IVT Seminar, "Gefährdete Verkehrsnetze?"
ETHZ, December 4, 2008.

Risk Assessment on the Roadway System

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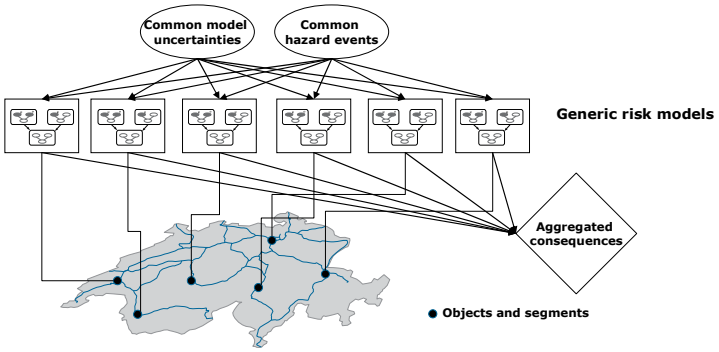
Institute of Structural Engineering, ETH.



ETH Swiss Federal Institute of Technology, Zurich

Contents of Presentation

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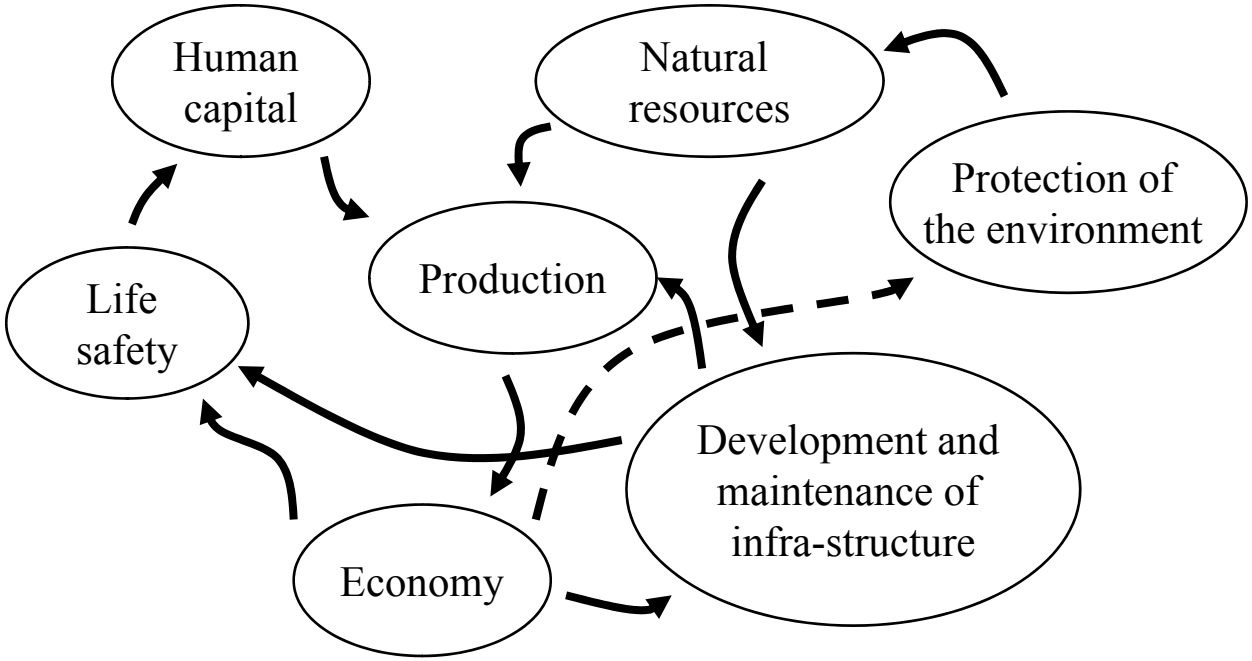
- **What are the needs for managing risks?**
- **System representation in risk assessments**
- **Indicator based risk management framework**
- **Decision optimization and life safety**
- **Illustrations**
- **Outlook**

Motivation

- Societal infrastructure play a crusial role for the existence and development of society



Motivation

- **There is a close connection between the functionality of roadway network and the functionality of society:**

  - health
  - safety
  - economy
  - environment

  The question is – how to decide on:

  how much to invest and where to invest into maintaining and developing the roadway network?

What are the needs for managing risks?

- **Fundamentally – at the highest level**

  if by the term risk we associate the expected consequences resulting from a decision alternative

  we can utilize the well developed economical decision theory for managing risks

  In fact this is the recommendation of the Joint Committee on Structural Safety :

  - ranking of decision alternatives for operatiion, maintenance and further developments

  - quantifies the value of additional information to support decision ranking

What are the needs for managing risks?

- **We need to be able to assess the societal benefit of:**

  - further developments
  - operating
  - maintaining the

  roadway network

- **This involves assessing the**

  - costs
  - life safety
  - environmental risks

  associated with relevant decision alternatives

What are the needs for managing risks?

- **Identifying how risks due to hazards caused by**

  - natural processes
  - human and organisational errors
  - technical failures

  may be managed efficiently

  - before
  - during
  - after

  events of hazards

What are the needs for managing risks?

