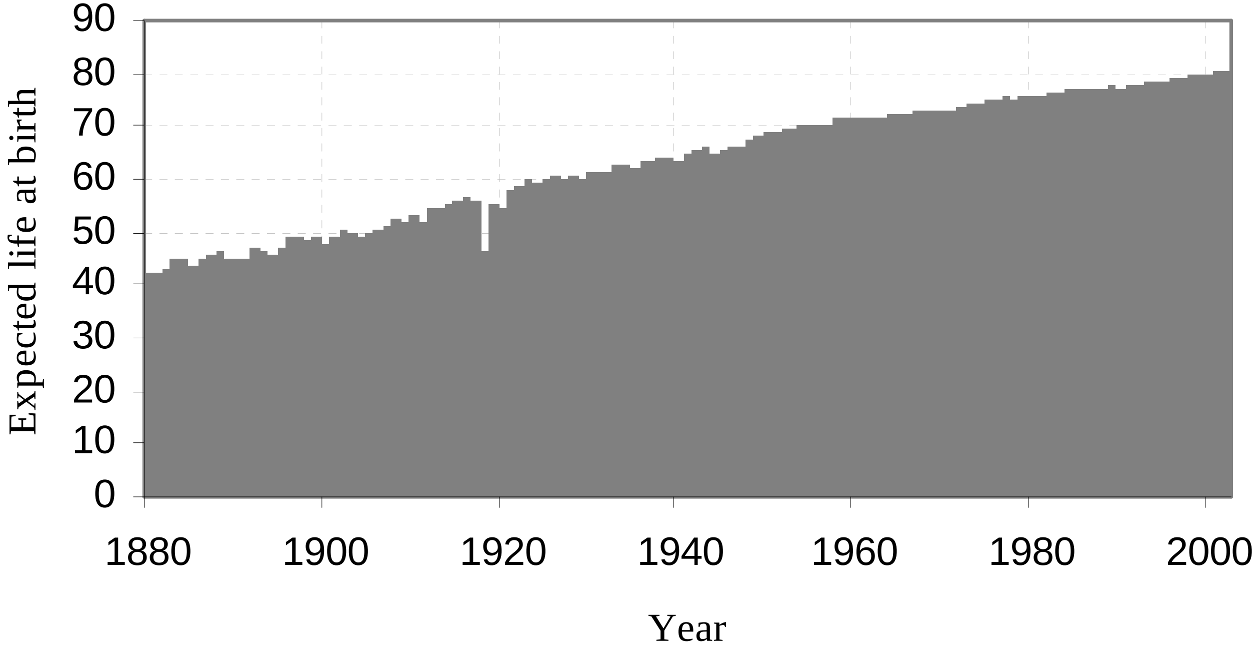
  - Gross domestic product (GDP) per capita



Life Quality

- **Demographical indicators**

  - Life expectancy at birth



Life Quality

- **Life quality can be assessed through the**

  “Human Development Index” (UNO) or
  “Life Quality Index” (JCSS)

  as a function of GDP, life expectancy, free time,…

  GDP and life expectancy are important components

  10-20% of the GDP is reinvested into life saving activities

  Maintenance of infrastructure costs around 10-15 per cent of the available GDP

  Cost efficiency is of tremendous importance!

Individual Risks

Based on statistical information the contribution to life risks of different activites may be assessed

Activity/course	Number of fatalities per hour per 10^8 persons
Mountaineering (international)	2700
Aviation transport (international)	120
Deep sea travling	59
Auto traffic	56
Mining (coal)	21
Construction work	7.7
Manufacturing/production	2.0
Accidents at home	2.1
Accidents at home (healthy persons)	0.7
Fires at home	0.1
Structural failures	0.002

