Lifelong Learning Programme

Seminar is an outcome of the European project
„Innovation Transfer in Risk Assessment and Management of Aging Infrastructures“
Agreement number: CZ/13/LLP-LdV/TOI/134014

Herzliche Grüße aus Prag

Infrastructures
Reliability assessment
Risk based approach

Milan Holický
Czech Technical University in Prague

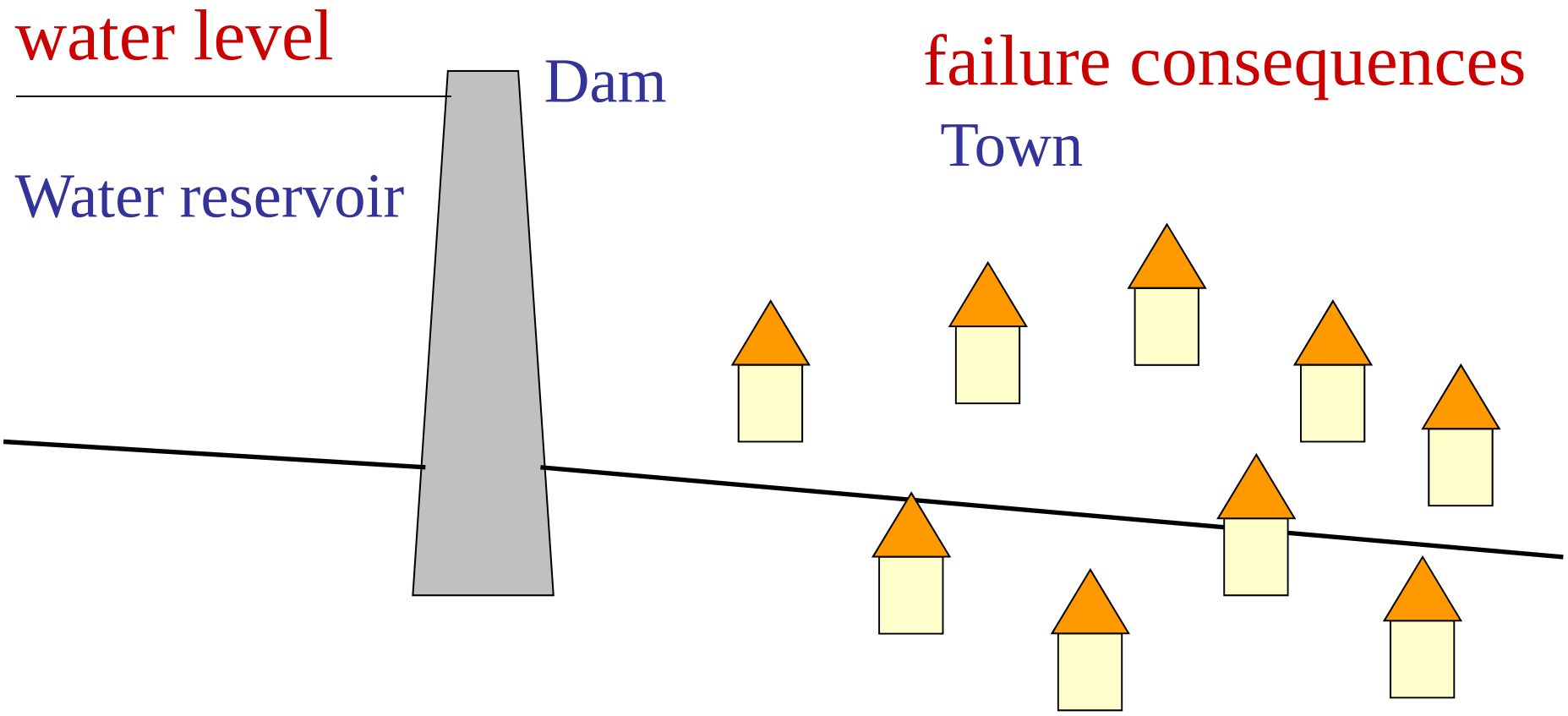
An example of an aging infrastructure

Bay Bridge, 2007

Collapse caused by accident and fire of a truck with propellant

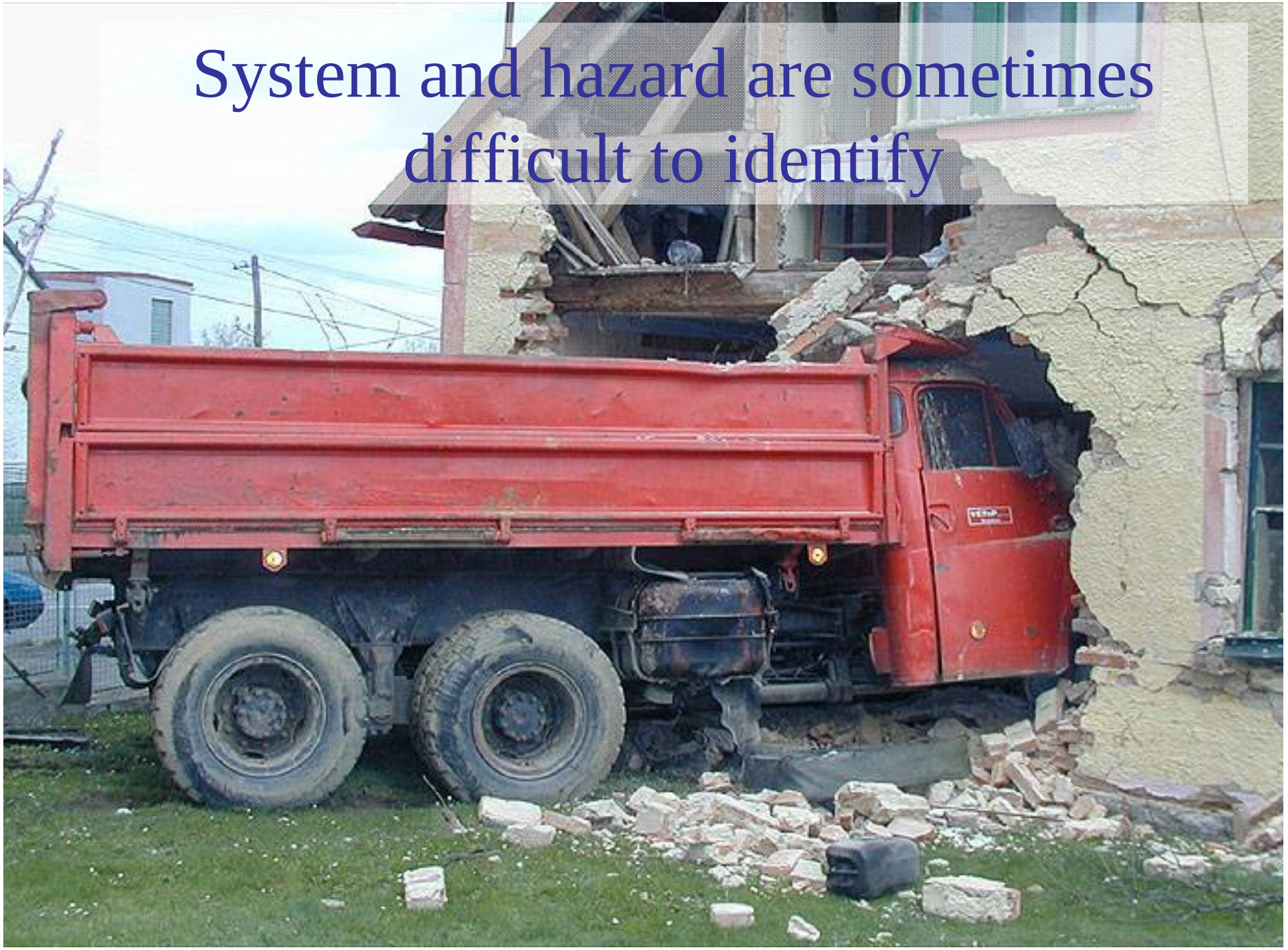
System of water reservoir-dam-town

probability of dam failure



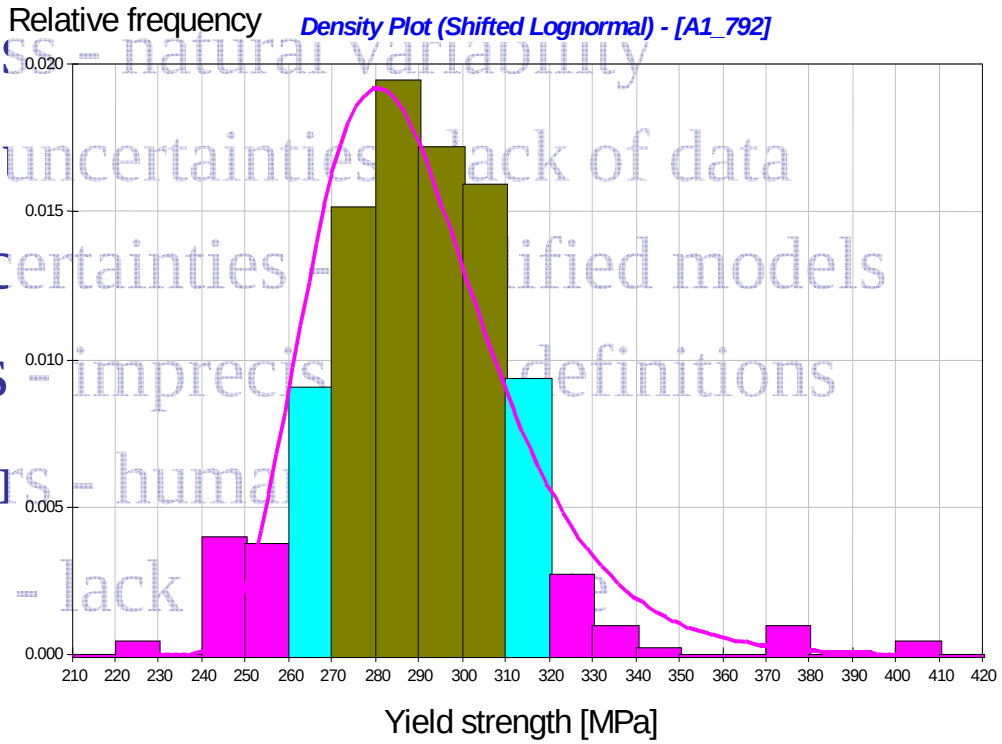
“The whole is more than the sum of its parts.” Aristotle, 384 – 322 BC