- **Considering the whole „life cycle" of engineered facilities and optimizing decisions in accordance with real strategies for renewals**

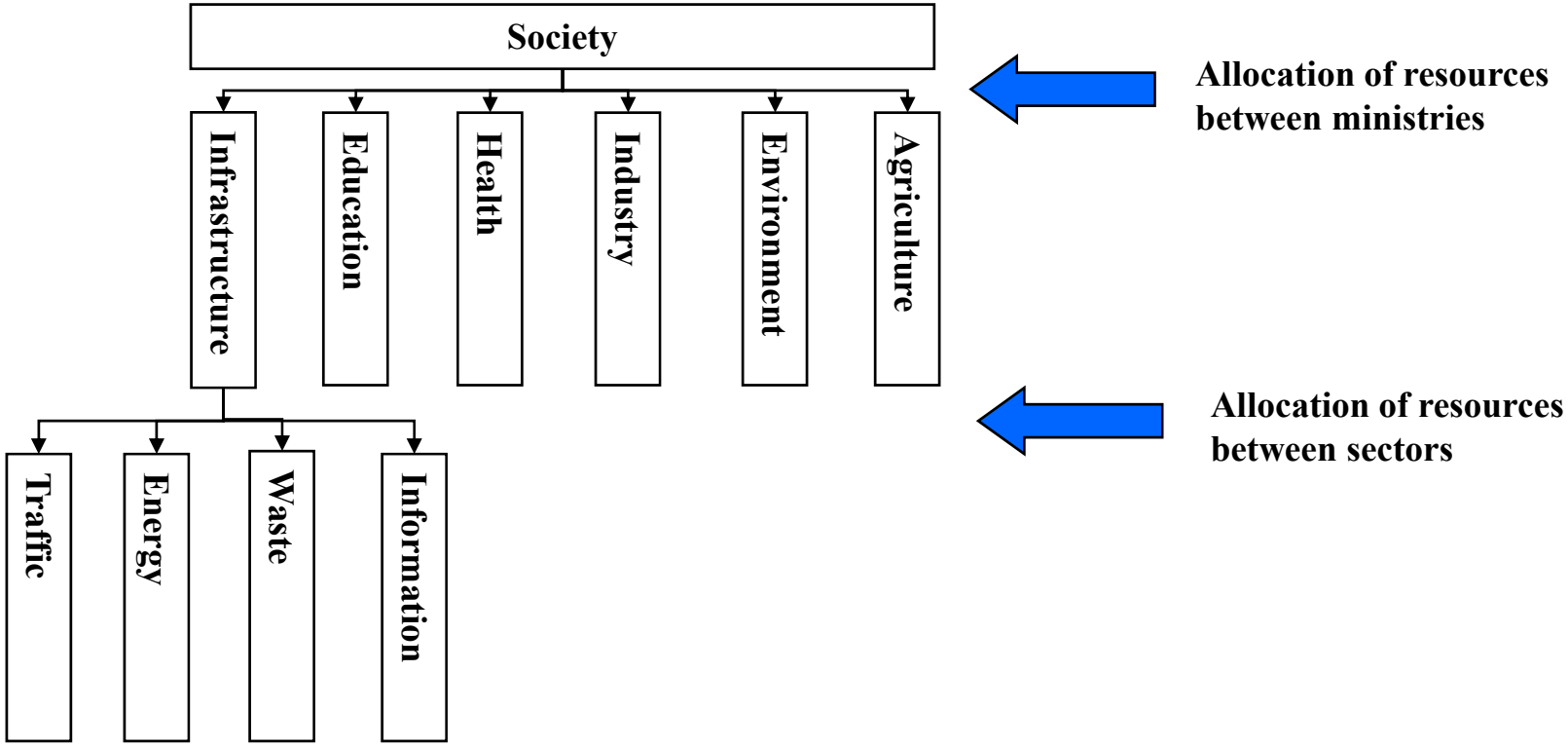
  Focus not on technical/economical life cycles

  but on

  functional life cycles!

What are the needs for managing risks?

- **Decisions can be organized hierarchically**



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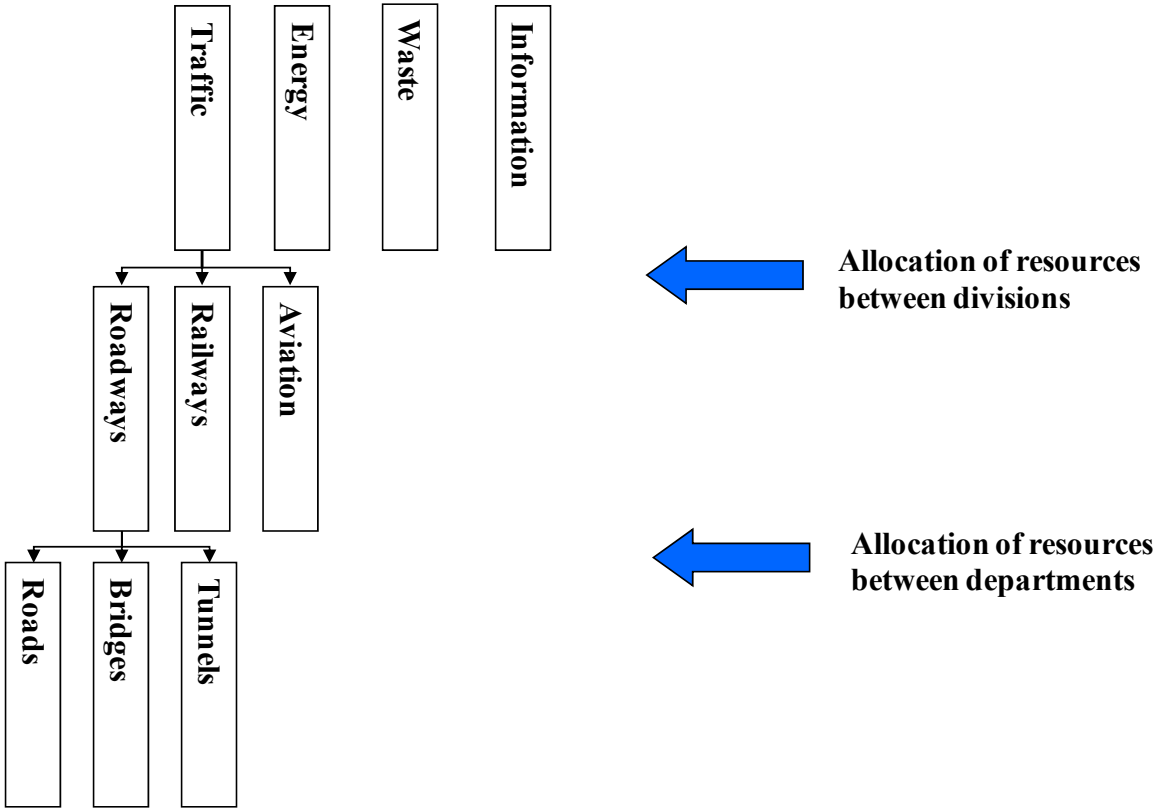