Individual Risks

- Accidents account only for 4% of all deaths

  Illness such as heart failure, cancer and strokes account for 58%

Causes of death	probability/year	probability/lifetime
Transport Accidents	1.66E-04	1.28E-02
- Pedestrian	2.13E-05	1.64E-03
- Pedal cyclist	2.78E-06	2.14E-04
- Motorcycle rider	1.07E-05	8.24E-04
- Car occupant	5.24E-05	4.05E-03
- Occupant of heavy transport vehicle	1.31E-06	1.01E-04
- Bus occupant	1.30E-07	1.00E-05
- Animal rider or occupant of animal-drawn vehicle	4.07E-07	3.14E-05
- Occupant of railway train or railway vehicle	9.12E-08	7.04E-06
- Air and space transport accidents	3.22E-06	2.49E-04
Non-transport Accidents	1.90E-04	1.47E-02
- Falls	5.27E-05	4.07E-03
- Struck by or against another person	1.58E-07	1.22E-05
- Accidental drowning and submersion	1.15E-05	8.88E-04
- Exposure to electric current, radiation, temperature, and pressure	1.51E-06	1.17E-04
- Exposure to smoke, fire and flames	1.16E-05	8.96E-04
- Uncontrolled fire in building or structure	9.38E-06	7.24E-04
- Contact with venomous animals and plants	2.14E-07	1.65E-05
- Earthquake and other earth movements	9.82E-08	7.58E-06
- Storm	1.89E-07	1.46E-05
- Flood	1.23E-07	9.48E-06
- Lightning	1.54E-07	1.19E-05
- Alcohol	1.06E-06	8.20E-05
- Narcotics and hallucinogens	2.28E-05	1.76E-03
Intentional self-harm	1.07E-04	8.26E-03
Assault	7.12E-05	5.49E-03
Legal intervention	1.39E-06	1.07E-04
Operations of war	5.96E-08	4.60E-06
Complications of medical and surgical care	1.06E-05	8.18E-04

Individual Risks

- ## Occupational risks

Occupation sector	% of employees	Fatalities per 100,000 employed
Private industry	**90**	4.2
- Agriculture, forestry and fishing	14	22.7
- Mining	2	23.5
- oil and gas exploitation	1	23.1
- Construction	20	12.2
- Manufacturing	10	3.1
- Transportation and public utilities	16	11.3
- Wholesale trade	4	4.0
- Retail trade	9	2.1
- Finance, insurance, and real estate	2	1.0
- Services	12	1.7
Government	**10**	2.7
- Federal (including resident armed forces)	2	3.0
Total	**100**	4.0

Individual Risks

- ## Natural disasters

Victims[1]	Insured losses[2,3]		Event	Country
300 000	–	14.11.1970	Storm and flood catastrophe	Bangladesh
250 000	–	28.07.1976	Earthquake in Tangshan (8.2 Richter scale)	China
138 000	3	29.04.1991	Tropical cyclone Gorky	Bangladesh
60 000	–	31.05.1970	Earthquake (7.7 Richter scale)	Peru
50 000	156	21.06.1990	Earthquake in Gilan	Iran
25 000	–	07.12.1988	Earthquake in Armenia	Armenia, ex-USSR
25 000	–	16.09.1978	Earthquake in Tabas	Iran
23 000	–	13.11.1985	Volcanic eruption on Nevado del Ruiz	Colombia
22 000	233	04.02.1976	Earthquake (7.4 Richter scale)	Guatemala
19 118	1063	17.08.1999	Earthquake in Izmit	Turkey
15 000	100	26.01.2001	Earthquake (moment magnitude 7.7) in Gujarat	India, Pakistan
15 000	106	29.10.1999	Cyclone 05B devastates Orissa state	India, Bangladesh
15 000	–	01.09.1978	Flooding following monsoon rains in northern parts	India
15 000	530	19.09.1985	Earthquake (8.1 Richter scale)	Mexico
15 000	–	11.08.1979	Dyke burst in Morvi	India
10 800	–	31.10.1971	Flooding in Bay of Bengal and Orissa state	India
10 000	234	15.12.1999	Flooding, mudslides, landslides	Venezuela, Colombia