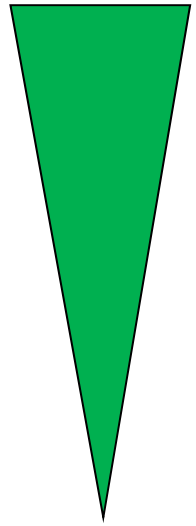
System and hazard are sometimes difficult to identify



Uncertainties of engineering decision

- Uncertainties (aleatoric and epistemic) Decription
  - randomness - natural variability
  - statistical uncertainties - lack of data
  - model uncertainties - simplified models
  - vagueness - imprecise definitions
  - gross errors - human
  - ignorance - lack





- Tools
  - theory of probability and statistics, fuzzy logic
  - reliability theory and risk engineering

Some uncertainties are difficult to quantify

Methods of reliability verification and decision making

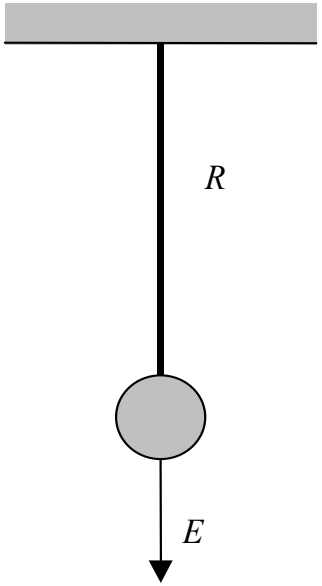
- Historical and empirical methods
- Permissible stresses
- Global safety factor
- Partial factor methods
- Probabilistic methods
- Risk assessment

