

Risk and Safety
in
Civil, Surveying and Environmental
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
 - Lecture notes
 - Exercises
 - Exercise Solutions
- **All available on course webpage**
 - PowerPoint presentations
- **Will be uploaded on the webpage the latest one day before the respective lecture.**
- **Support will be available – you are always welcome to contact me in my office HIL E 23.3 or contact Miss Eva Sabiote in room HIL E 13.1 on Mondays from 1400 to 1600 hours**

Organisation of the Lecture

- The exam for the present course is an oral exam
 - the emphasis of the exam is to ensure that the fundamental understanding of the area of risk and safety in engineering is acquired by the students

Why Risk and Safety in Engineering?

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

Infrastructure

Roads, water supply systems, tunnels, sewage systems, waste deposits, power supply systems, channels

Structures

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



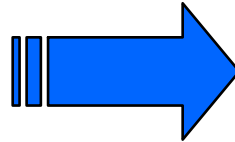
Hong Kong Island - China

Engineering Decision Making for Society?

- Helping to control risks due to Natural Hazards



Tornados and strong winds

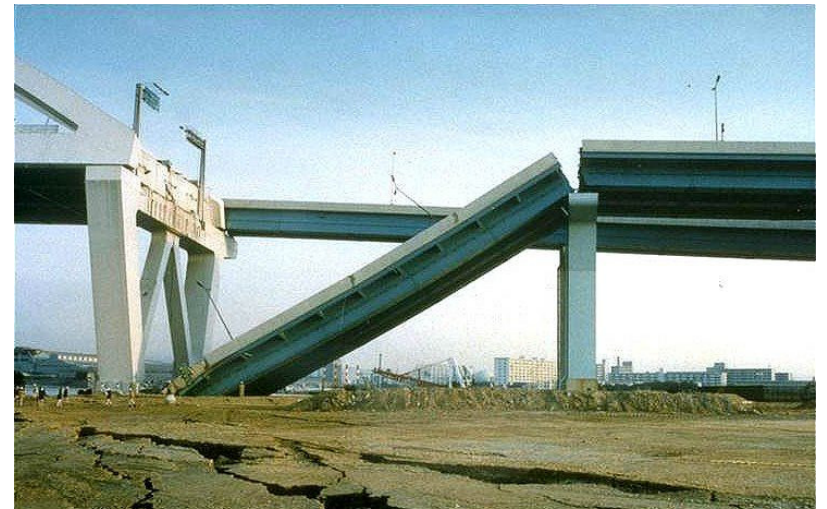


Engineering Decision Making for Society?

- 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



Bombs

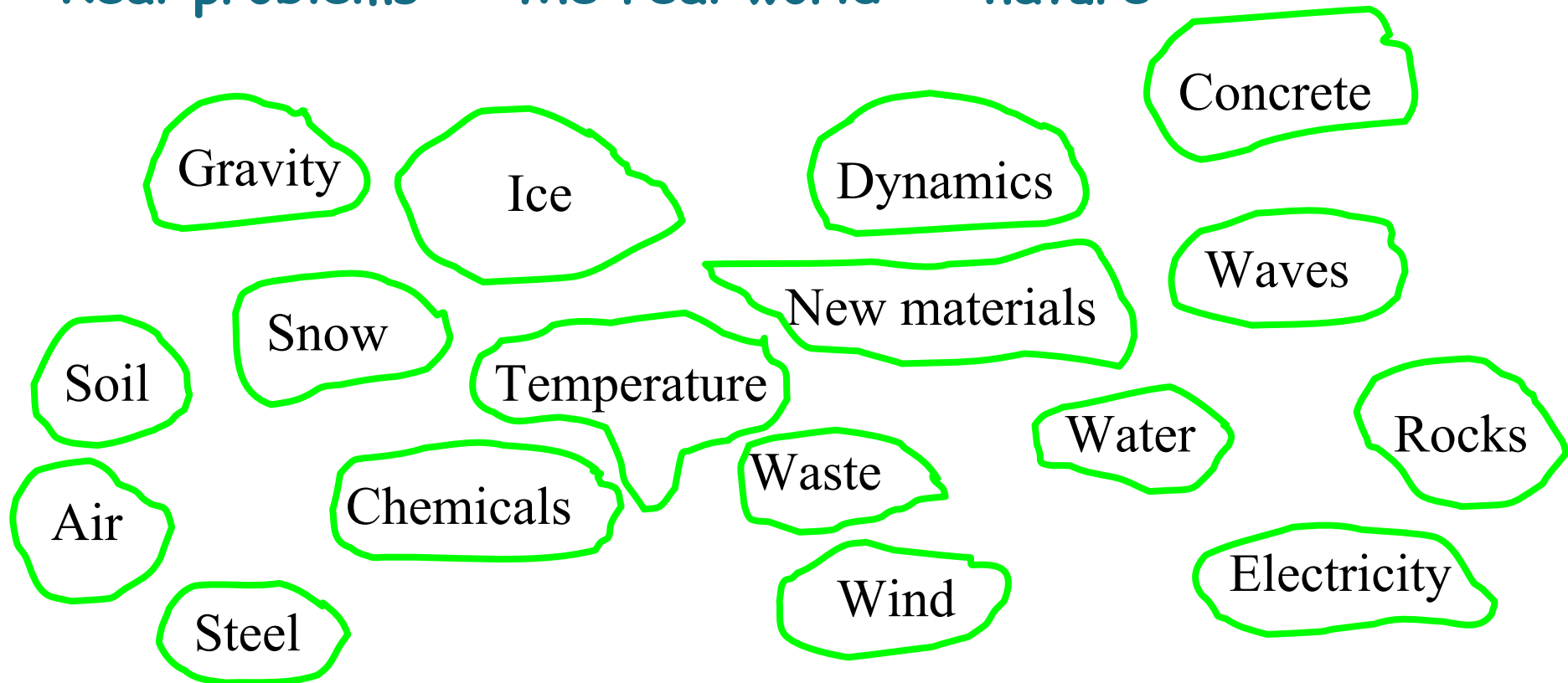


Airplane impacts

Why Risk and Safety in Engineering?

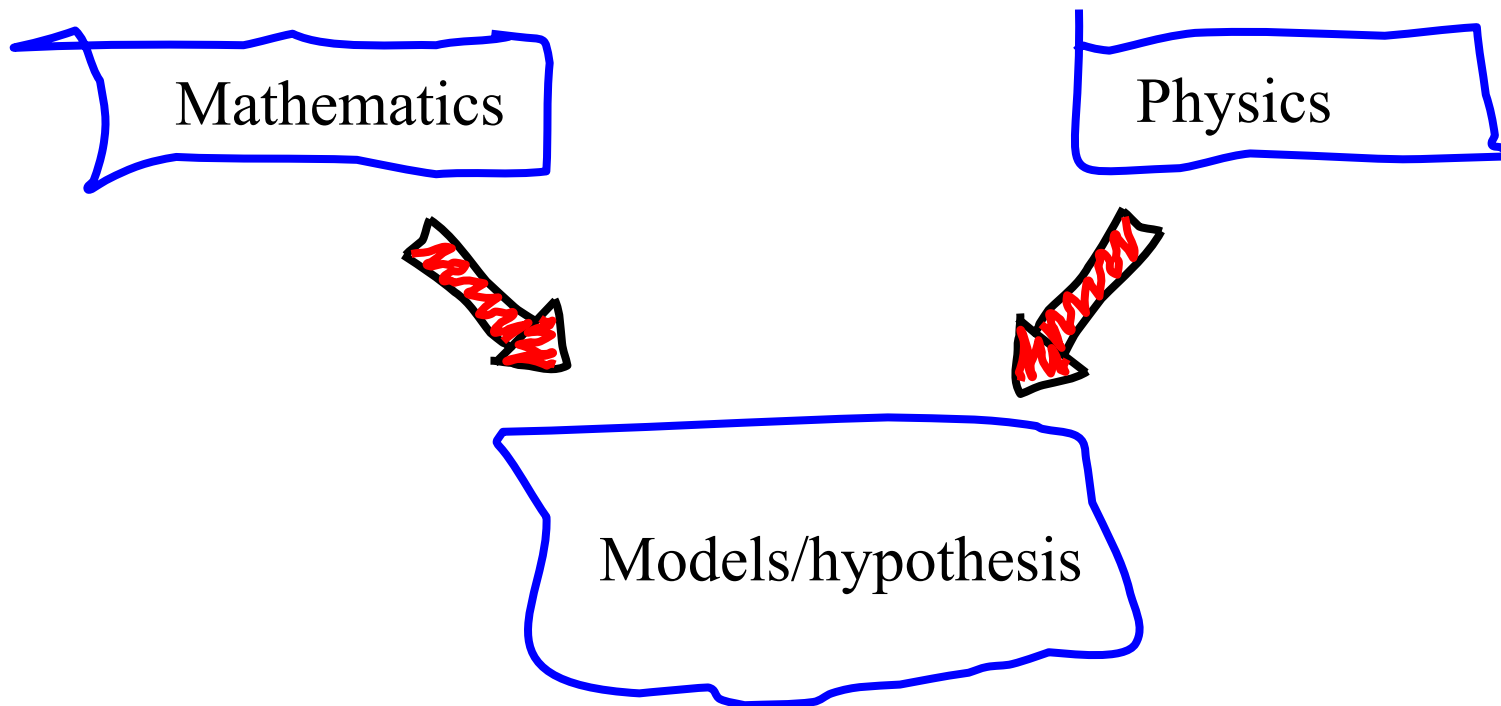
- What are engineers working with ?