Individual Risks

- ## Malevolence - terrorism

Victims[1]	Insured losses[2]	Date	Event	Country
at least 3000	19 000	11.09.2001	Terror attack against WTC, Pentagon and other buildings	USA
300	—	23.10.1983	Bombing of US Marine barracks and French paratrooper base in Beirut	Lebanon
300	6	12.03.1993	Series of 13 bomb attacks in Mumbai	India
270	138	21.12.1988	PanAm Boeing 747 crashes at Lockerbie due to bomb explosion	UK
253	—	07.08.1998	Two simultaneous bomb attacks on US embassy complex in Nairobi	Kenya
166	145	19.04.1995	Bomb attack on government building in Oklahoma City	USA
127	45	23.11.1996	Hijacked Ethiopian Airlines Boeing 767-260 ditched at sea	Indian Ocean
118	—	13.09.1999	Bomb explosion destroys apartment block in Moscow	Russia
100	—	04.06.1991	Arson in arms warehouse in Addis Ababa	Ethiopia
100	6	31.01.1999	Bomb attack on Ceylinco House in Colombo	Sri Lanka

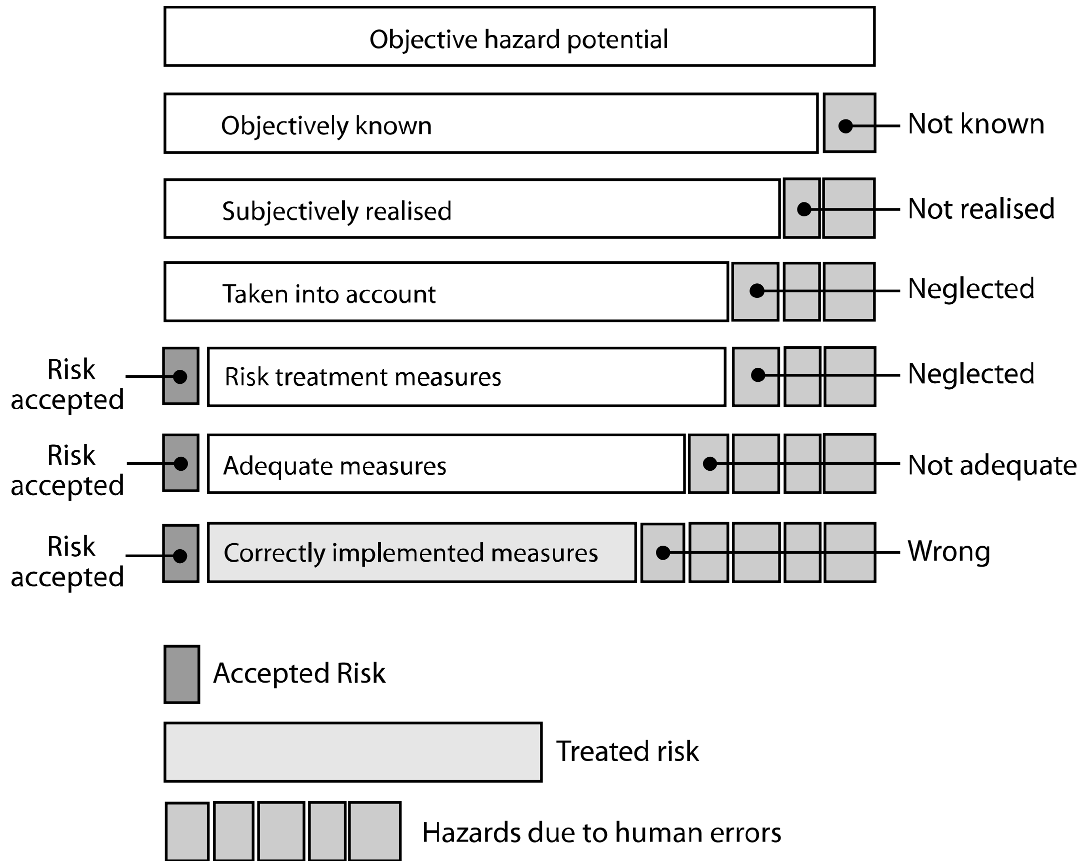
[1]Dead or missing [2] Excluding liability losses; in USD m, at 2001 price level

Sources of Risks in Engineering

Any activity carries a risk potential

It is important that this potential is fully understood

Only when the risk potential is fully understood can rational decisions be identified and implemented