Applicable at present

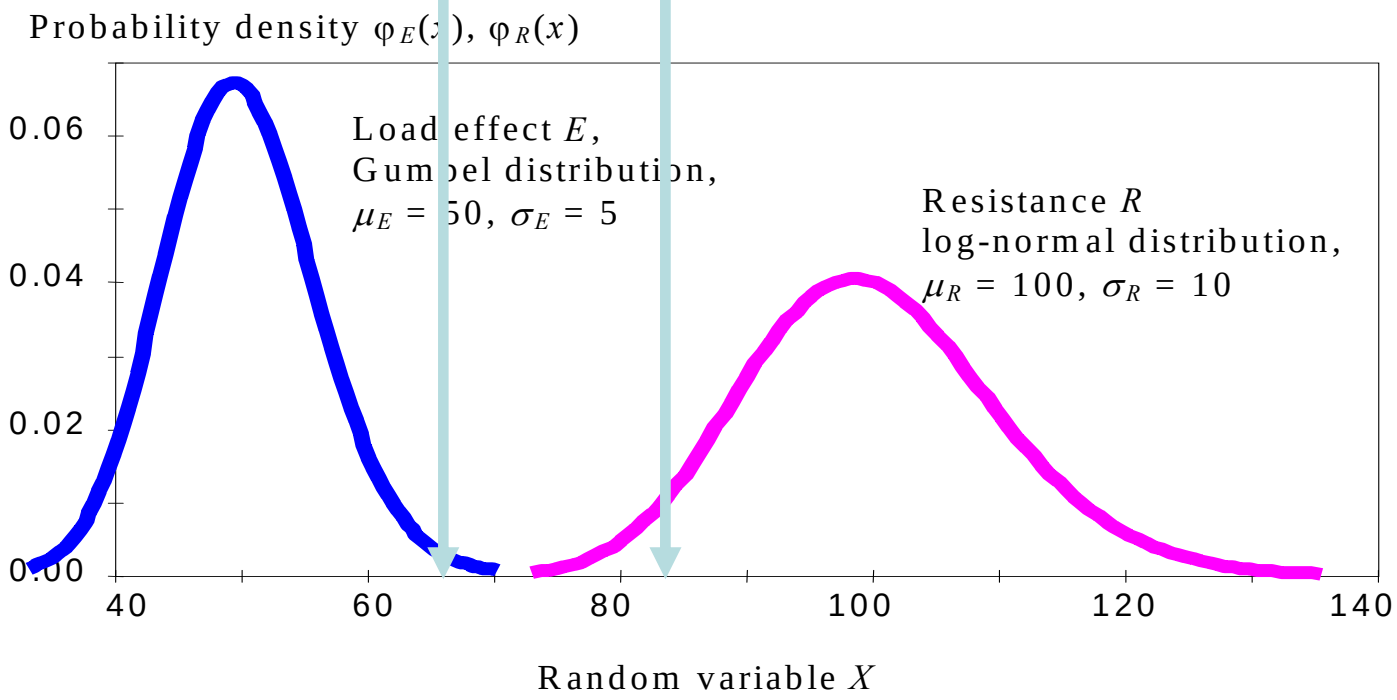
Increasing demands on design procedure

Partial factor approach

		distribution	mean	sd
R	resistance	Lognormal	100	10
E	load effect	Gumbel	50	5



E_k R_k $R_k/\gamma_m > E_k\gamma_Q$

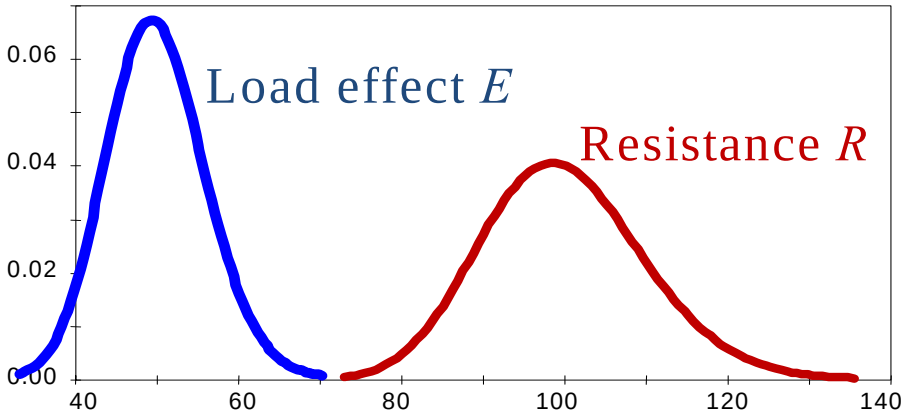


Reliability margin $Z = R - E$ and index β

Probability density

Wahrscheinl. Dichte

$\varphi_E(x)$, $\varphi_R(x)$



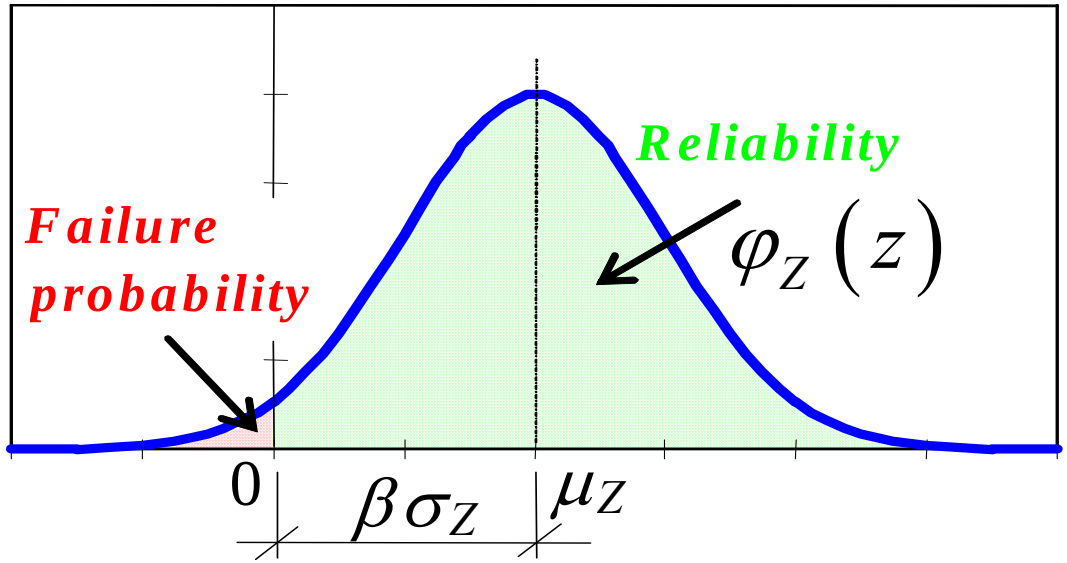
Reliability margin

Zuverlässigkeit Reserve

$$Z = R - E$$

$$\mu_Z = \mu_R - \mu_E$$

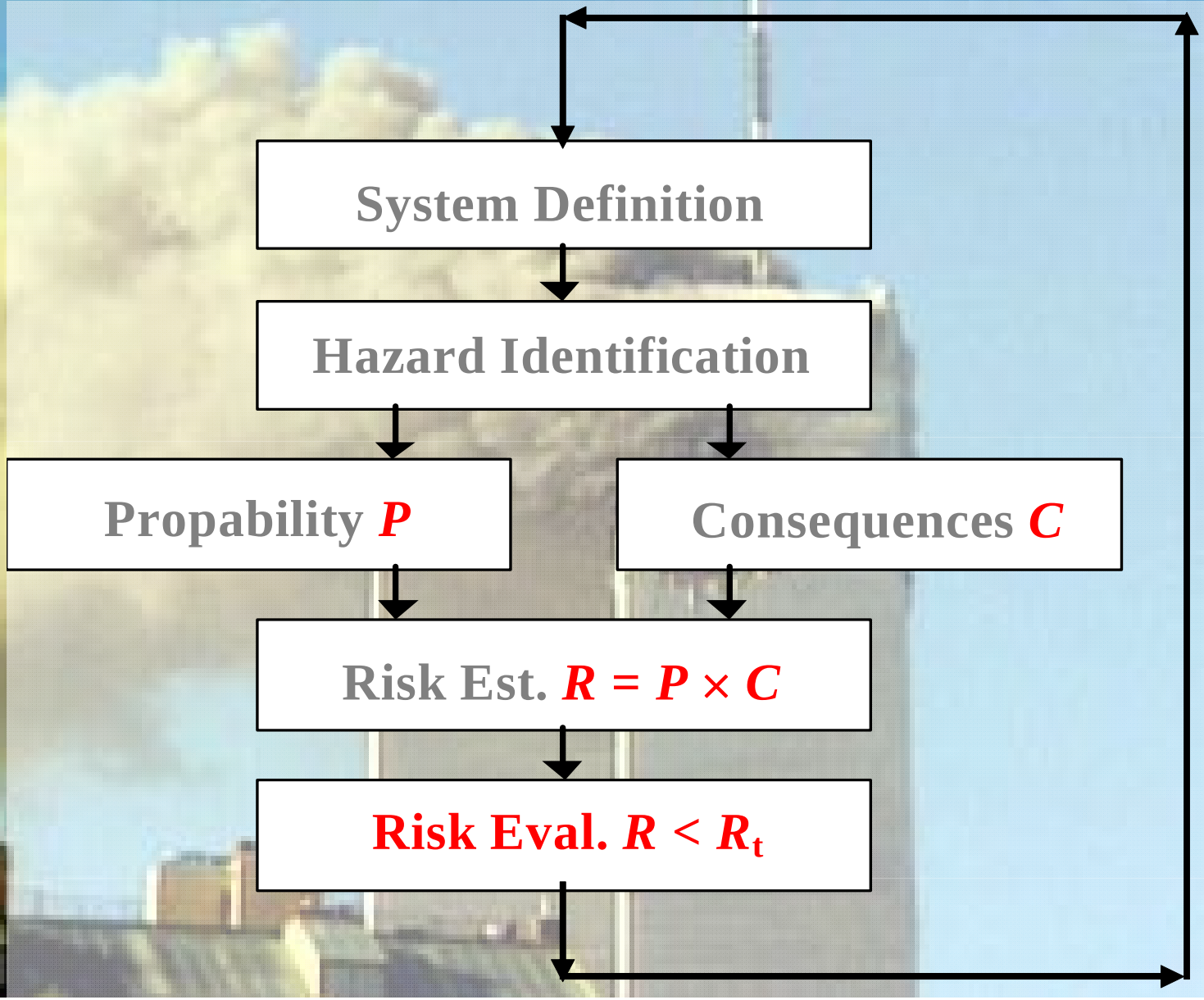
$$\sigma_Z^2 = \sigma_R^2 + \sigma_E^2$$



$\beta = \mu_Z / \sigma_Z = 3.54$, $P_f = P(Z < 0) = \Phi_Z(0) = 0.0002$

β *is* the distance of the mean of reliability margin Z from the origin

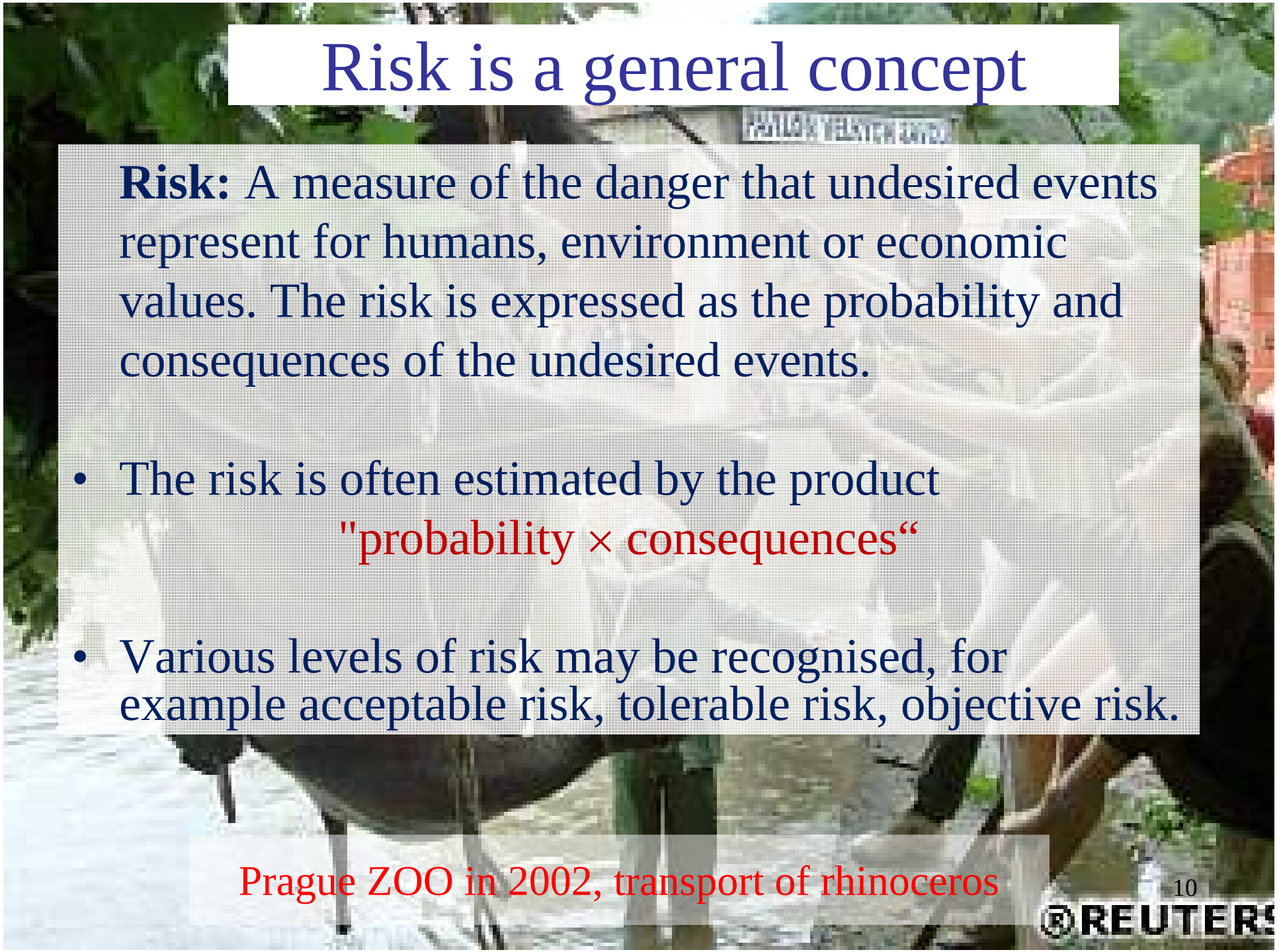
Flow chart of risk assessment



Risk is a general concept

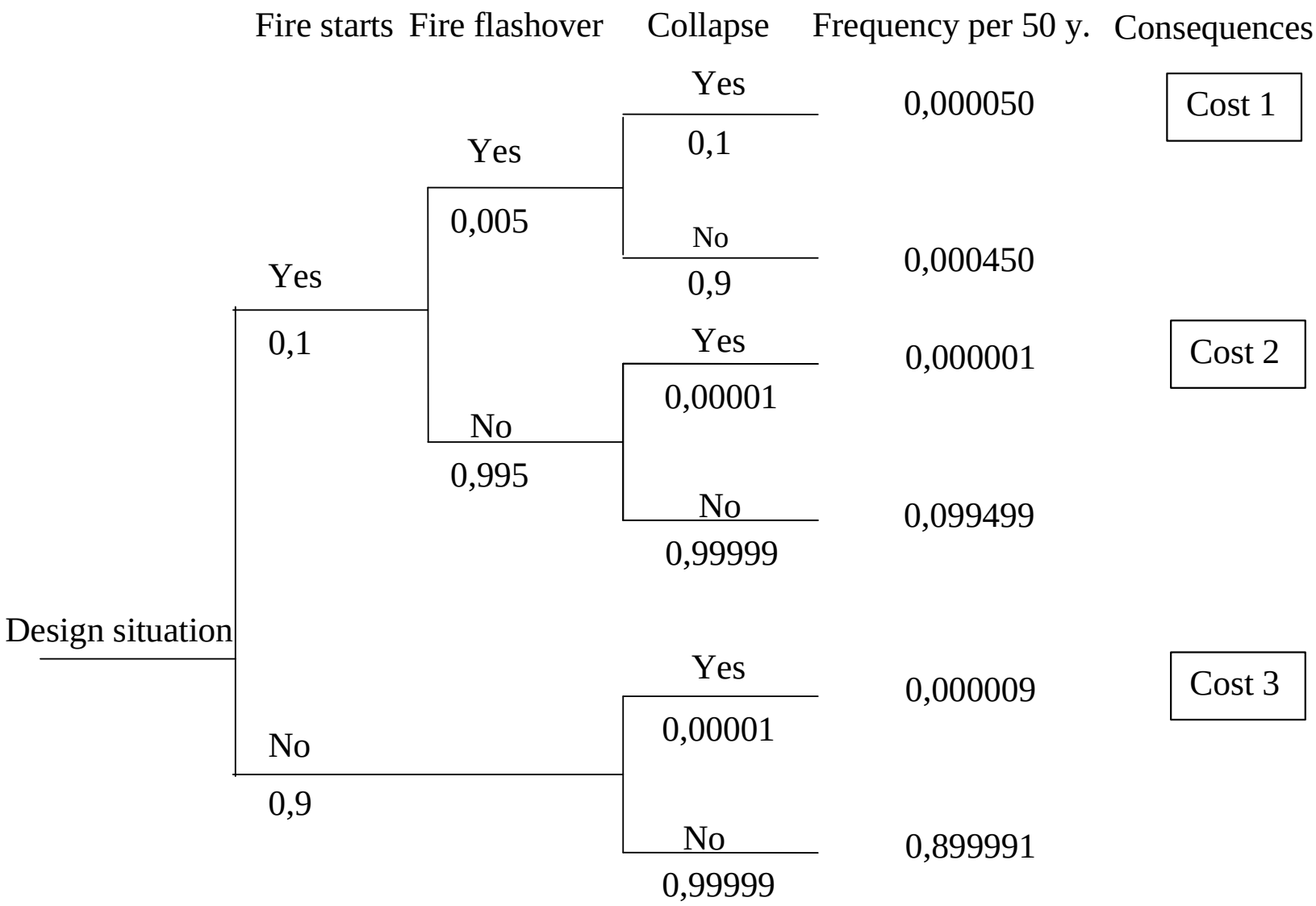
Risk: A measure of the danger that undesired events represent for humans, environment or economic values. The risk is expressed as the probability and consequences of the undesired events.