Real problems - the real world - nature



Why Risk and Safety in Engineering?

- How do engineers work with the real world ?

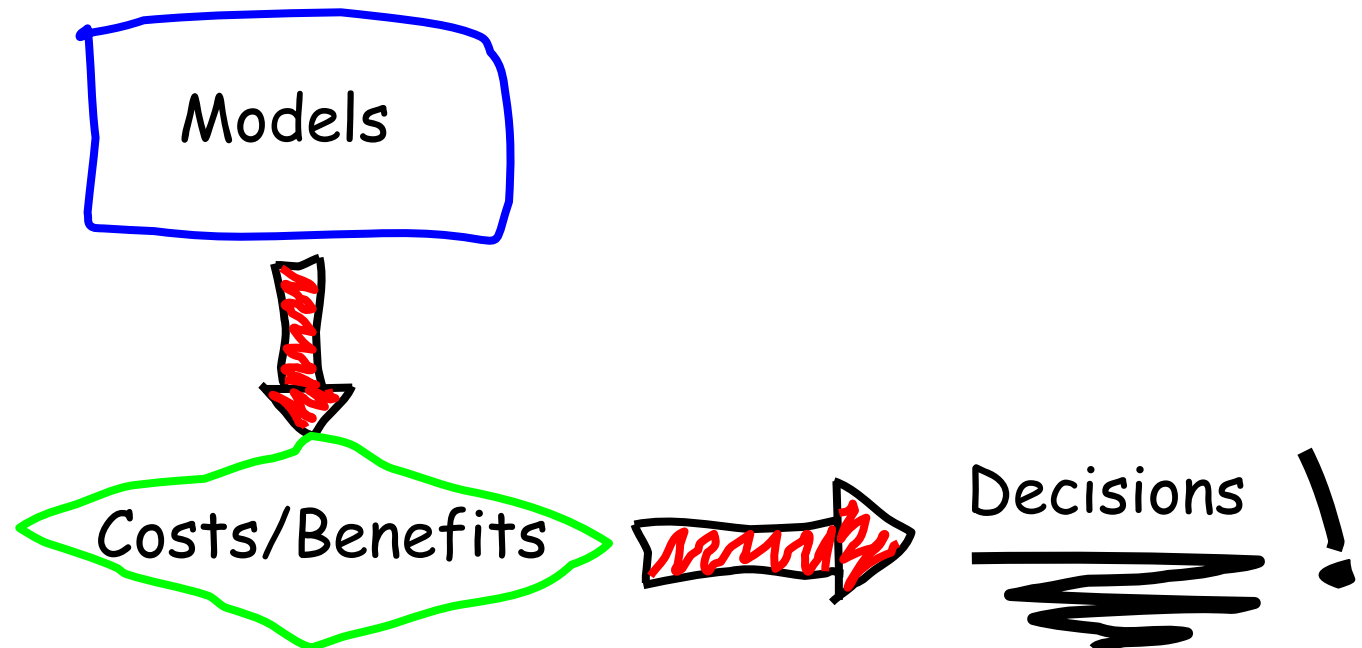


We model the real world to the „best“ of our knowledge

Why Risk and Safety in Engineering?