What are the needs for managing risks?

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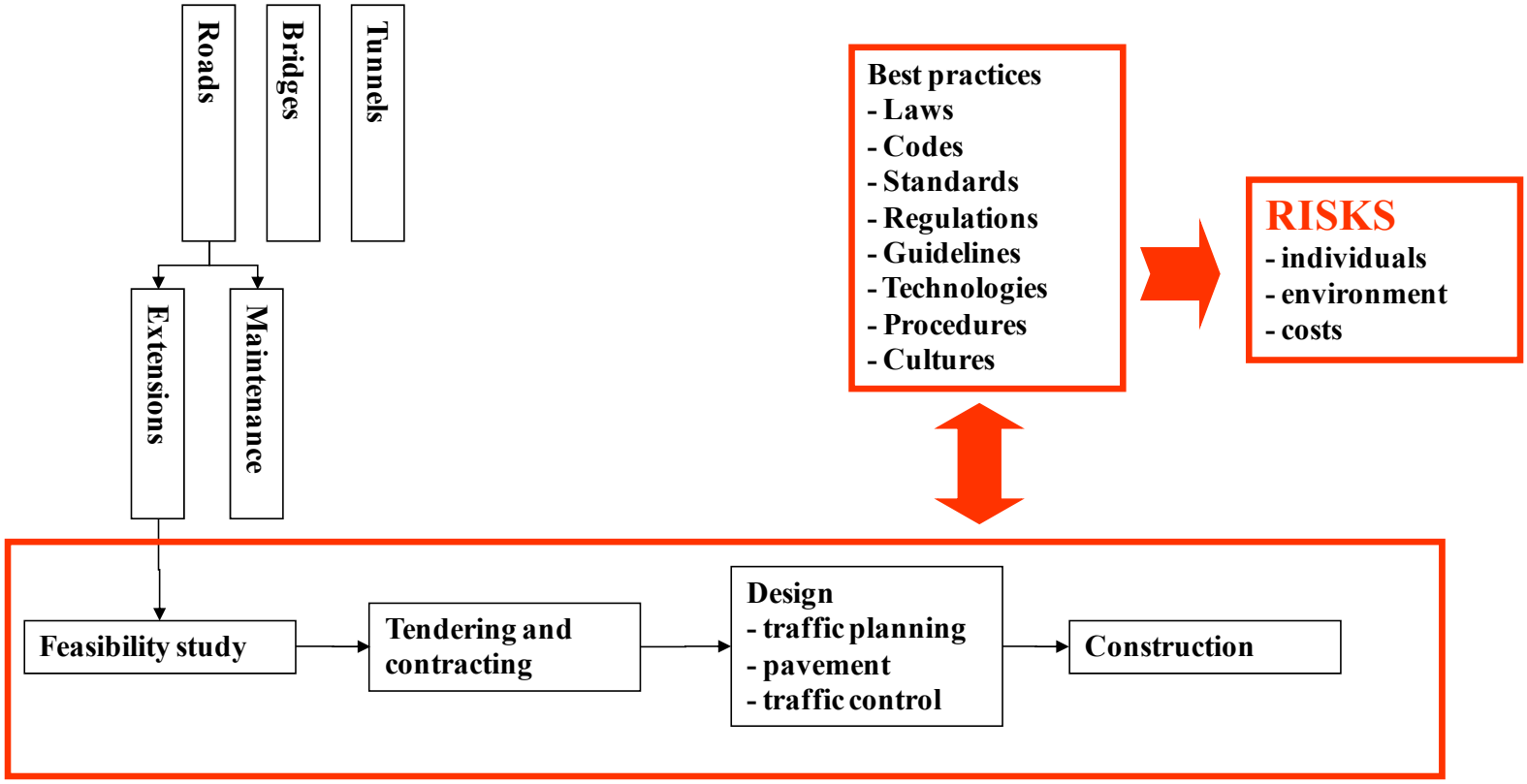
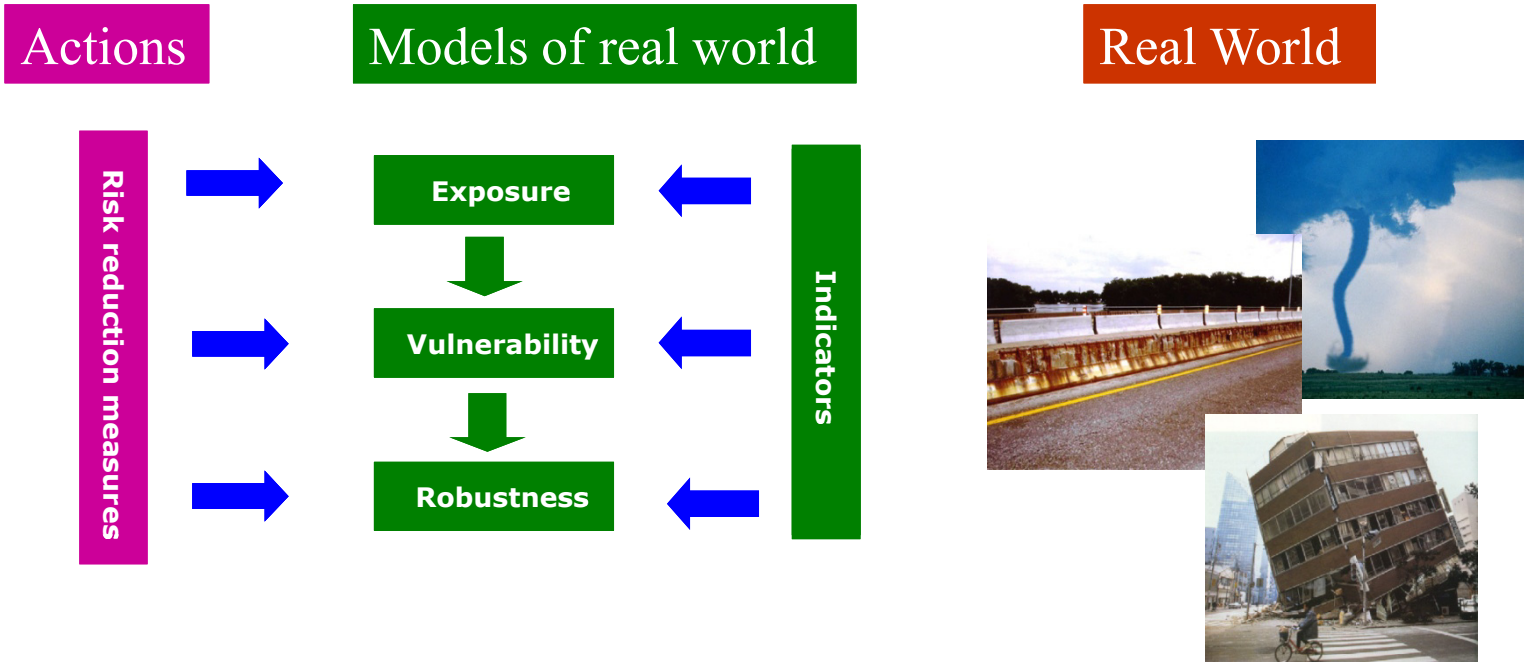