- The risk is often estimated by the product
  "probability × consequences“
- Various levels of risk may be recognised, for example acceptable risk, tolerable risk, objective risk.



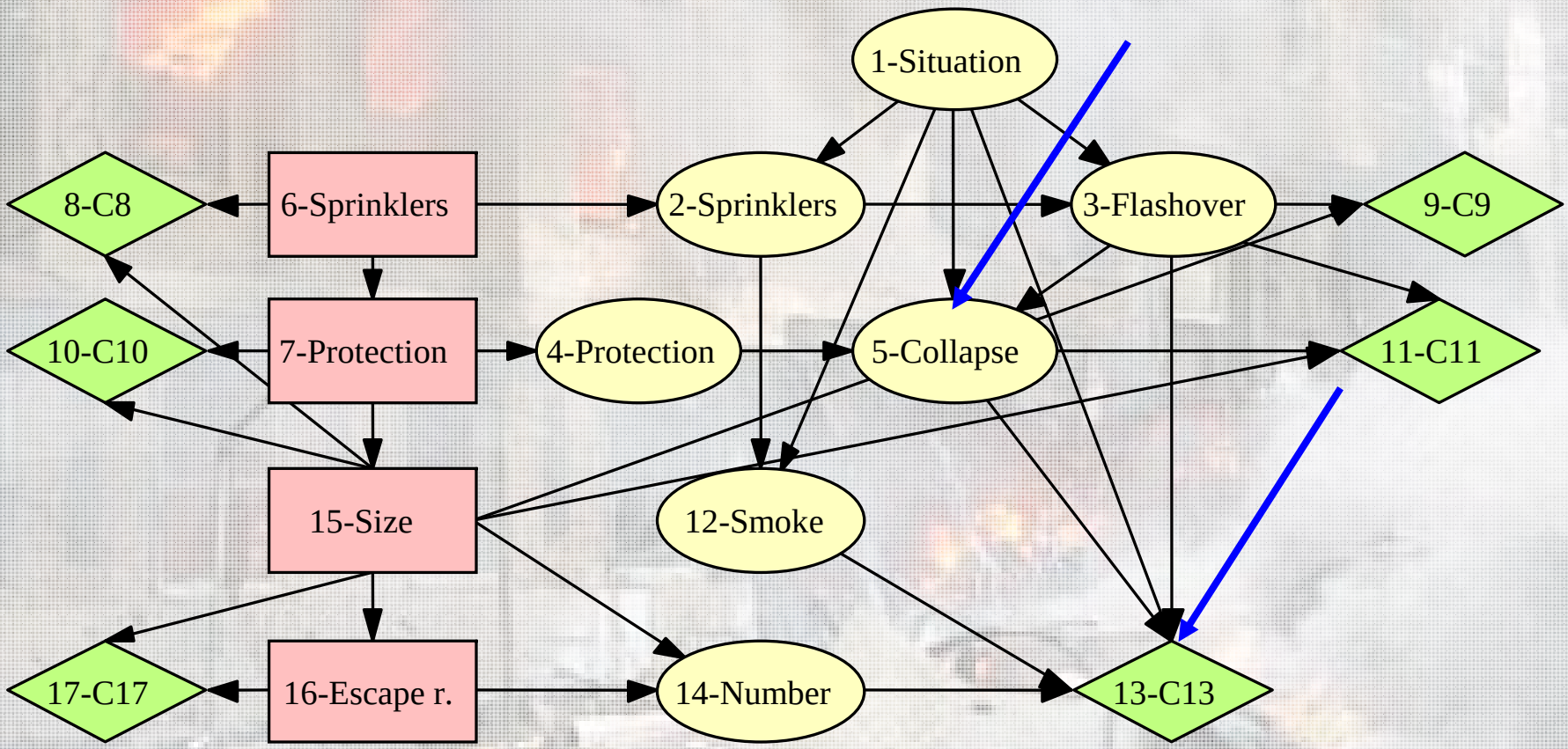
Prague ZOO in 2002, transport of rhinoceros

Event – consequence tree



Bayesian network

Permanent and fire situation



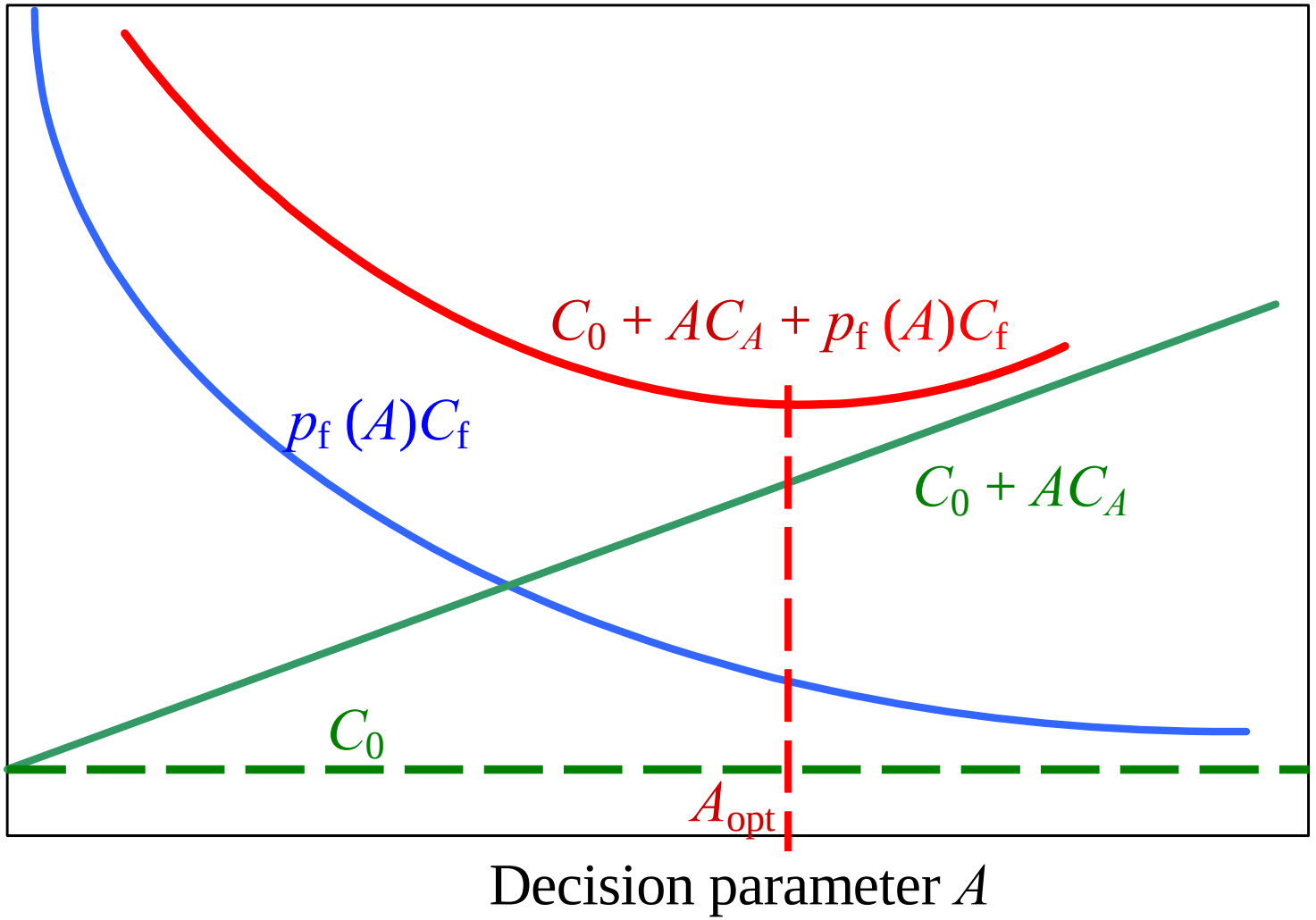
Conditional probability tables: $P(A|B_1, B_2, \ldots B_n)$

$D = \{A_1, A_2, \ldots, A_n\}$, $P(D) = \Pi_i P(A_i \mid \text{parents}\{A_i\})$