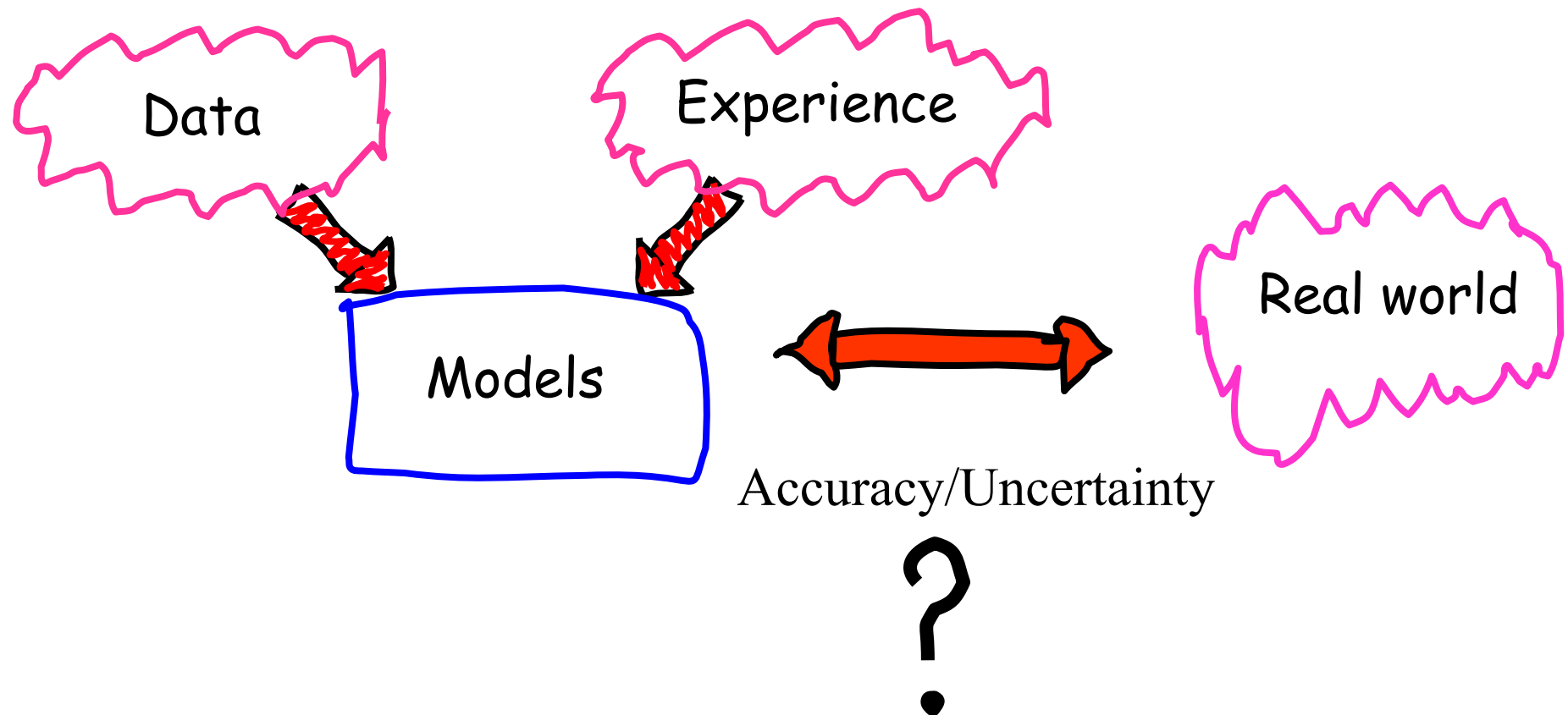
- How do engineers use knowledge

In a perfectly known world



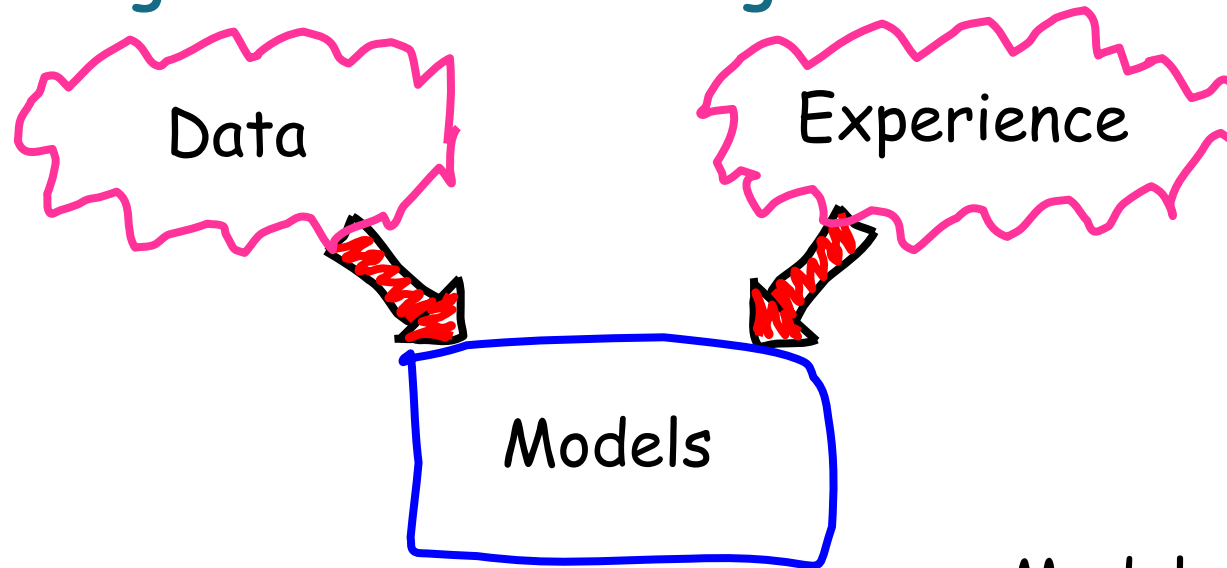
Why Risk and Safety in Engineering?

- How do engineers establish knowledge



Why Risk and Safety in Engineering?

- How do engineers use knowledge



Uncertainty

WHY ?

Models are not precise

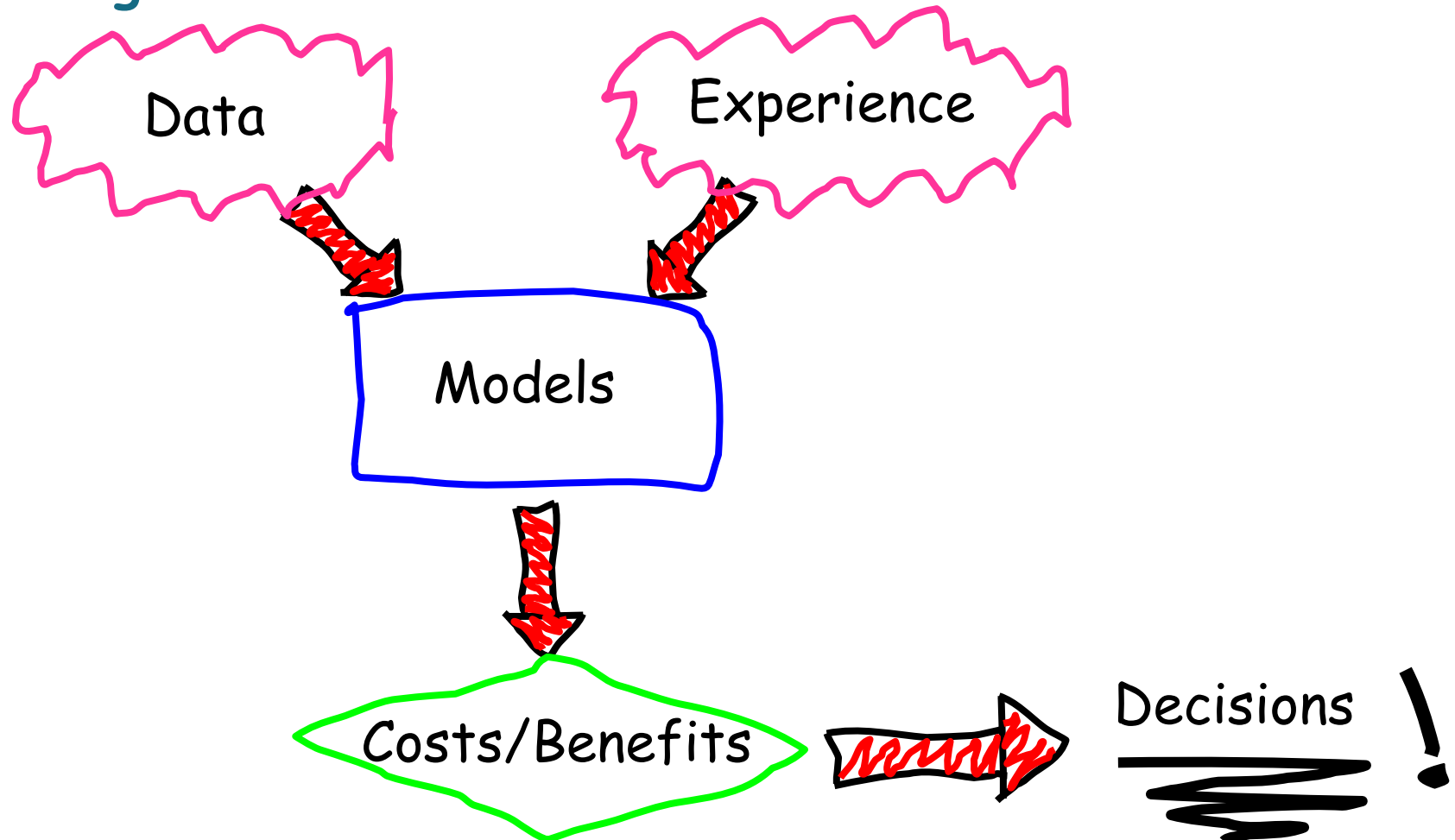
Data are not sufficient

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 are e.g.

- Transport
- Work
- Sport

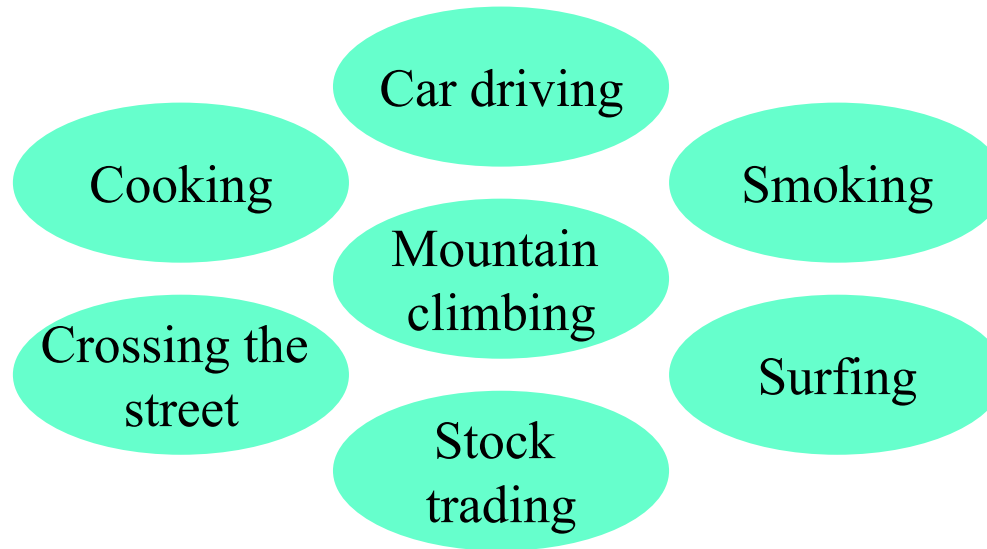
but also

- 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



Concord, North Carolina, 2000



Concorde, Paris, 2000

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



Canada, 1993

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 must 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