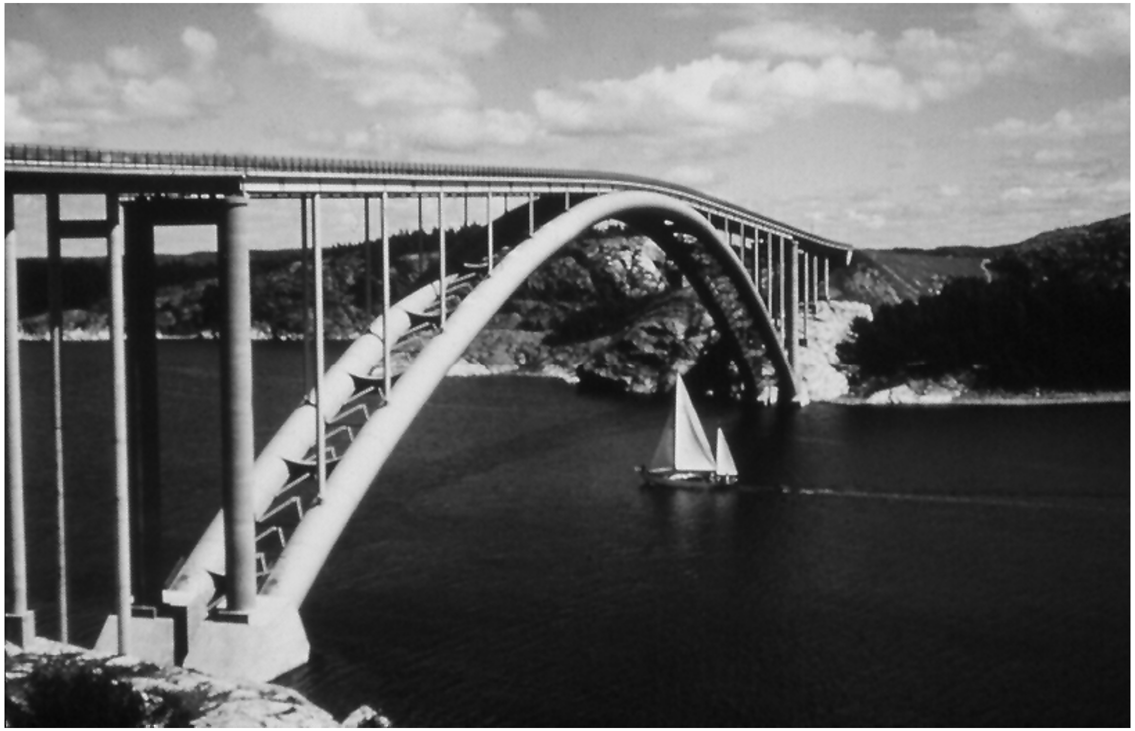


Sources of Risks in Engineering

Case where the risk potential was not fully appreciated

The Tjörn bridge in Sweden