Optimization of the decision parameter

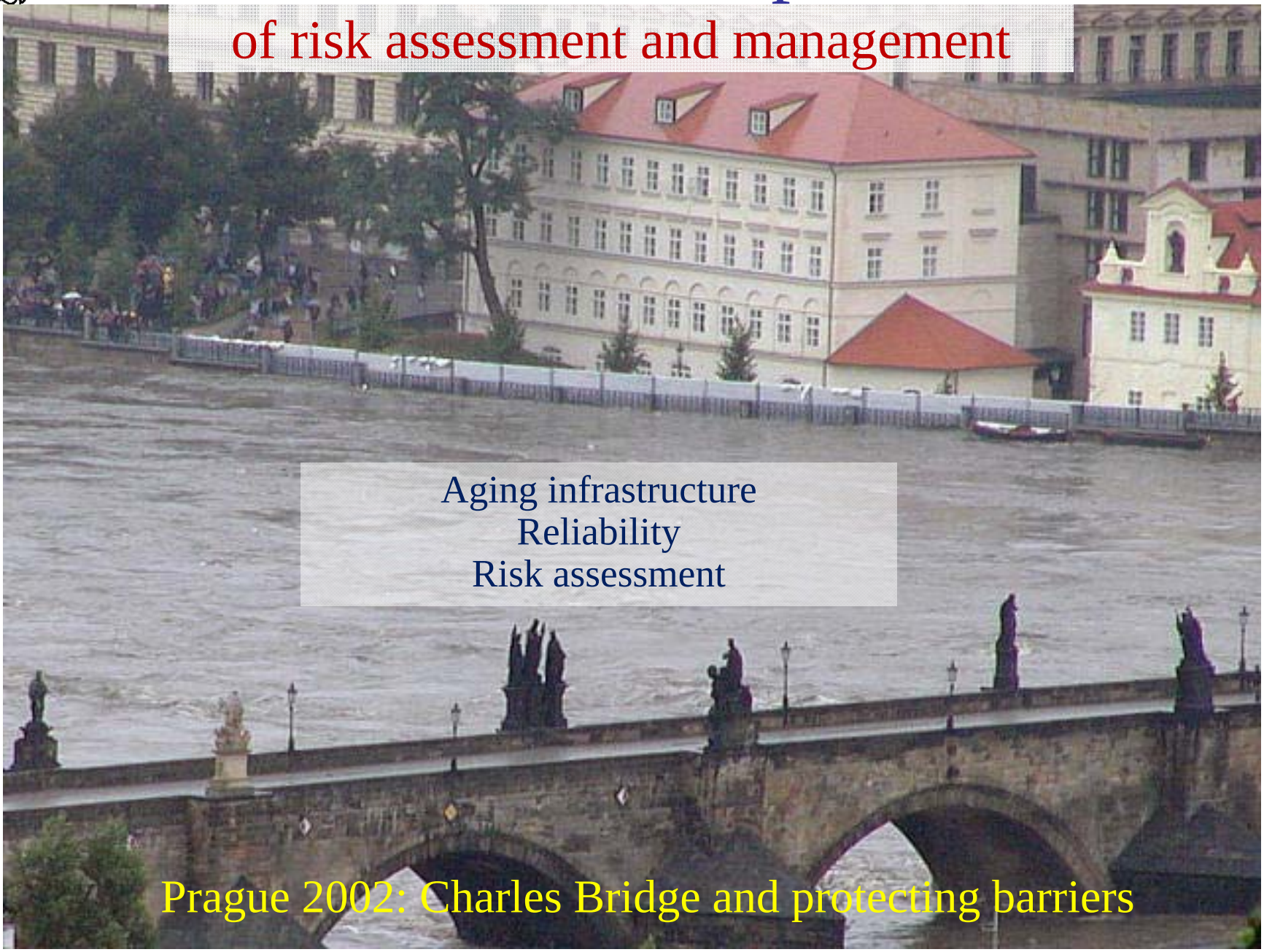
A size of fire compartment

The total cost $C_{tot} = C_0 + AC_A + p_f(A)C_f$



Basic Concepts

of risk assessment and management



Aging infrastructure
Reliability
Risk assessment

Prague 2002: Charles Bridge and protecting barriers

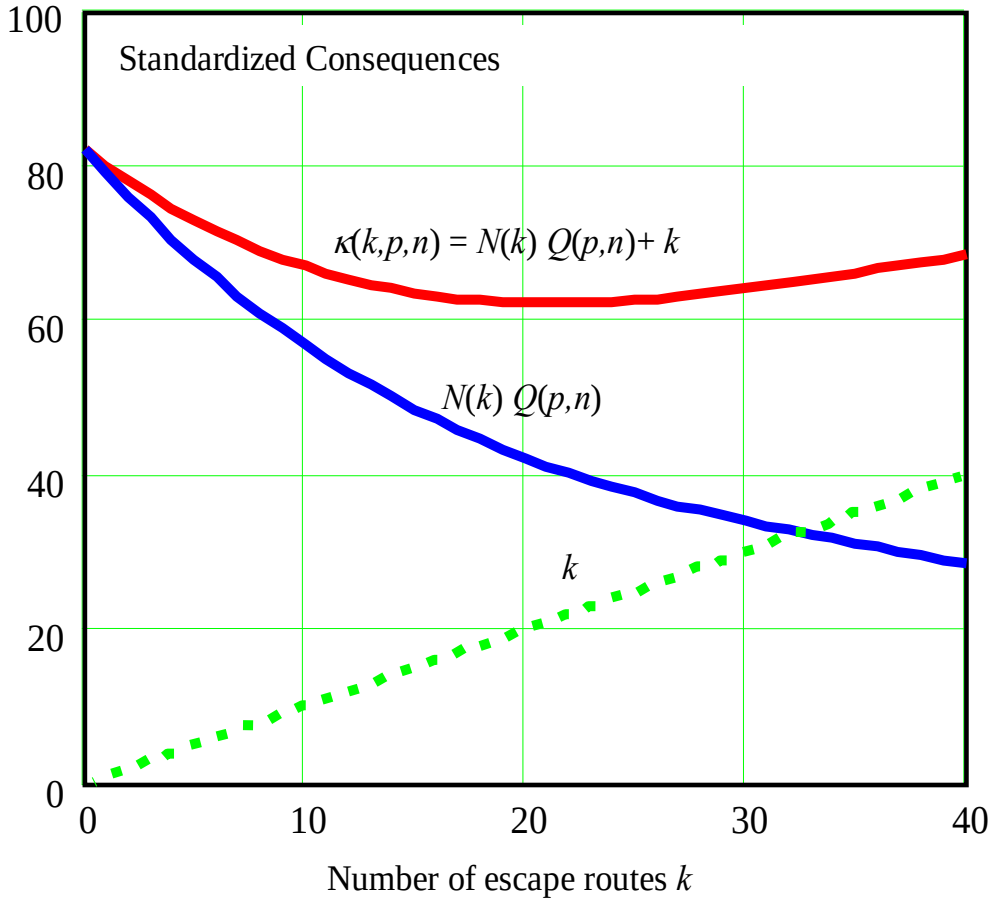
Summary

- Partial factor method is a common design procedure
- Reliability index β is the distance of the mean of reliability margin from the origin, $\beta = 3.8$ corresponds to the probability $7{,}23 \times 10^{-5}$
- The risk is often estimated by the product:
  "probability × consequences“
- Consequences concern societal and economic values
- Risk assessment is usually an iterative process
- Common tools for risk assessment include
  - logical trees, fault and event trees
  - Bayesian networks, influence diagrams
- Risk assessment and optimization suffer from lack of relevant data, particularly for consequences
- Expert judgments are often needed for comparative studies

Optimization of the escape routes

The necessary condition for the minimum

$$\frac{\partial N(k)}{\partial k} = -\frac{C_1}{R_1}\frac{1}{Q(p,n)}$$



Standardized total consequences $\kappa(k,p,n)$ for the discount rate p = 0,03, the cost ratio $\zeta = C_1/R_1 = 1$ and the life time n = 100 years

LQI, *ICAF* and *SVSL*

$LQI = g^{w}\, l^{(1-w)}$, $ICAF = (g\, l/4)\,(1 - w)/w$, $SVSL = g\, E/q$

$g \sim 0{,}6\ GPD$, $q \sim 0{,}25$, $w \sim 0{,}125$, $E \sim 30$ years

Country	*GDP* 2006 [US-$ per capita]	g = 0,6 *GDP* [US-$ per capita]	l the mean life (years)	*LQI*	*ICAF* [mio.US $]	*SVSL* [mio.US $]
USA	44000	26400	78,00	162	3,60	3,17
Norway	46300	27780	79,67	166	3,87	3,33
Hong Kong	37300	22380	81,68	165	3,20	2,69
Switzerland	34000	20400	80,62	161	2,88	2,45
Denmark	37000	22200	77,96	158	3,03	2,66
Iceland	38000	22800	80,43	163	3,21	2,74
Canada	35600	21360	80,34	161	3,00	2,56
Austria	34600	20760	79,21	159	2,88	2,49
Australia	33300	19980	80,62	161	2,82	2,40
UK	31800	19080	78,70	156	2,63	2,29
Netherlands	32100	19260	79,11	157	2,67	2,31
Japan	33100	19860	82,02	163	2,85	2,38
Finland	33700	20220	78,66	157	2,78	2,43
Germany	31900	19140	78,95	157	2,64	2,30
France	31100	18660	80,59	159	2,63	2,24
Sweden	32200	19320	80,63	160	2,73	2,32
Italy	30200	18120	79,94	157	2,53	2,17
Spain	27400	16440	79,78	155	2,30	1,97
Greeze	24000	14400	79,38	152	2,00	1,73
Czech Republic	21900	13140	76,42	145	1,76	1,58
Poland	14300	8580	75,19	136	1,13	1,03