Example – Decommissioning of the Frigg Field

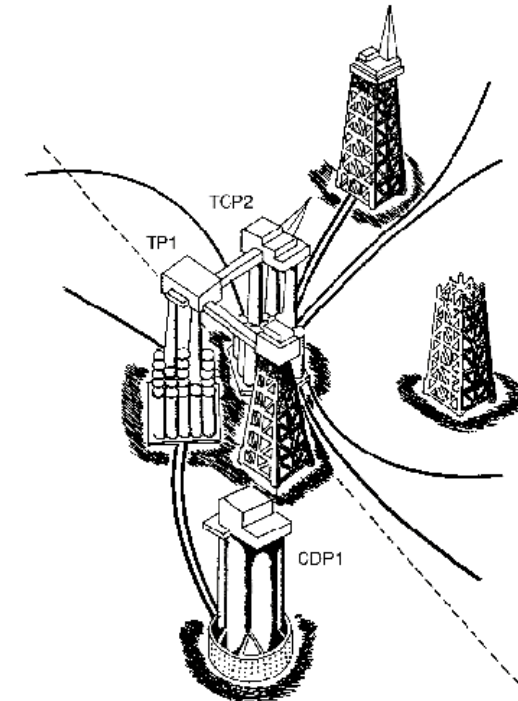
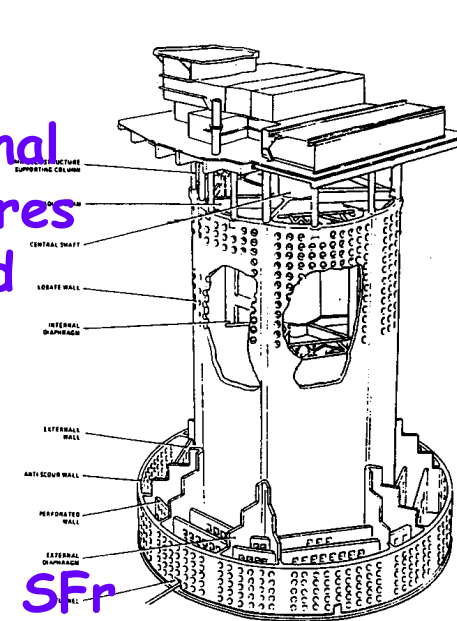
- The Frigg Field - built 1972-1978

- TCP2
- TP1
- CDP1

According to international conventions the structures must be decommissioned

Each structure :

Weight : 250000 t
Costs : 200 - 600 Mio. SFr



- 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



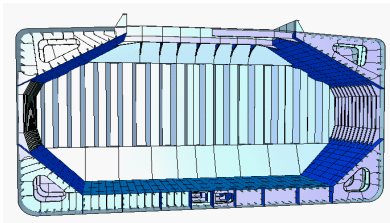
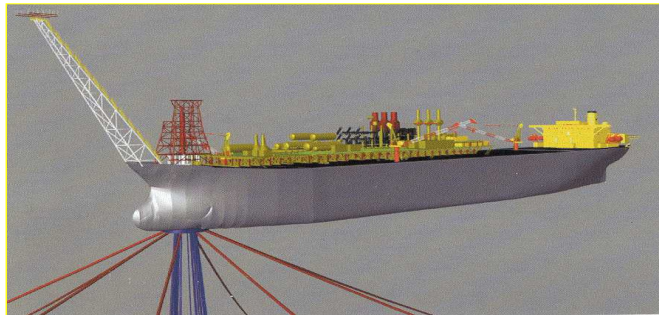
Concept drawing of the Troll platform

Decision Problems in Engineering

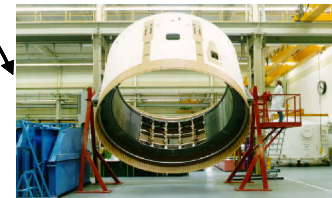
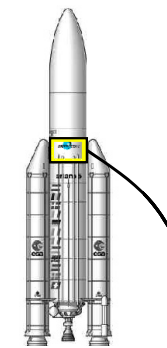
- **Structural Design**