System representation in risk assessment

Engineered systems exhibit generic characteristics



System representation in risk assessment

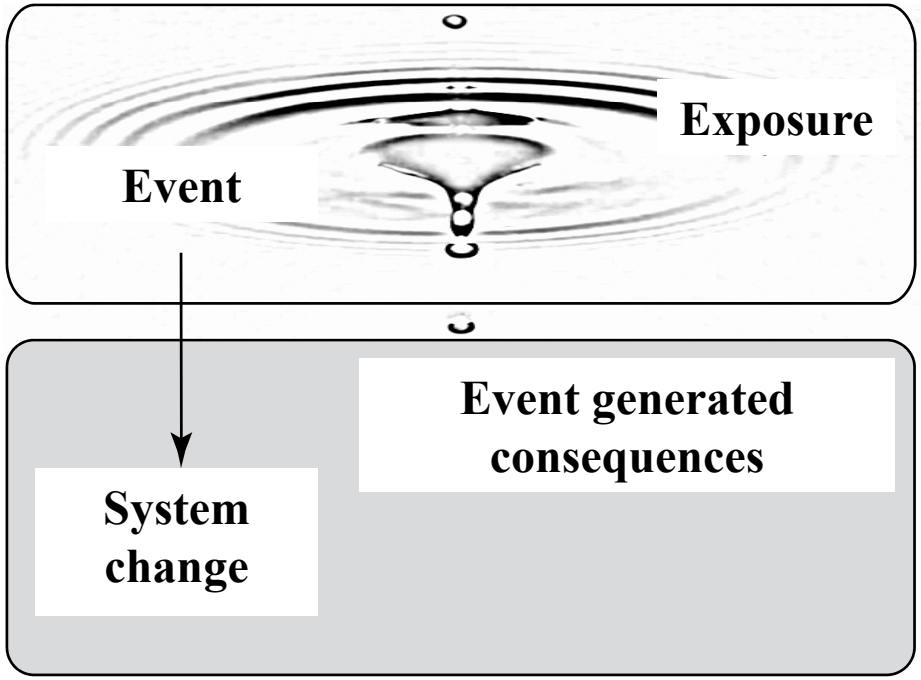
What must be accounted for in engineering modeling?

- Preferences (aim, purpose)
- Consequences (states of marginal utility)
- Uncertainties (aleatory and epistemic)
- Temporal and spatial variations/dependencies
- Options for decision making

System understanding !

System representation in risk assessment

How are consequences generated?