Source: https://www.cia.gov/library/publications/the-world-factbook/index.html

Probabilities and consequences

Probability of failure under the situations H_i

$$\mathrm{P}\{F|H_i\} = \int_{g(\boldsymbol{x})<0} \mathrm{f}_{\boldsymbol{X}}(\boldsymbol{x} \mid H_i)\mathrm{d}\boldsymbol{x}$$

For mutually exclusive situations H_i

$$p_F = \sum_i \mathrm{P}\{H_i\}\mathrm{P}\{F \mid H_i\}$$

Probability of event E_{ij} under the situation H_i

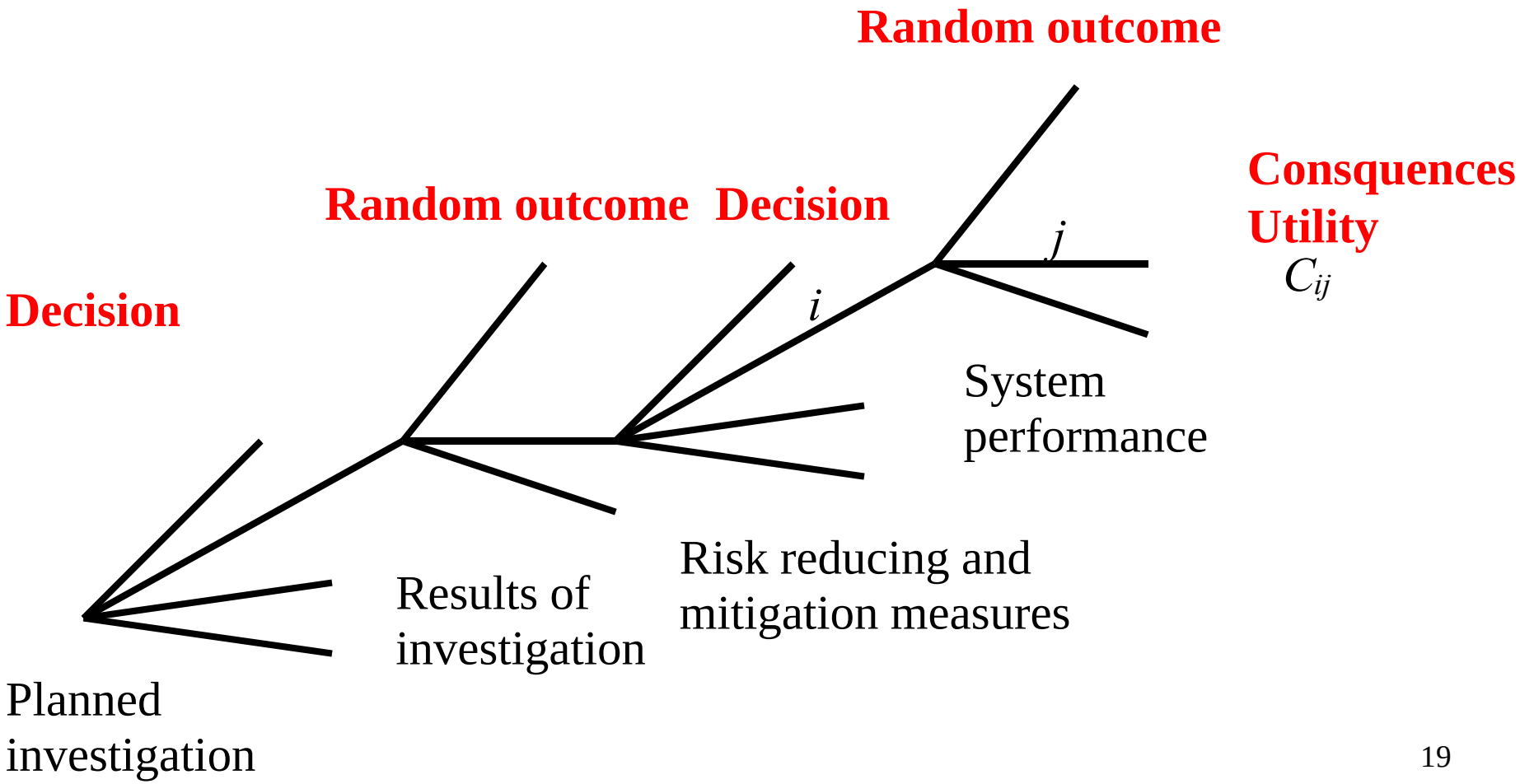
$$\mathrm{P}\{E_{ij} \mid H_i\}$$

The component R_k of the total risk for consequences $C_{ij,k}$

$$R_k = \sum_{ij} C_{ij,k}\mathrm{P}\{E_{ij} \mid H_i\}\mathrm{P}\{H_i\}$$

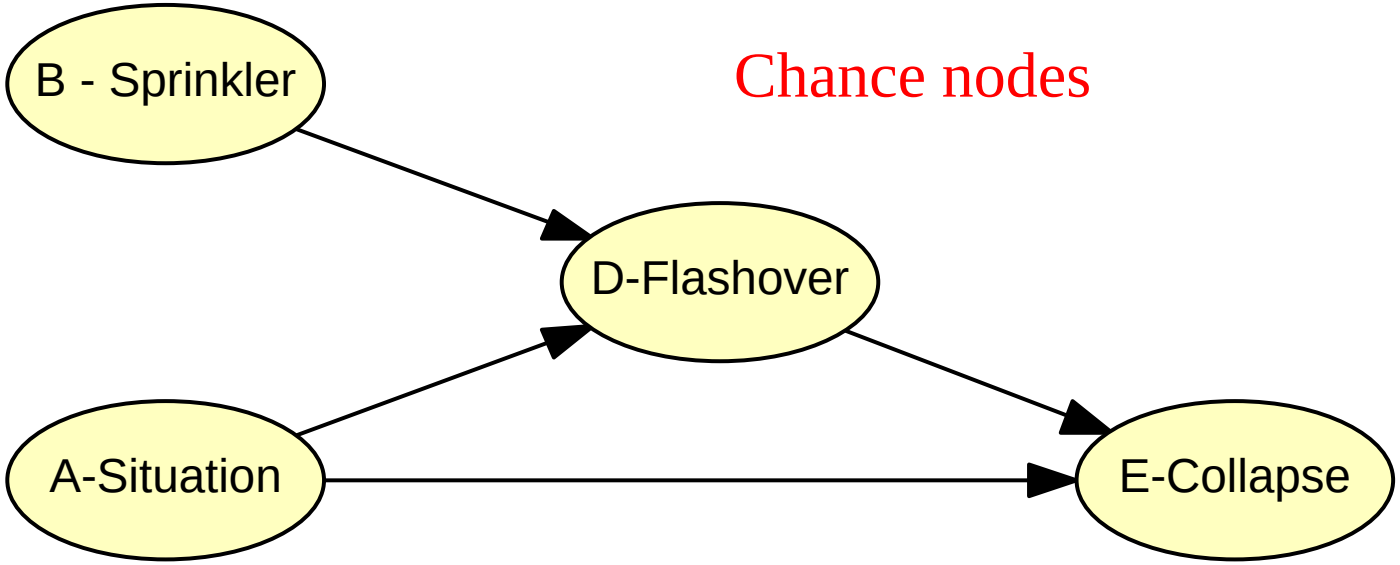
Logical trees

Decision tree for pre-posterior analysis



Bayesian believe or causal networks

Acyclic directed graphs in which nodes represent random variables and arcs (arrows) represent direct probabilistic dependences among them (causal links).