or associated with structures fulfilling

„New and Innovative Purposes“

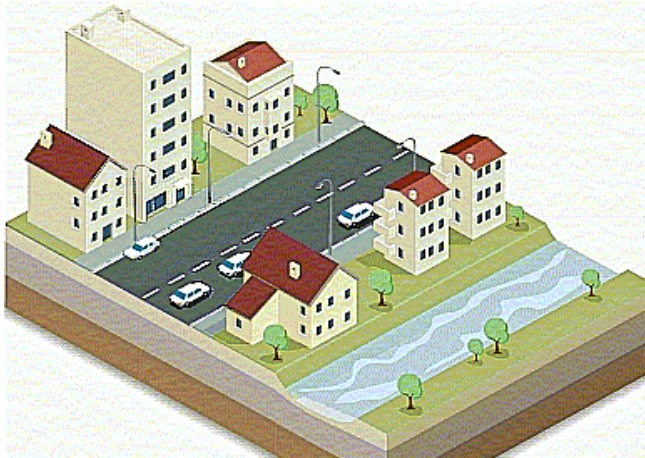


Concept drawing of
Floating Production, Storage and Offloading unit

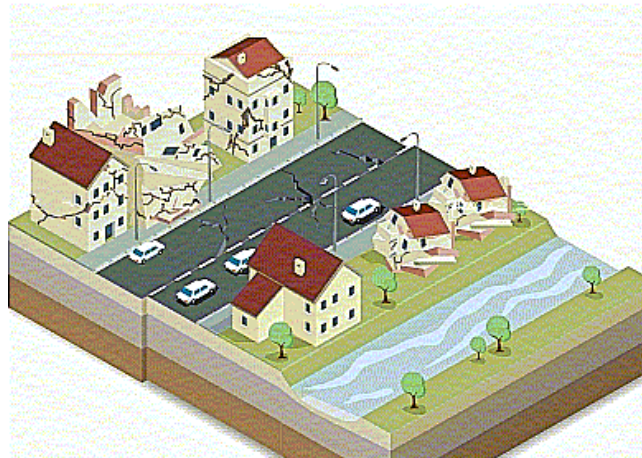


Illustrations of the ARIANE 5 rocket

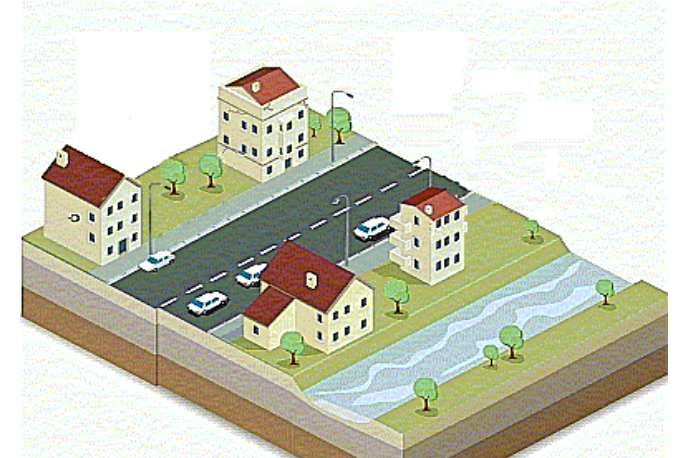
Decision Problems in Engineering



Before



During



After

Optimal allocation of available resources for risk reduction

- strengthening
- rebuilding

in regard to possible earthquakes

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

Reduction of production down time

Safety of workers

Safeguarding the environment



Decision Problems in Engineering

- **Inspection and Maintenance Planning**

For industrial facilities inspection and maintenance is also an important issue

Reduction of production down time

Safety of workers

Safeguarding the environment



Decision Problems in Engineering

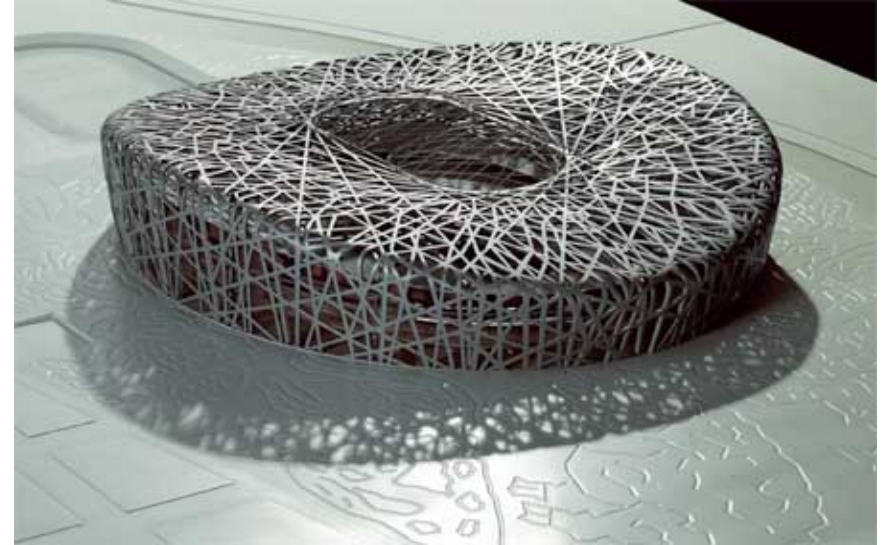
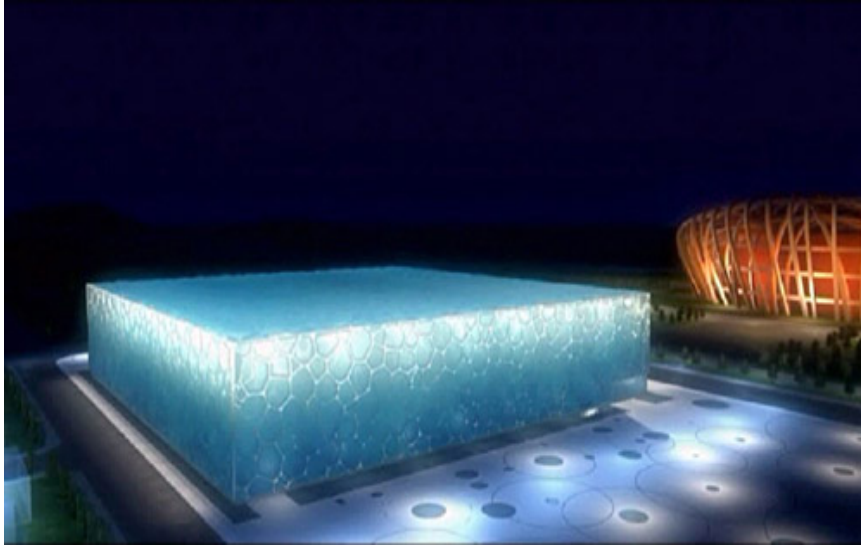
- Construction Management and Safety

The structures presently being constructed in Beijing for the Olympic Games 2008 are all exceptional - and the time is short for their completion

The Olympic Committee has requested that risk assessments are carried out and reported every 3 months



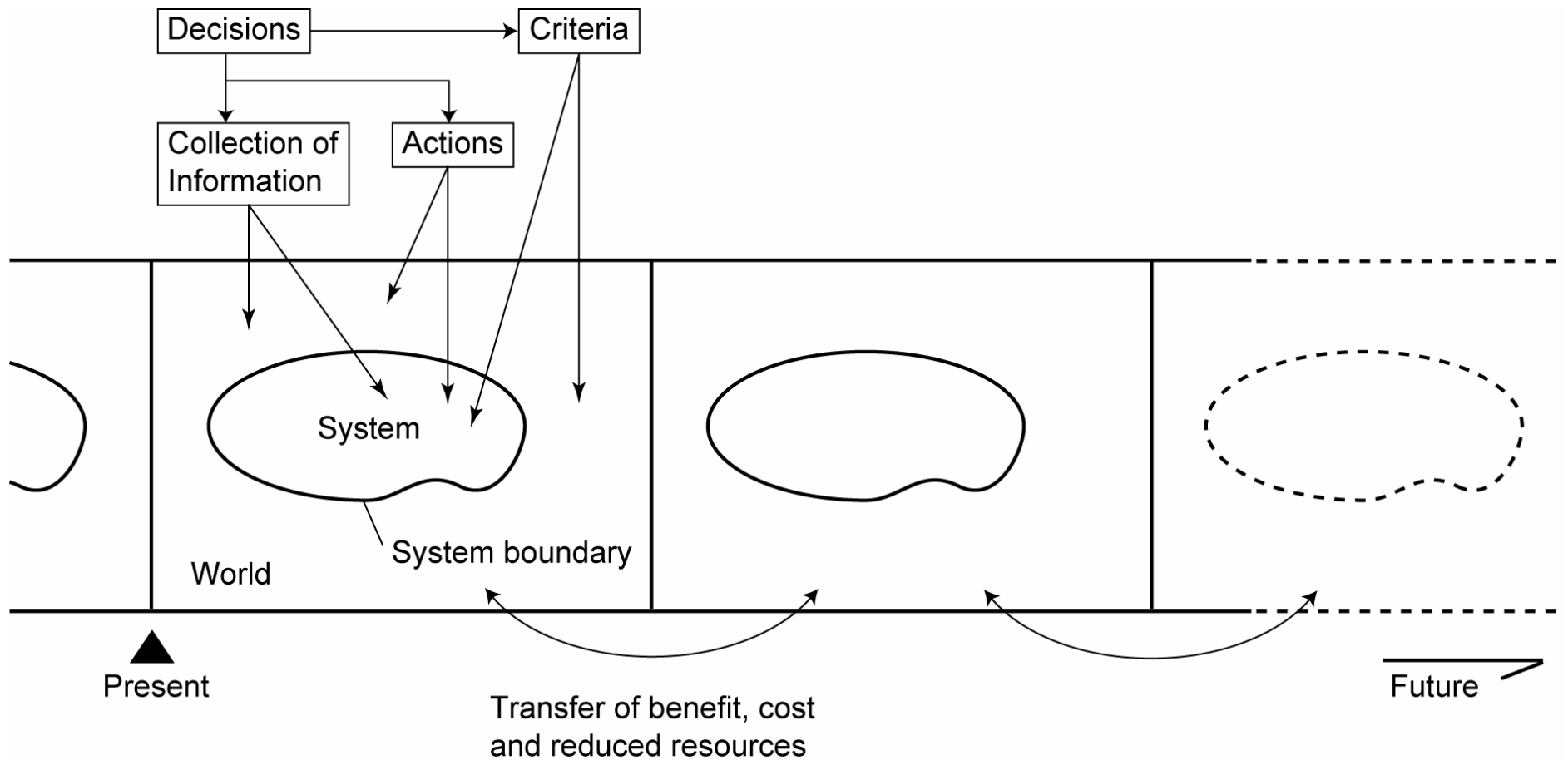
Decision Problems in Engineering



Decision Problems in Engineering



The Risk Based Decision Process

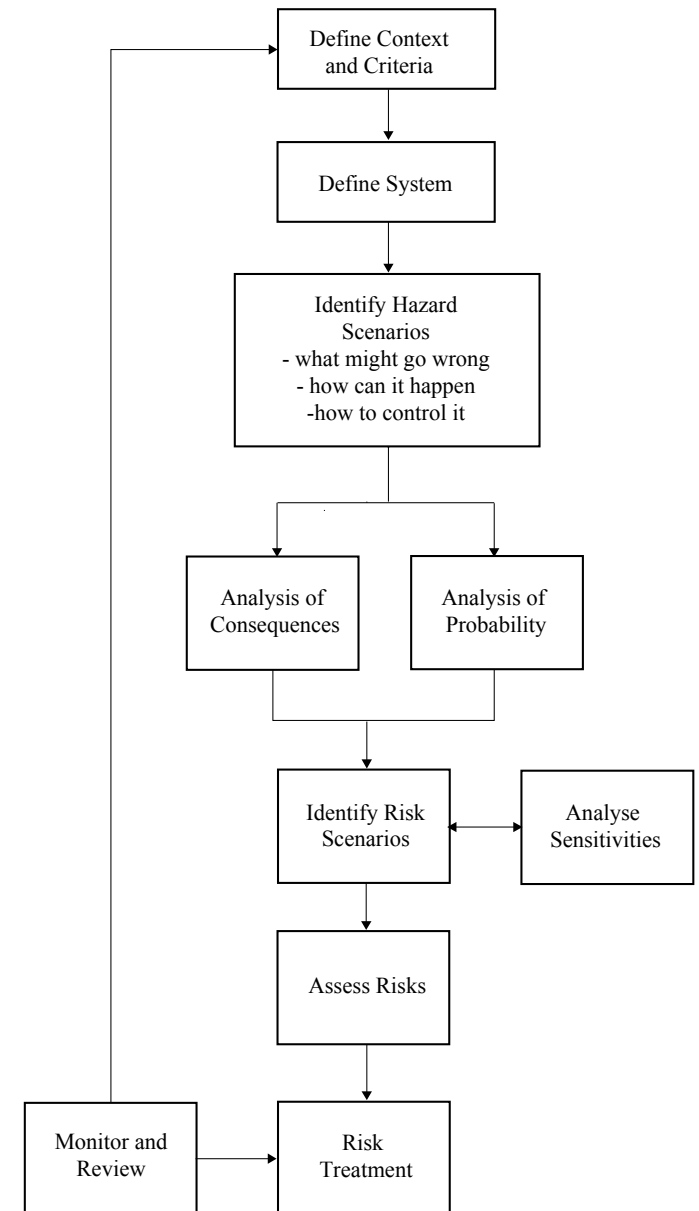


The Risk Based Decision Process

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 being to optimally manage risks in terms of life safety, economical 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 occurrence of critical events