System representation in risk assessment

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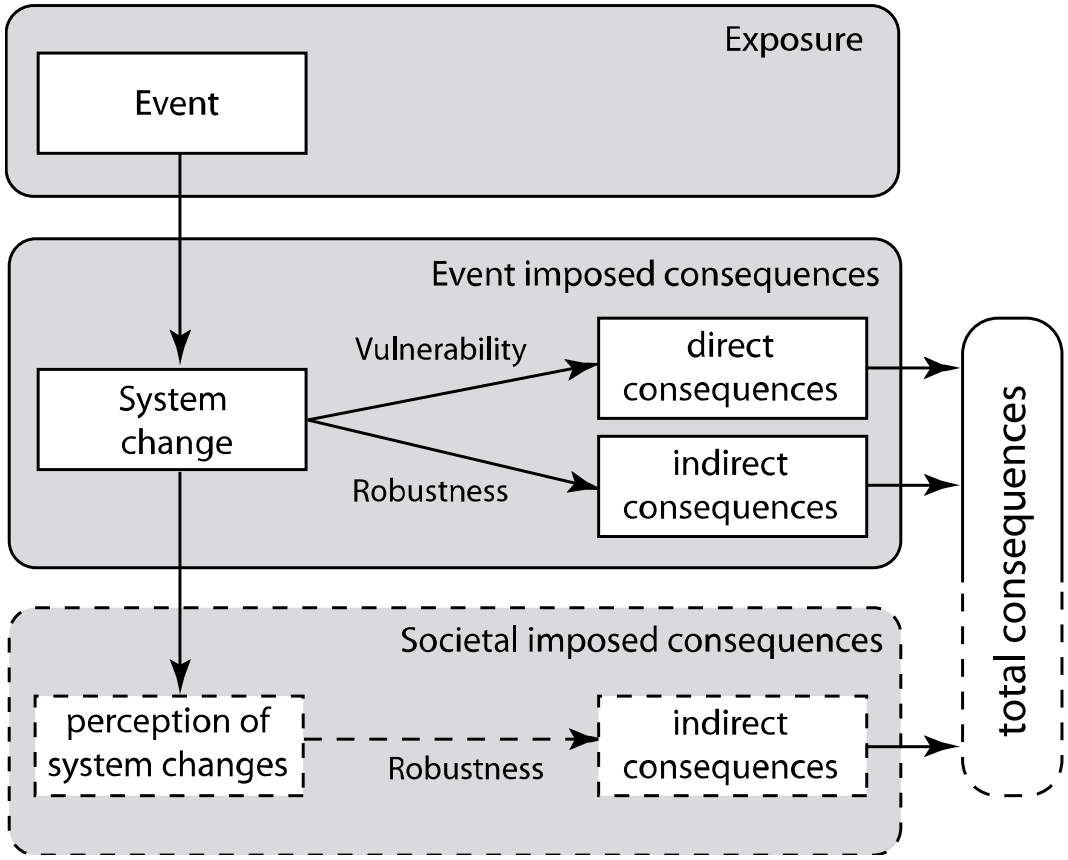
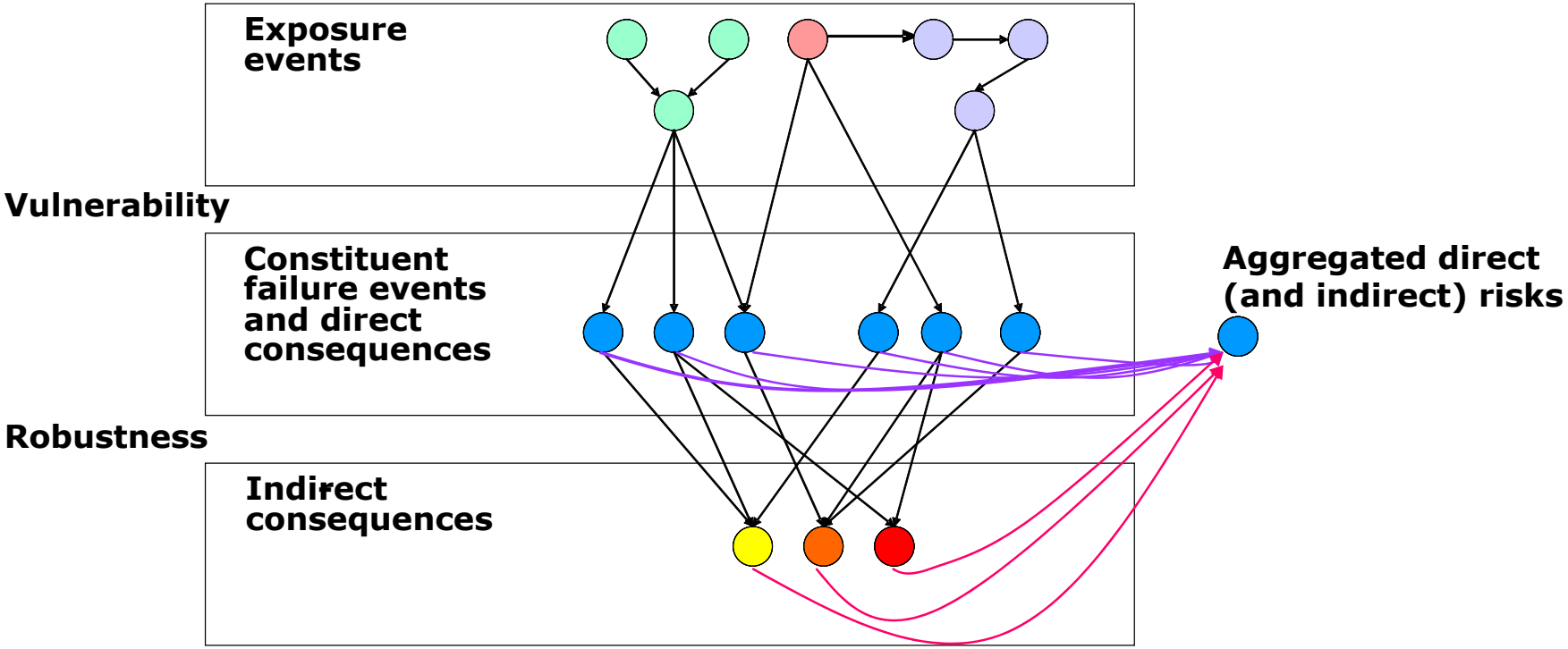