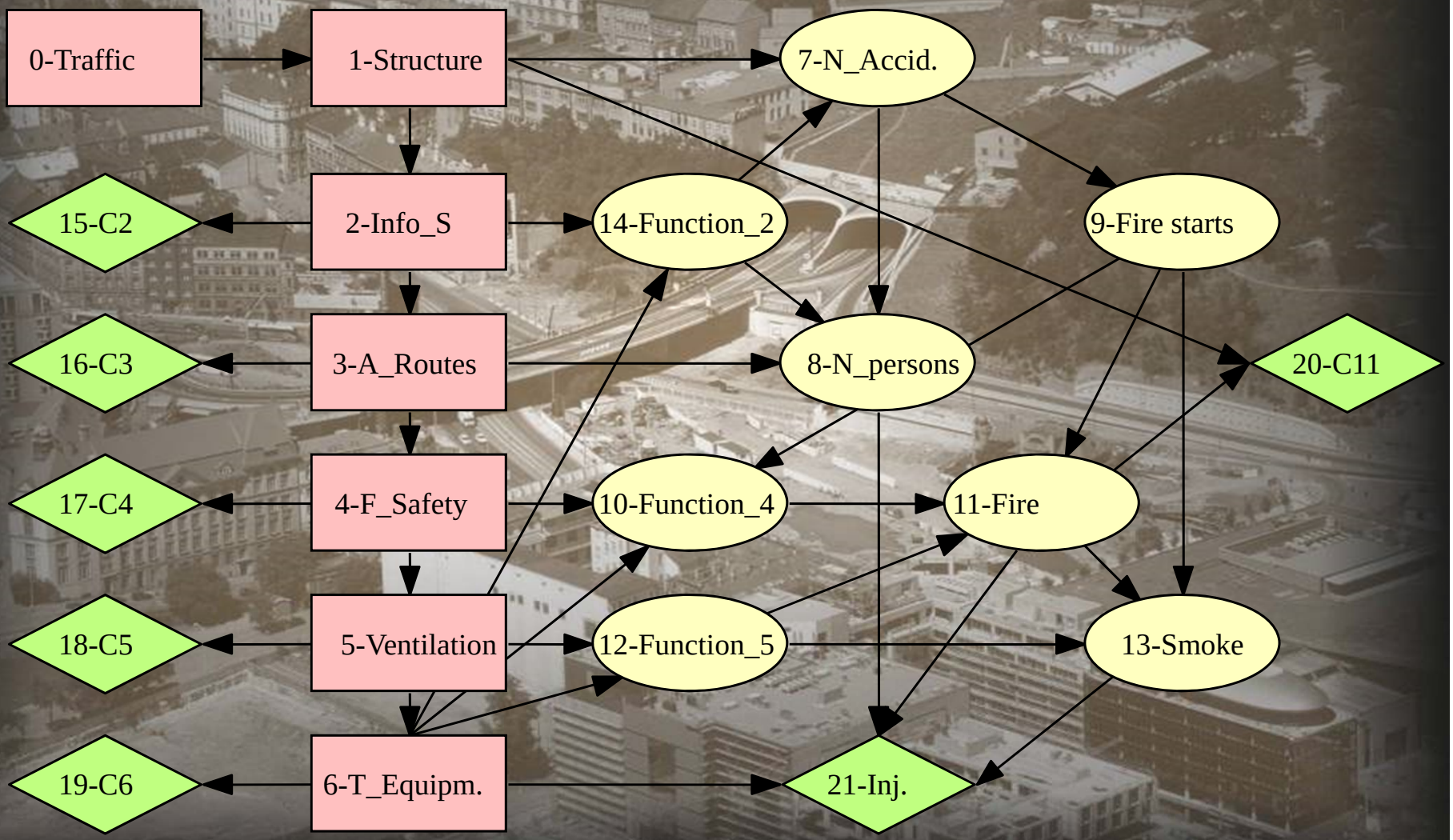


Analysis is based on Bayesian theorem

$$P(D_k) = \sum P(D_k | A_i B_j) P(A_i)\, P(B_j)$$

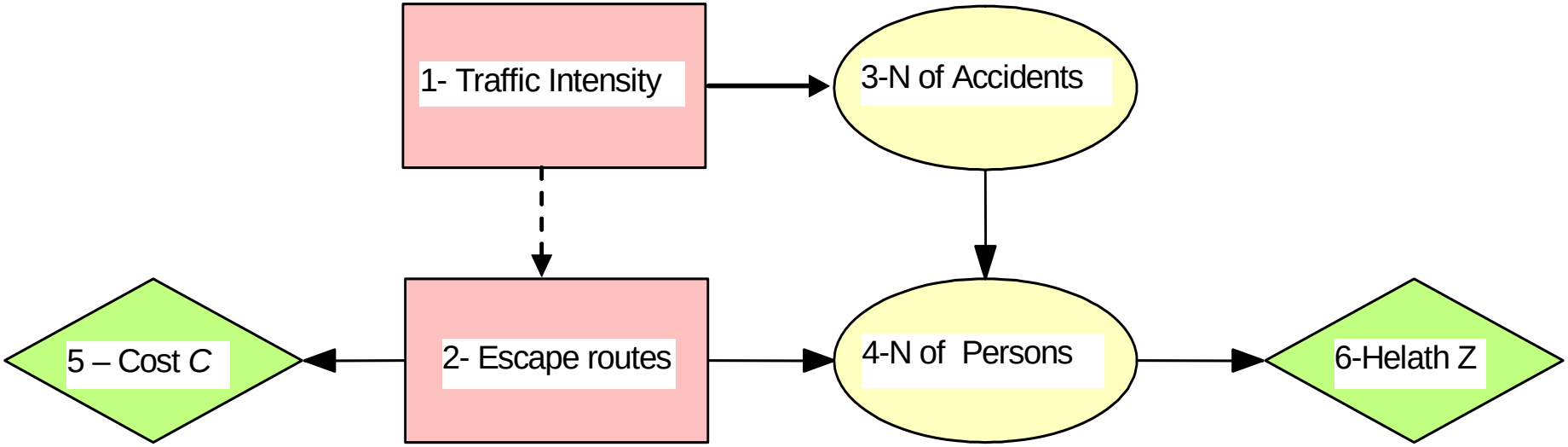
Bayesian and influential diagrams

Risk analysis of tunnels



Influence Diagram

Bayesian network suplemented by decision and utility nodes.



Number of accident per 1 km and 1 year

1- Traffic intensity	Low	Average	High
3- N of Accidents	2	4	6

Number of endangered persons per one accident

2- Escape routes	Basic	Good	Very Good	Excellent
4- N of Persons N_1	8	4	2	1

Conclusions

Target probability of failure should be specified with a clear reference to the design situations considered.

It appears that the target probability of structural failure $7{,}23\times10^{-5}$ is very likely to be exceeded if neither sprinklers nor structural protection are used.

Cost of averting a fatality of 4 millions of USD seems to be rather low.

Baysian network supplemented by decision and utility nodes seems to be an effective tool for risk assessment under fire design situation.

More information on economic and societal consequences is needed to improve fire risk assessment.

System in trafic engineering

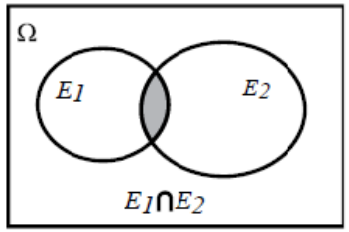
A bounded group of interrelated, interdependent or interacting elements forming an entity that achieves a defined objective in its environment through interaction of its parts.

“Life was simple before World War II. After that, we had systems“.