Level 2 :

Analysis of the probabilities of occurrence of critical events and the corresponding consequences

Level 3 :

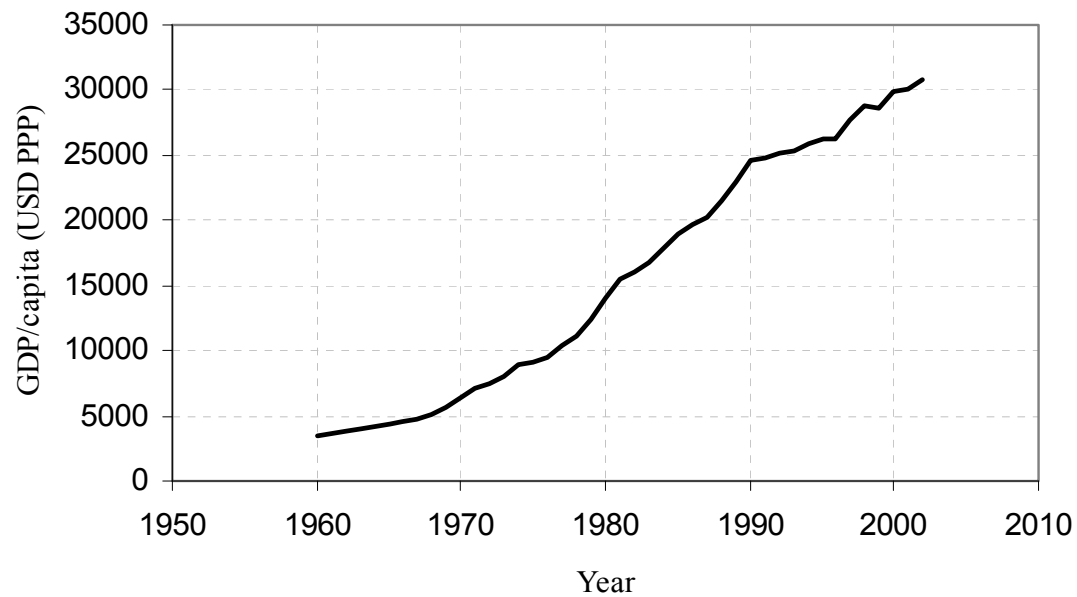
iAs for level 2 but with consideration of human errors as well as potential loss of lives – if relevant

Categorization of risk assessments is useful!

Documents to what detail the risk assessment was performed!

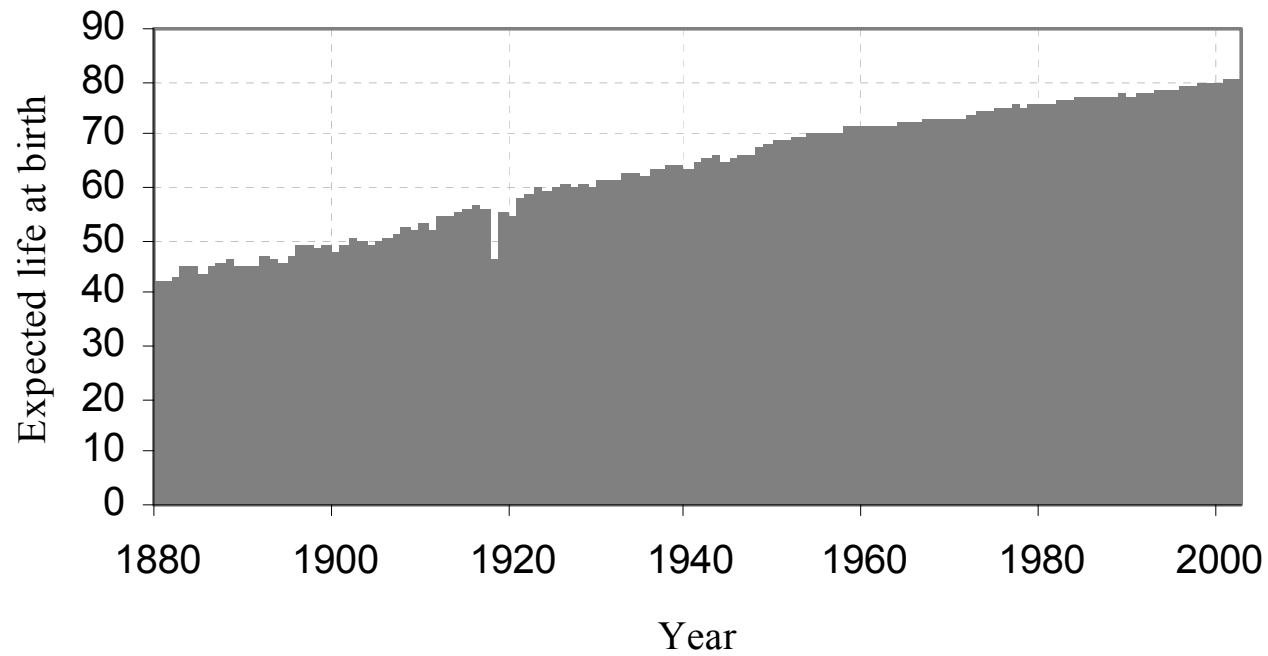
Life Quality

- 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
„the Life Quality Index“ (JCSS)

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

GDP and life expectancy constitute 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 activities may be assessed

Activity/course	Number of fatalities per hour per 10 ⁸ persons
Mountaineering (international)	2700
Aviation transport (international)	120
Deep sea traveling	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

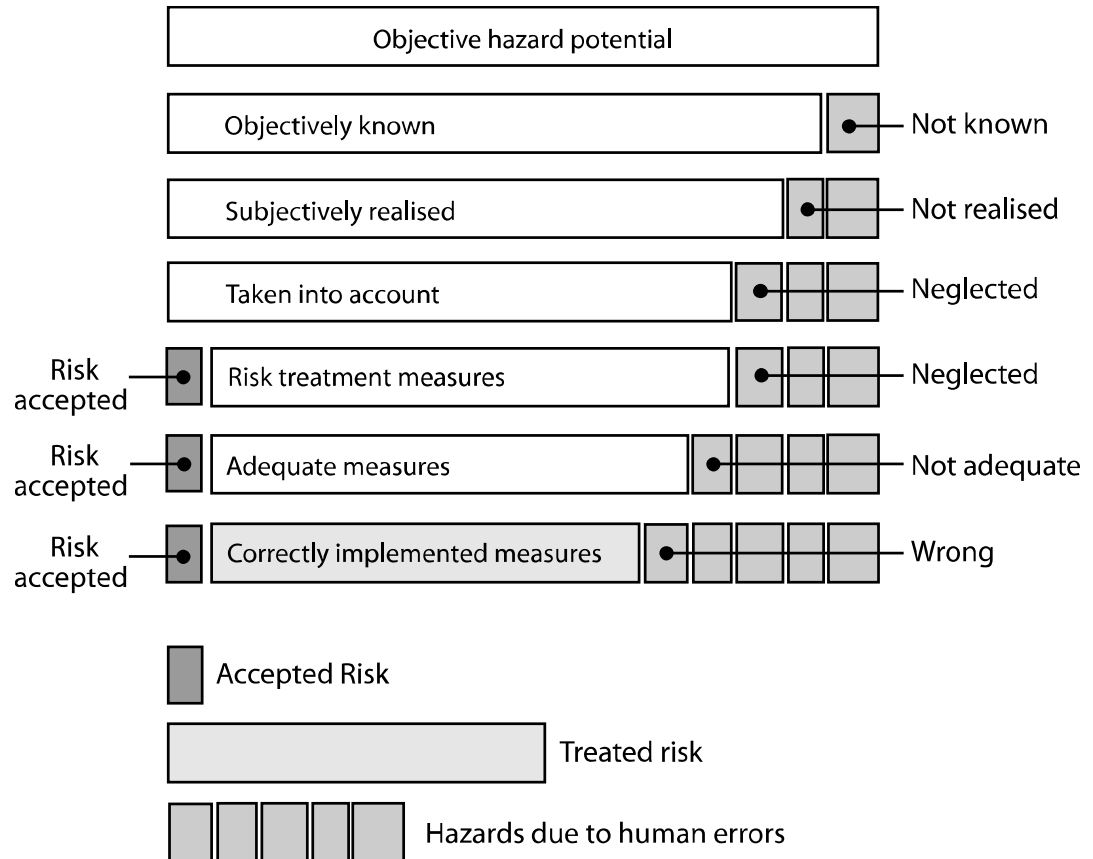
¹Dead or missing ² Excluding liability losses; in USD m, at 2001 price level