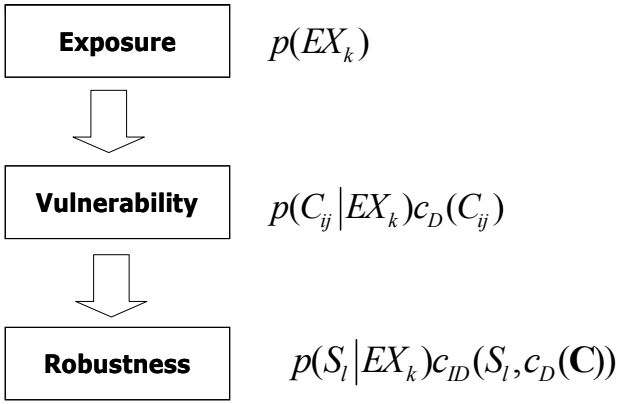
System representation in risk assessment

How may systems be modeled?



System representation in risk assessment

Quantifying risks



Direct risks:

$$R_D = \sum_{k=1}^{n_{EXP}} p(C_{ij}|EX_k)c_D(C_{ij})p(EX_k)$$

Indirect risks:

$$R_{ID} = \sum_{k=1}^{n_{EXP}} \sum_{l=1}^{n_{STA}} p(S_l|EX_k)c_{ID}(S_l, c_D(\mathbf{C}))p(EX_k)$$

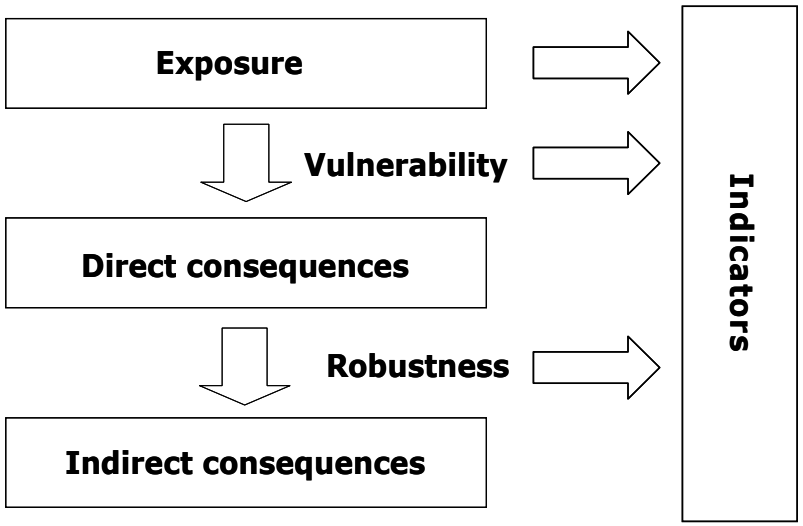
Index of robustness:

$$I_R = \frac{R_D}{R_{ID} + R_D}$$

System representation in risk assessment

Updating of risks

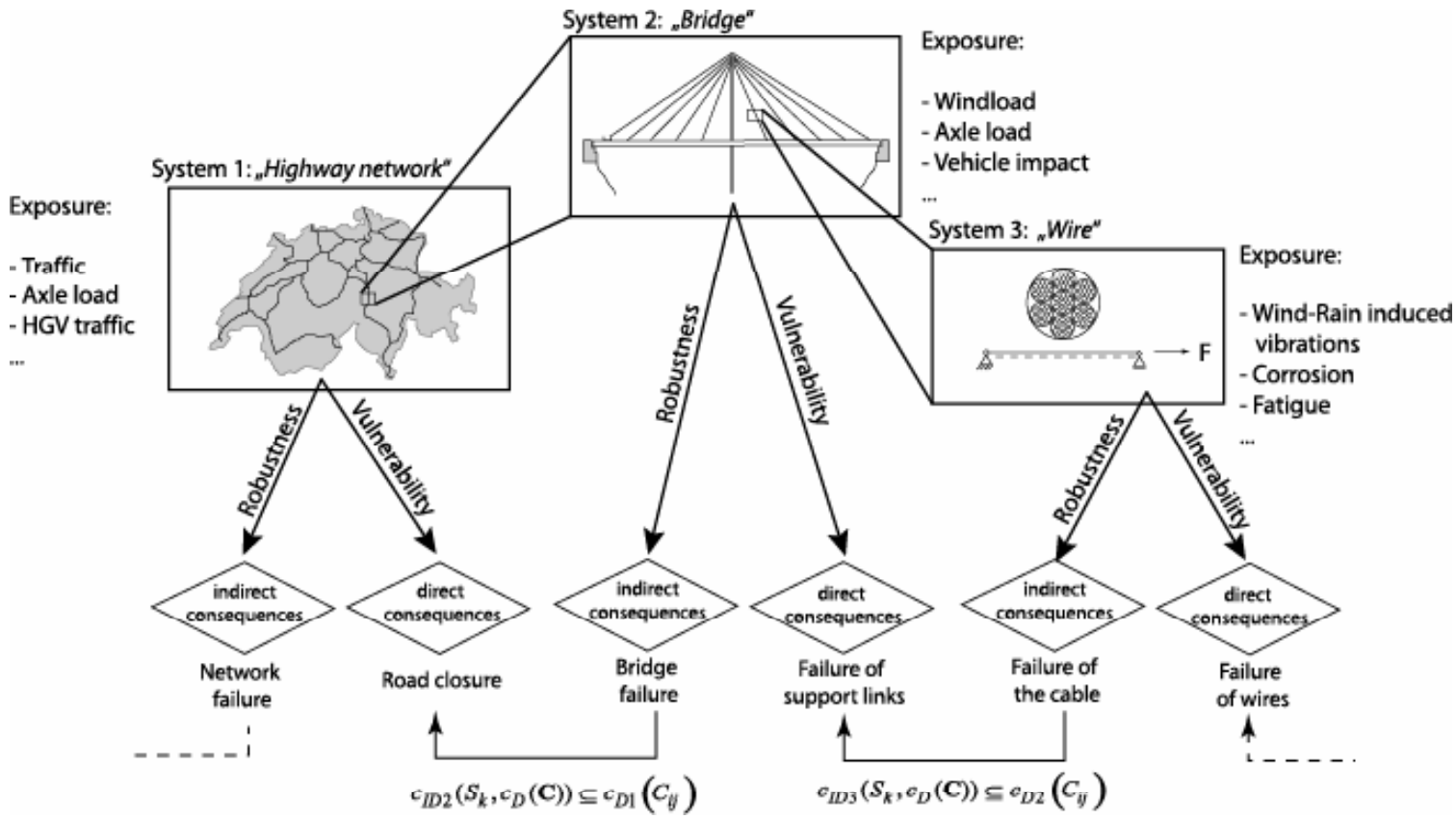
Bayesian updating
- spatial
- temporal



$$P(C_{ij}|e) = \frac{P(e|C_{ij})P(C_{ij})}{P(e|C_{ij})P(C_{ij}) + P(e|\overline{C_{ij}})(1 - P(C_{ij}))}$$

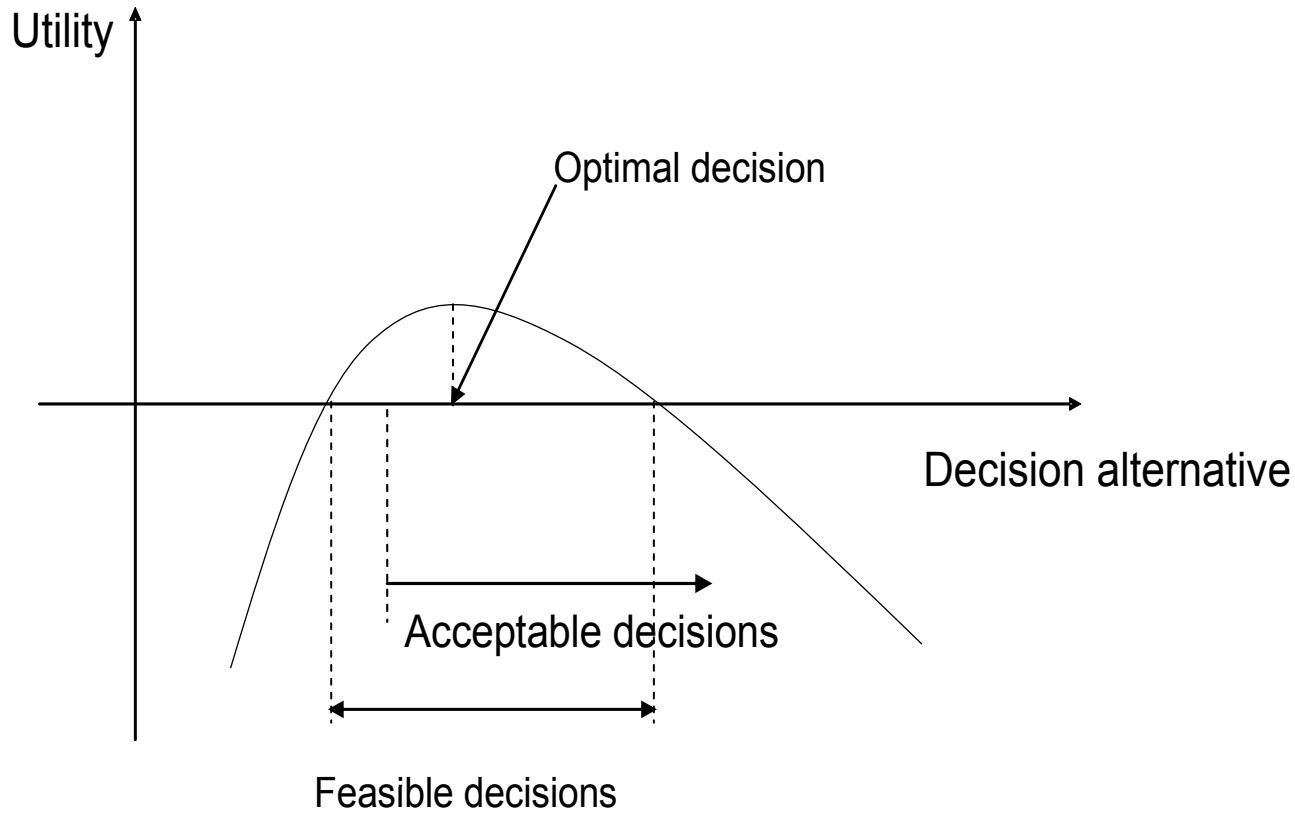
Indicator based risk management framework