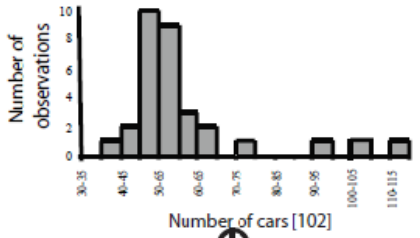
Fire in tunnel

Engineering decision under uncertainty

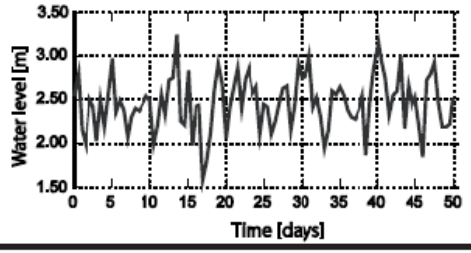
1 Basic probability theory



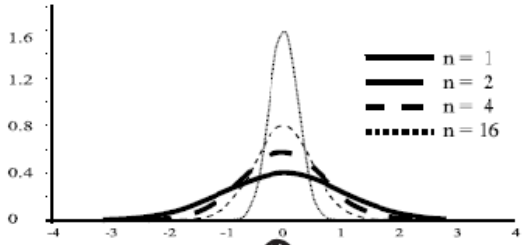
2 Descriptive statistics



3 Uncertainty modeling

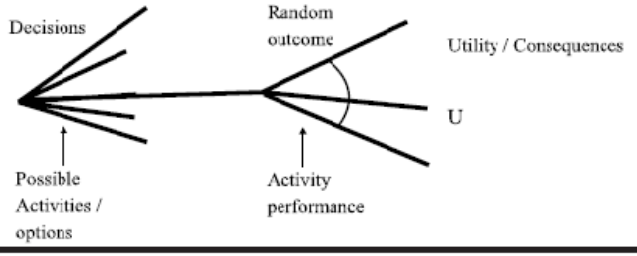


4 Estimation and model building



5 Methods of structural reliability

6 Bayesian decision analysis

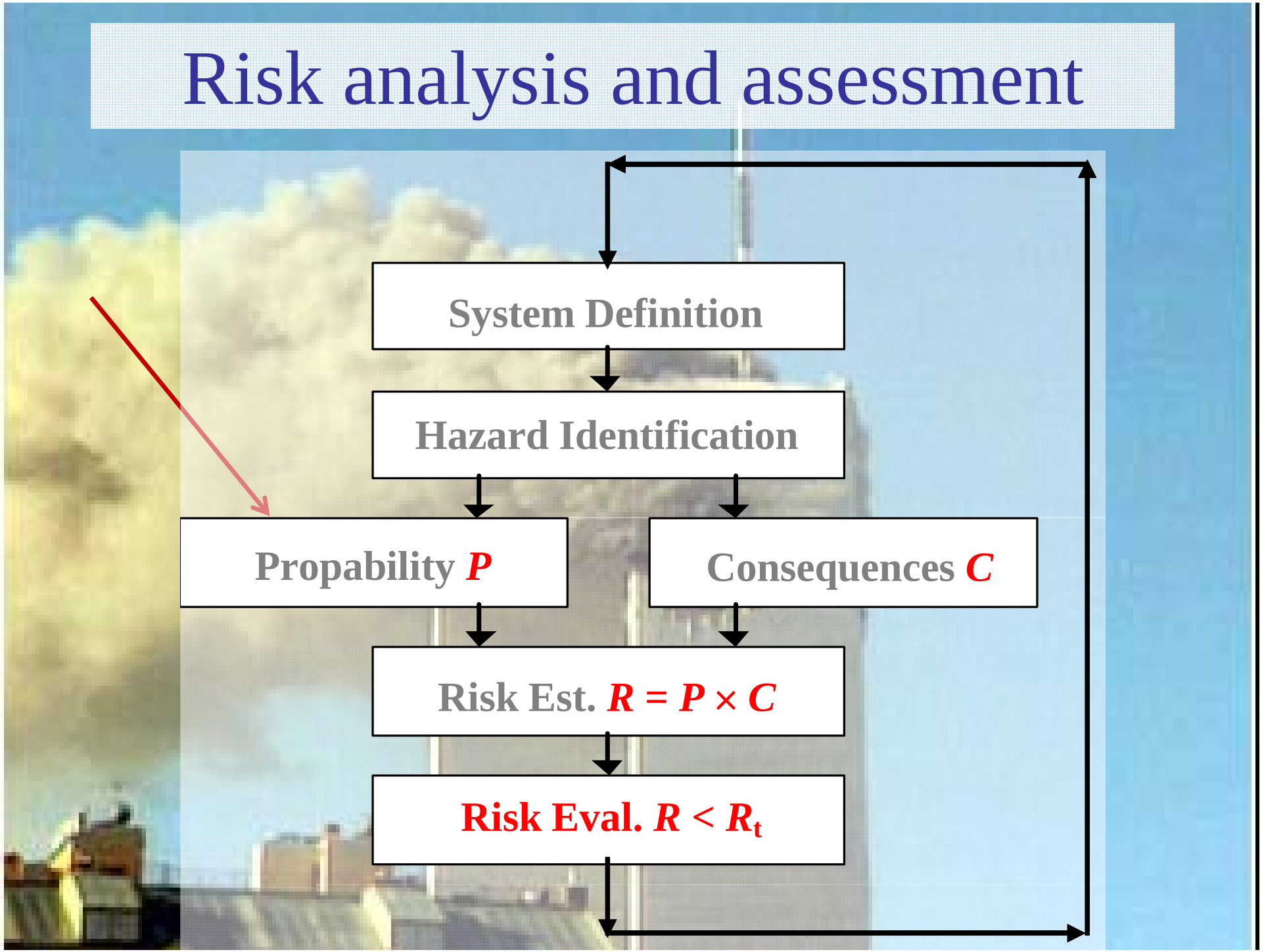


Methods of reliability verification and decision making

- Historical and empirical methods
- Permissible stresses
- Safety factor methods
- Partial factor methods
- Probabilistic methods
- Risk assessment

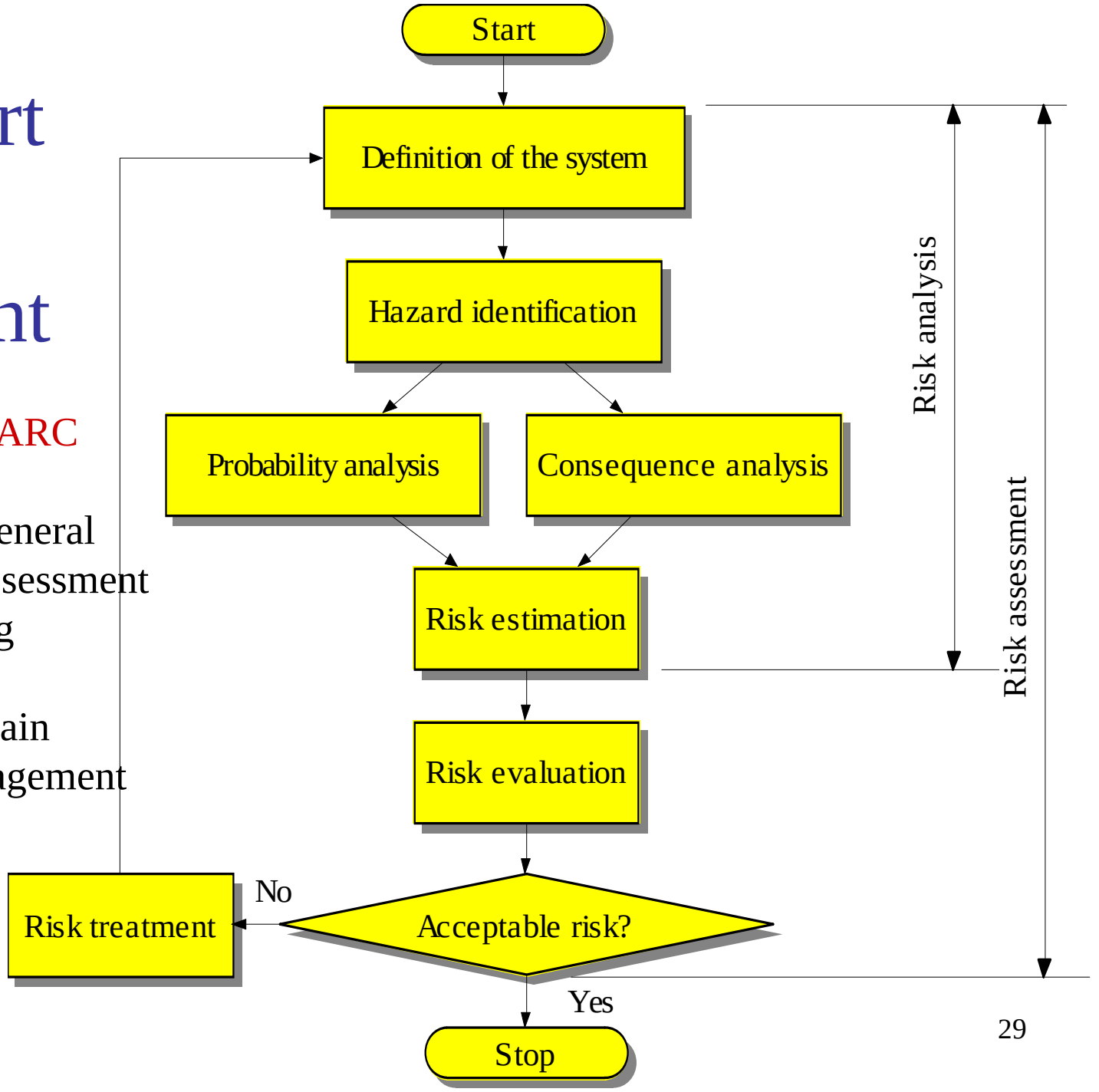
Decision making is becoming more and more difficult

Risk analysis and assessment



Flow chart of risk assessment

ISO, CIB, JCSS, PIARC
ISO TC98/SC2:
ISO 13824: 2009 General principles on risk assessment of systems involving structures
ISO 31000: 2009 Plain English - Risk management dictionary

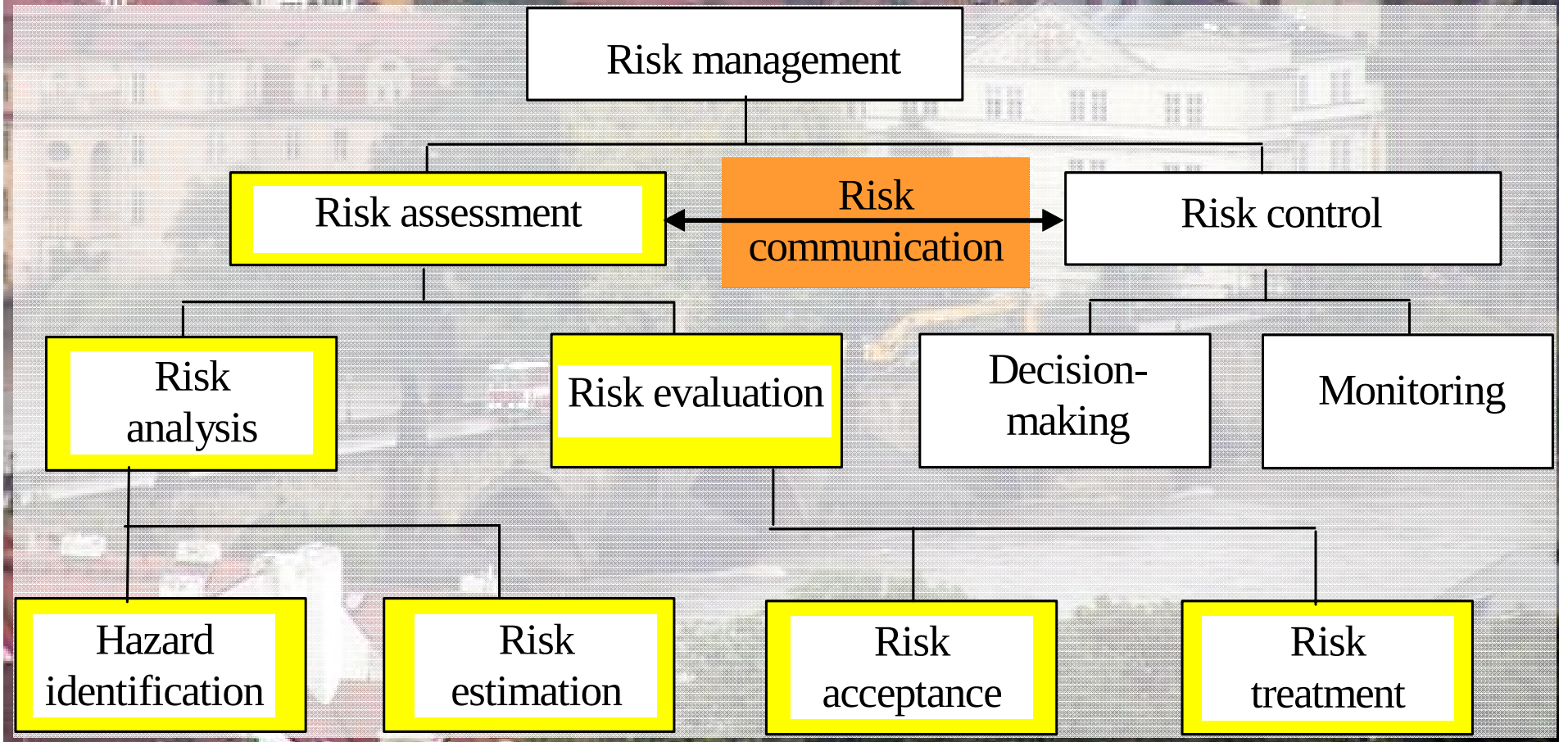


An infrastructure in hydraulic engineering

Hoover dam in Colorado

Hoover dam in Colorado, 1931-1936

An example of aging infrastructure

San Francisco, 2007 – Bay Bridge
No casualties, serious economic consequences, daily 75 000 vehicles

Risk management – Basic concepts