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

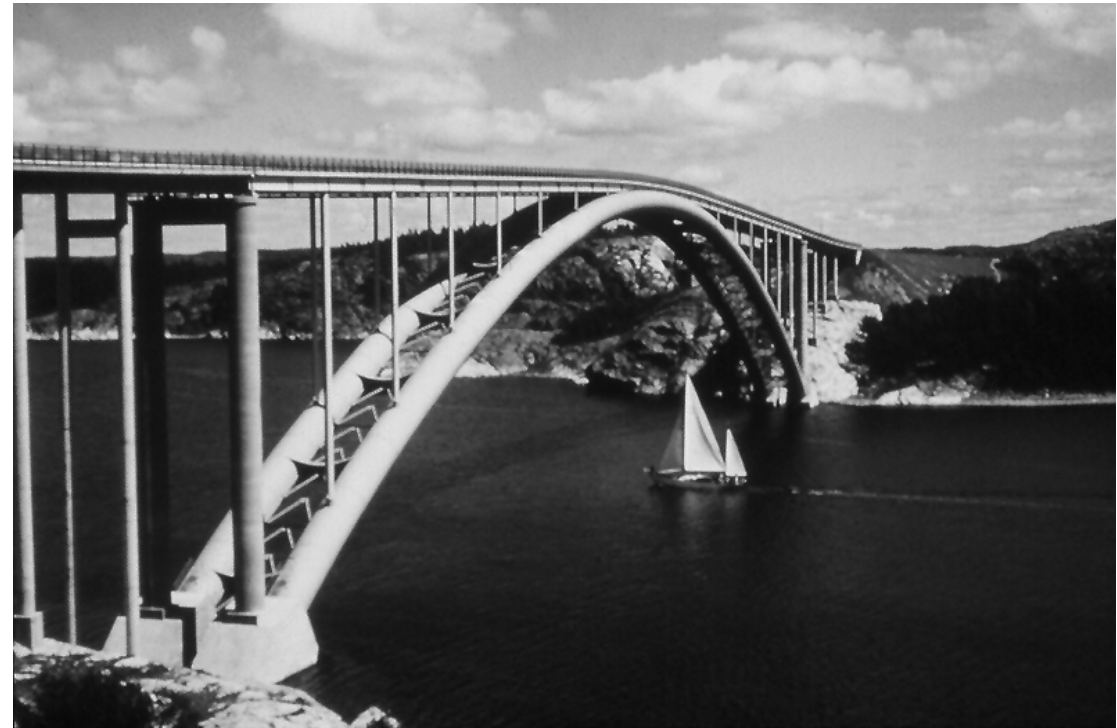


Sources of Risks in Engineering

Case where the risk potential
was not fully appreciated

The Tjörn bridge in Schweden

Just after construction



Sources of Risks in Engineering

Case where the risk potential
was not fully appreciated

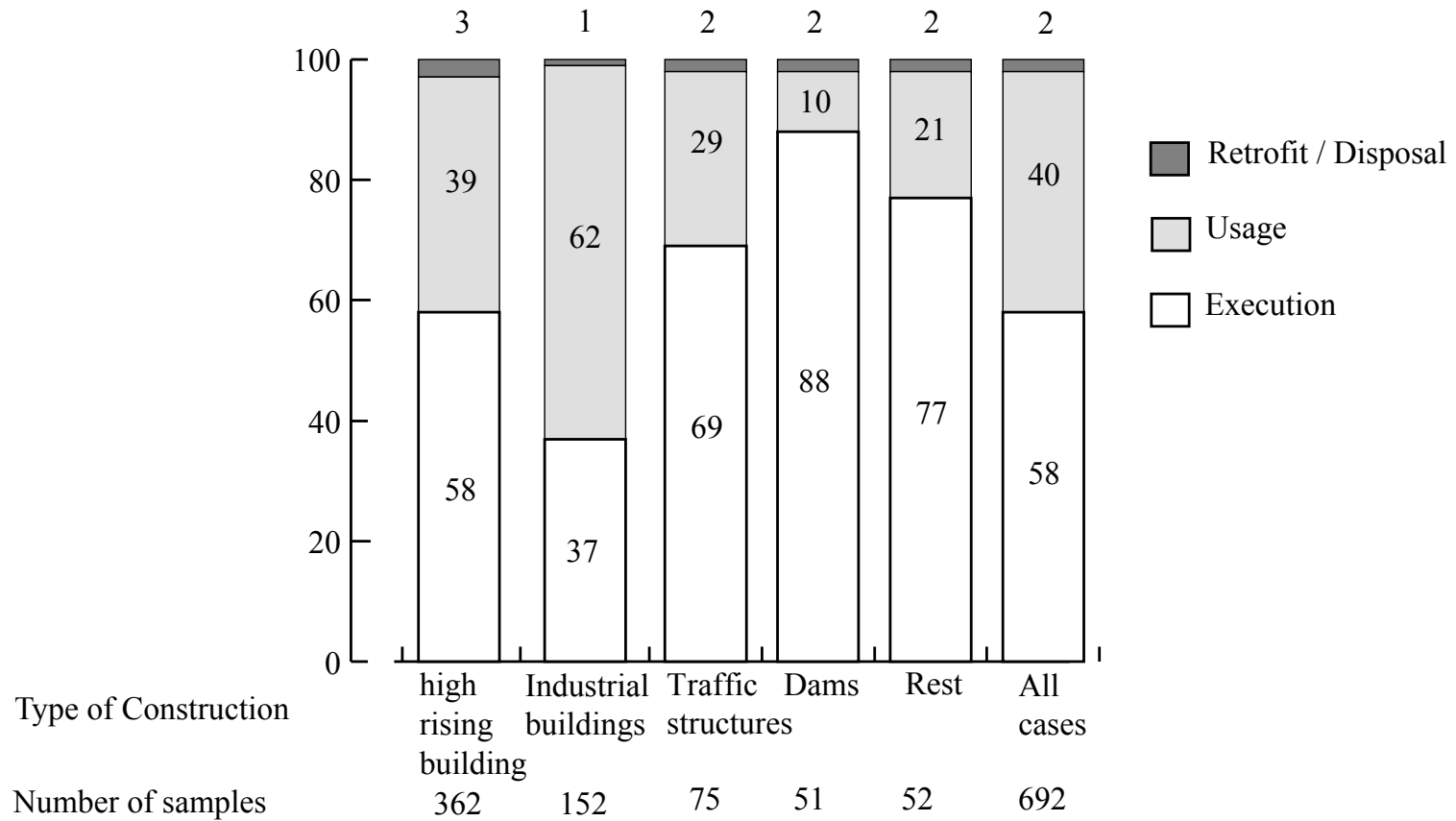
The Tjörn bridge in Schweden



A few weeks later

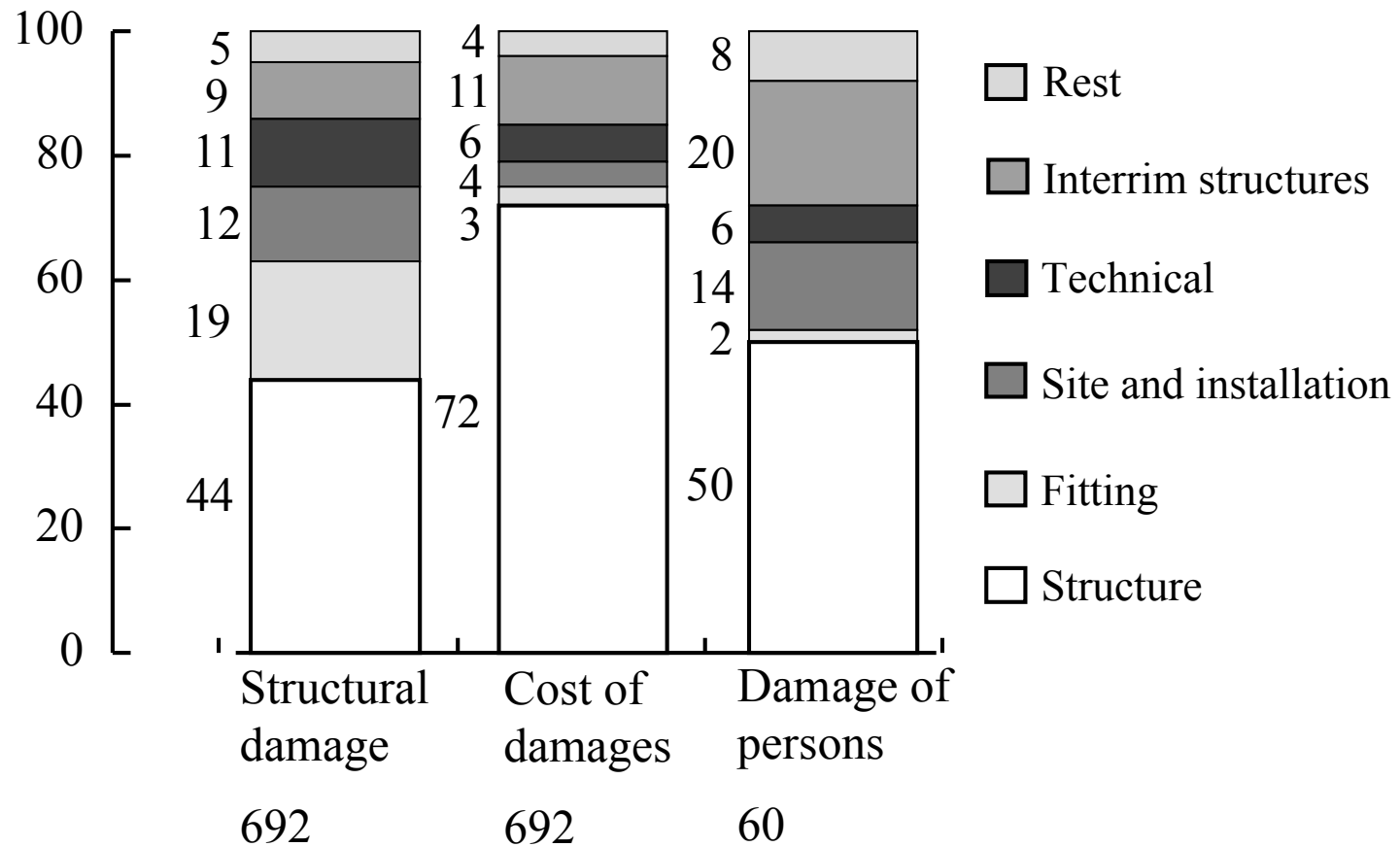
Sources of Risks in Engineering

Failures in structural engineering



Sources of Risks in Engineering

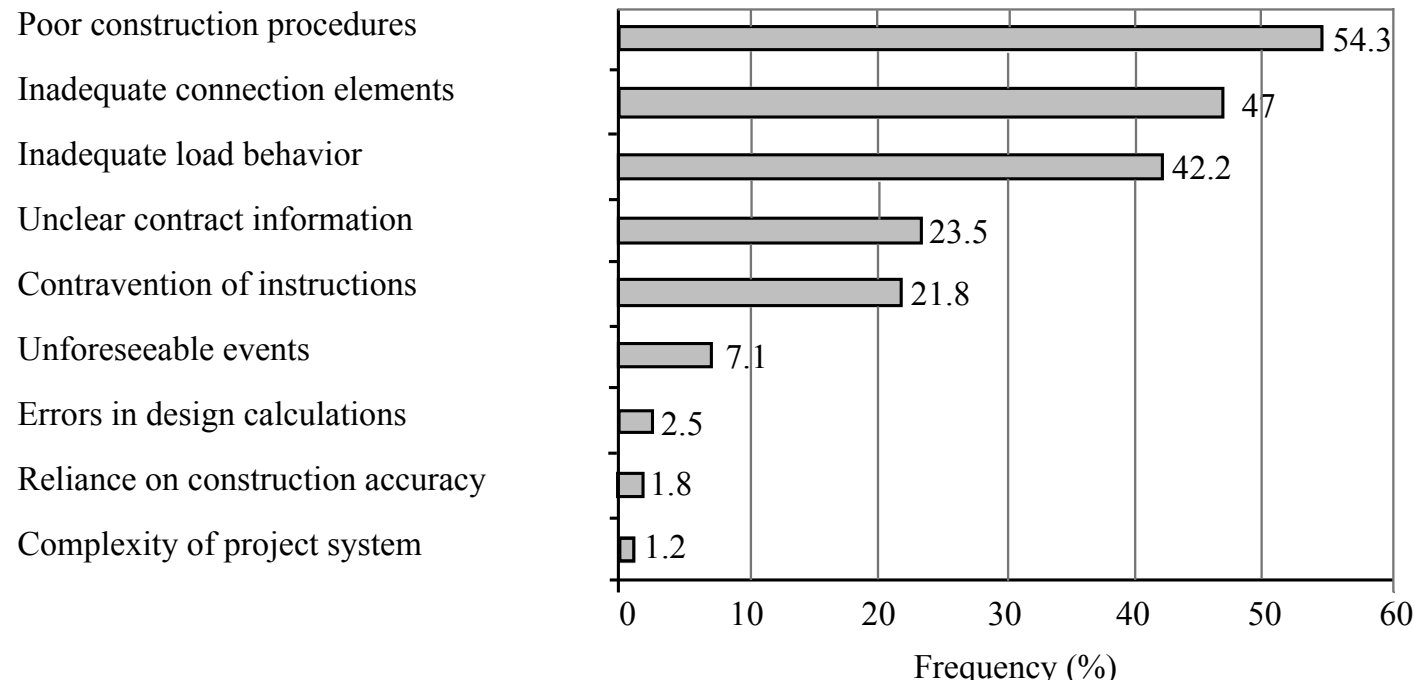
Failures in structural engineering



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 the probabilistic model code by the JCSS
- Introduction to time variant and systems reliability analysis
- Illustration of computer tools for risk and reliability analysis
- Applications for design, assessment and maintenance planning
- Understanding of engineering optimization and risk acceptance

Organisation of the Lecture

DATE	SUBJECT	DATE	SUBJECT
26.09.07	Introduction and overview <ul style="list-style-type: none"> - Life quality, risks and decision making - Hazards and causes of failures 	Announced later	Software tools for reliability analysis <ul style="list-style-type: none"> - Presentation of the COMREL program - Exercises in the PC-lab
03.10.07	Review of probability theory and statistics <ul style="list-style-type: none"> - Uncertainties in engineering modeling - Basic data analysis - Random variables and processes - Engineering model building 	14.11.07	Time variant reliability analysis <ul style="list-style-type: none"> - 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