Just after construction



Sources of Risks in Engineering

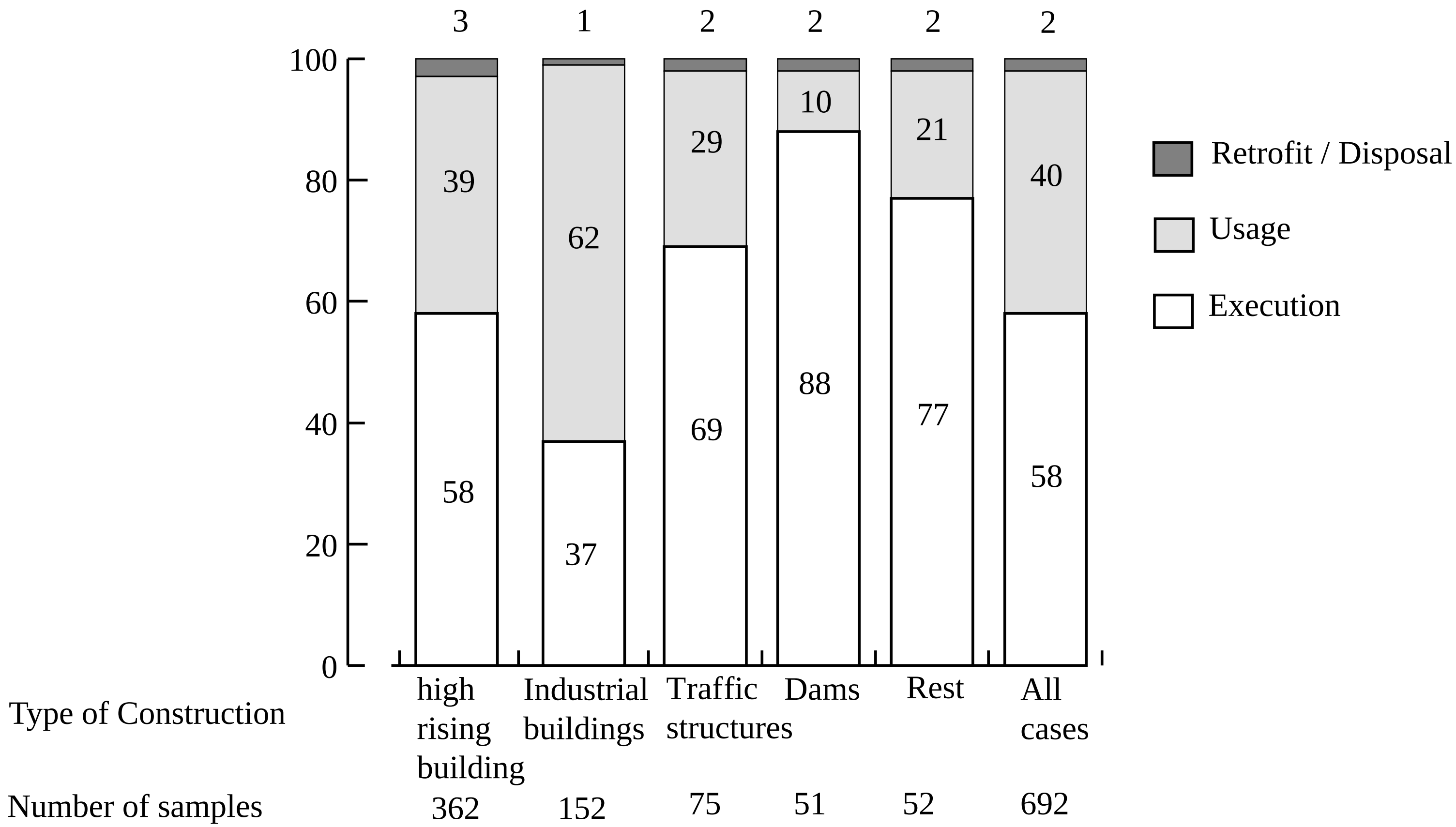
Case where the risk potential was not fully appreciated

The Tjörn bridge in Sweden

A few weeks later

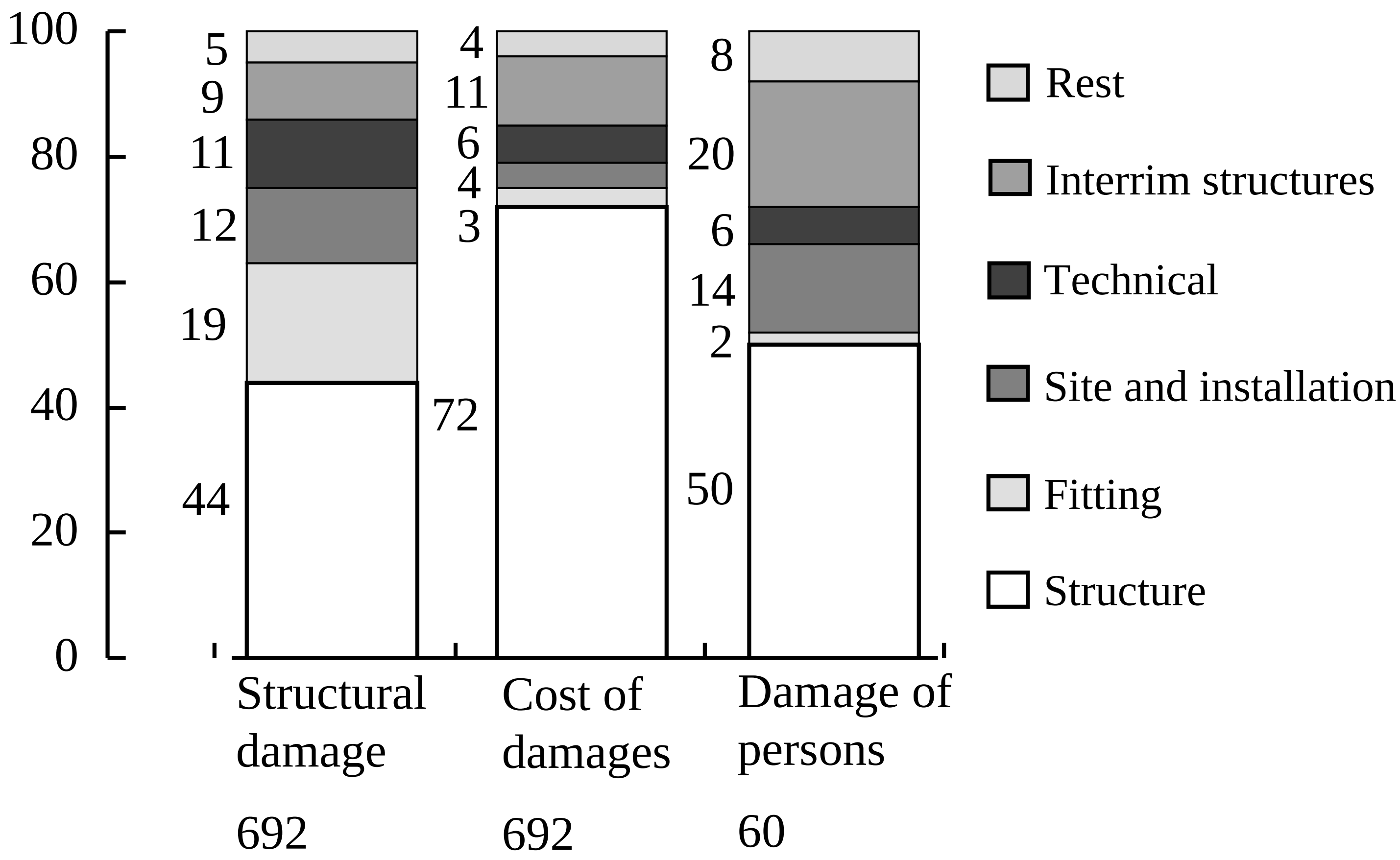
Sources of Risks in Engineering

Failures in structural engineering



Sources of Risks in Engineering

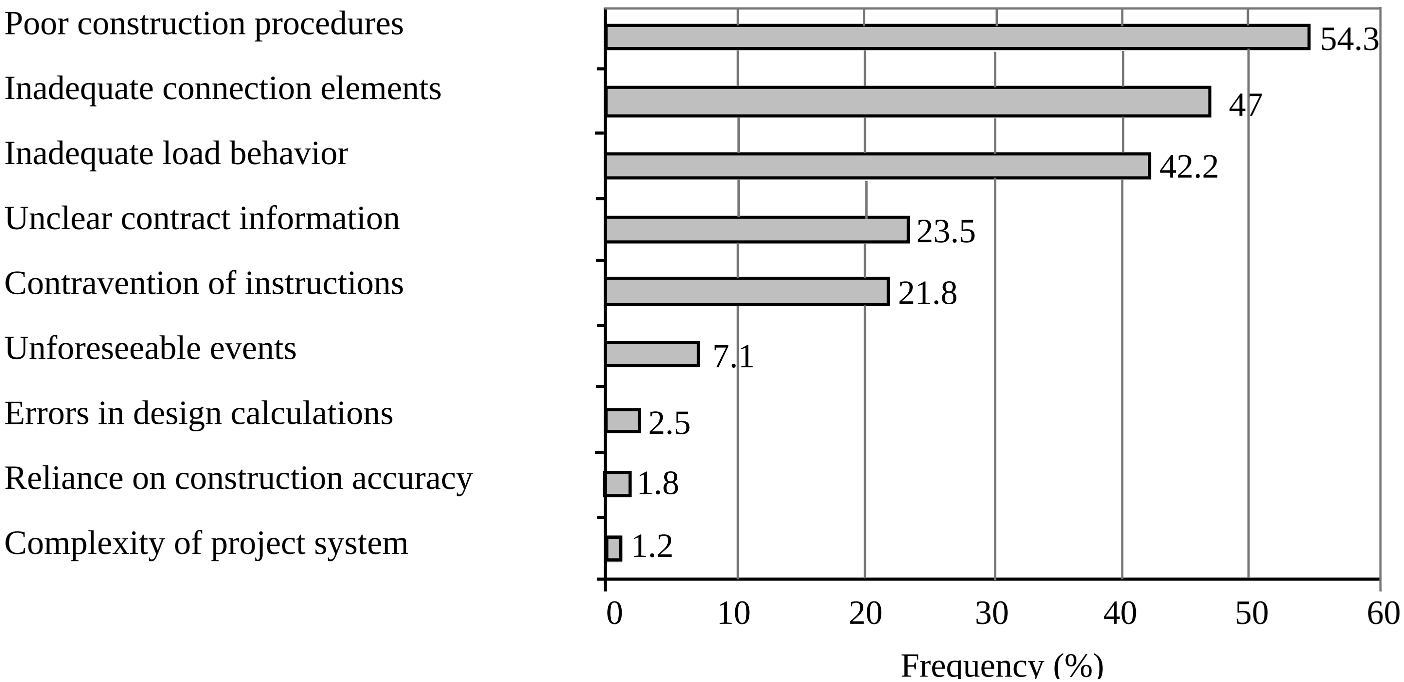
Failures in structural engineering



Sources of Risks in Engineering

Failures in structural engineering

Primary causes of structural failure



Aim of the lecture

- General introduction to risk and safety in engineering
- Basics and principles of risk based decision analysis
- Theory and technical aspects of risk assessment
- Methods of reliability analysis and introduction to the JCSS probabilistic model code
- Introduction to time variant and systems reliability analysis and assessment of structural robustness
- Illustration of computer tools for risk and reliability anaylsis
- Applications for design, assessment and maintenance planning
- Understanding of engineering optimization and risk acceptance

Organisation of the Lecture

DATE	SUBJECT
16.09.09	**Introduction and overview** - Life quality, risks and decision making - Hazards and causes of failures
23.09.09	**Review of probability theory and statistics** - Uncertainties in engineering modeling - Basic data analysis - Random variables and processes - Engineering model building
30.09.09	**Engineering decision analysis** - Prior decision analysis - Posterior decision analysis - Pre-posterior decision analysis
07.10.09	**Risk assessment in civil engineering** - Procedures of risk assessment - Scenario identification and analysis - System representation - Probabilities and consequences - Multi scale indicator based risk assessment