10.10.07	Engineering decision analysis <ul style="list-style-type: none"> - Prior decision analysis - Posterior decision analysis - Pre-posterior decision analysis 	21.11.07	Systems reliability analysis <ul style="list-style-type: none"> - Series and parallel system analysis - Structural systems analysis - Robustness assessment of structures
17.10.07	Risk assessment in civil engineering <ul style="list-style-type: none"> - Procedures of risk assessment - Scenario identification and analysis - System representation - Probabilities and consequences - Multi scale indicator based risk assessment 	28.11.07	Bayesian Probabilistic Nets (BPN) in risk assessment <ul style="list-style-type: none"> - Basic theory of BPN - Application of BPN in risk assessment - Application of BPN in large scale risk management
24.10.07	Classical reliability analysis <ul style="list-style-type: none"> - Failure rate data - The reliability function - Updating of failure rates based on data - Failure rate functions and the bath-tub curve 	05.12.07	Reliability based structural design and assessment <ul style="list-style-type: none"> - Safety formats of design codes - Calibration of design codes - Reliability updating - Assessment of existing structures (and SIA 269)
31.10.07	Structural reliability analysis <ul style="list-style-type: none"> - First and Second Order Reliability Methods - Monte Carlo and importance sampling 	12.12.07	Risk based inspection and maintenance planning <ul style="list-style-type: none"> - The basic problem - Modeling of degradation processes - Inspection quality and the PoD concept - Generic approaches to inspection planning
07.11.07	The JCSS probabilistic model code <ul style="list-style-type: none"> - Probabilistic modeling of resistances - Probabilistic modeling of loads 	19.12.07	Optimal decision making and risk acceptance criteria <ul style="list-style-type: none"> - 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