14.10.09	**Classical reliability analysis** - Failure rate data - The reliability function - Updating of failure rates based on data - Failure rate functions and the bath-tub curve
21.10.09	**Structural reliability analysis** - First and Second Order Reliability Methods - Monte Carlo and importance sampling
28.10.09	**Software tools for reliability analysis** - Presentation of the COMREL program - Exercises in the PC-lab

DATE	SUBJECT
04.11.09	**The JCSS probabilistic model code** - Probabilistic modeling of resistances - Probabilistic modeling of loads
11.11.09	**Systems reliability analysis and robustness** - Series and parallel system analysis - Structural systems analysis - Robustness assessment of structures
18.11.09	**Time variant reliability analysis** - The Poisson and the Normal processes - The first excursion problem and mean out crossing rates - Approximations in time variant reliability analysis - Treatment of non ergodic variables and random sequences
25.11.09	**Bayesian Probabilistic Nets (BPN) in risk assessment** - Basic theory of BPN - Application of BPN in risk assessment - Application of BPN in large scale risk management
02.12.09	**Reliability based structural design and assessment** - Safety formats of design codes - Calibration of design codes - Reliability updating - Assessment of existing structures (and SIA 269)
09.12.09	**Risk based inspection and maintenance planning** - The basic problem - Modeling of degradation processes - Inspection quality and the PoD concept - Generic approaches to inspection planning
16.12.09	**Optimal decision making and risk acceptance criteria** - Optimality in engineering decision making - The ALARP principle for acceptability - The Life Quality Index and acceptable life safety - Societal life saving costs and willingness to pay