Engineered systems exhibit generic characteristics



Decision optimization and life safety

- **Decisions may be ranked based on their expected value of benefit (utility)**

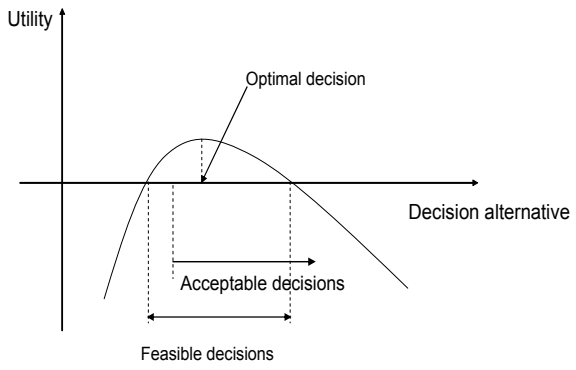


Decision optimization and life safety

- **The expected value of the benefit must include the expected value of all discounted costs and incomes resulting from the different decision alternatives**

  - failures
  - repairs
  - inspections
  - compensations to third parties

  - benefit due to increased economy



Decision optimization and life safety

- **Societal preferences concerning investments into life saving activities must be respected –**
- ***The Life Quality Index* facilitates the assessment of the acceptability of a given decision alternative:**

$$L(g,\ell) = g^q \ell$$

g : is the part of the GDP available for investment into life safety

ℓ : is the life expectancy at birth

w : is the part of life spent for work

$$q = \frac{1}{\beta}\frac{w}{1-w}$$

Decision optimization and life safety

- **Every investment into life safety should lead to an increase in life-expectancy:**

$$\frac{dg}{g} + \frac{1}{q}\frac{d\ell}{\ell} \geq 0$$

which leads to the important Societal Willingness To Pay (SWTP) criterion:

$$SWTP = dg = -\frac{g}{q}\frac{d\ell}{\ell}$$

GDP	59451 SFr
l	80.4 years
w	0.112
β	0.722
g	35931 SFr
q	0.175

Decision optimization and life safety

- **The SWTP criterion is readily applied for the purpose to determining acceptable mortality rates and structural failure probabilities**

$$\frac{d\ell}{\ell} \approx C_x d\mu = C_x k dm$$

where

C_x is a demographical constant

k is the probability of dying

m is the failure rate

Decision optimization and life safety

- **The SWTP criterion is readily applied for the purpose to determining acceptable probabilities of e.g. accidents, incidents and failures**

$$dC_y(p) \geq -\frac{g}{q} C_x N_{PE} kdm(p)$$

where

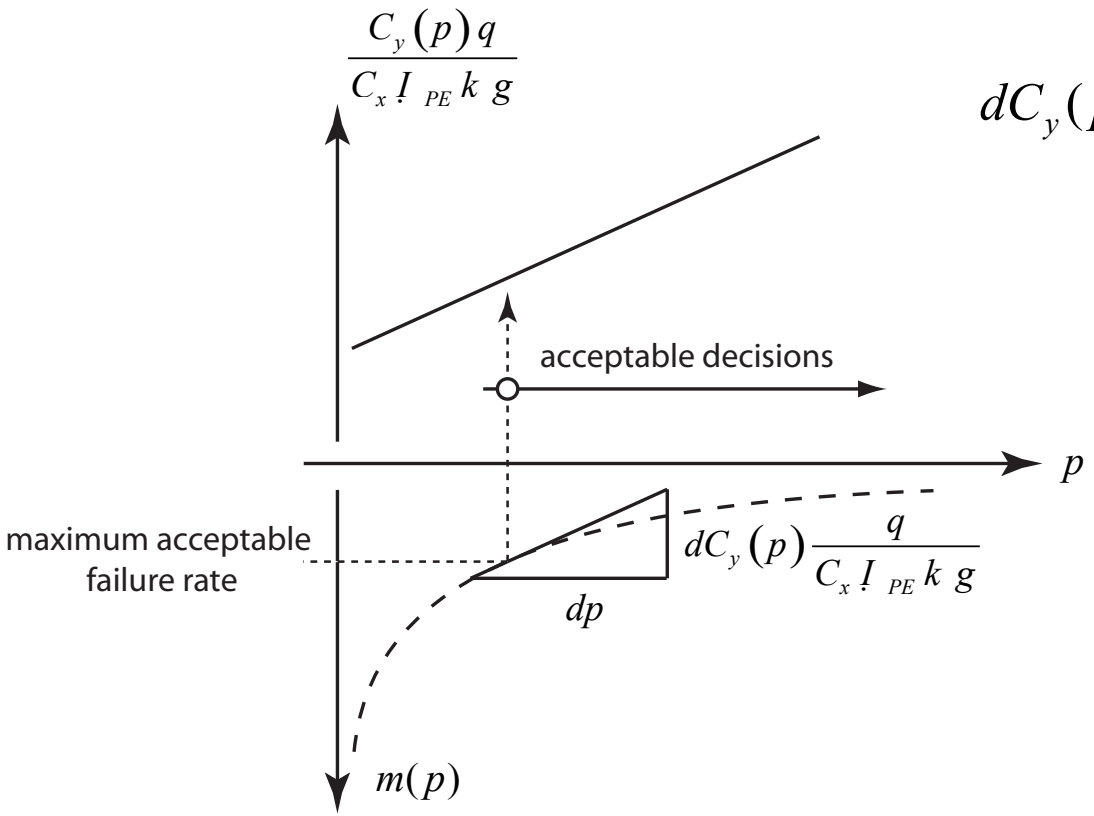
$dC_y(p)$ are the annual costs spent for risk reduction

N_{PE} is the number of people exposed

p is a decision alternative

Decision optimization and life safety

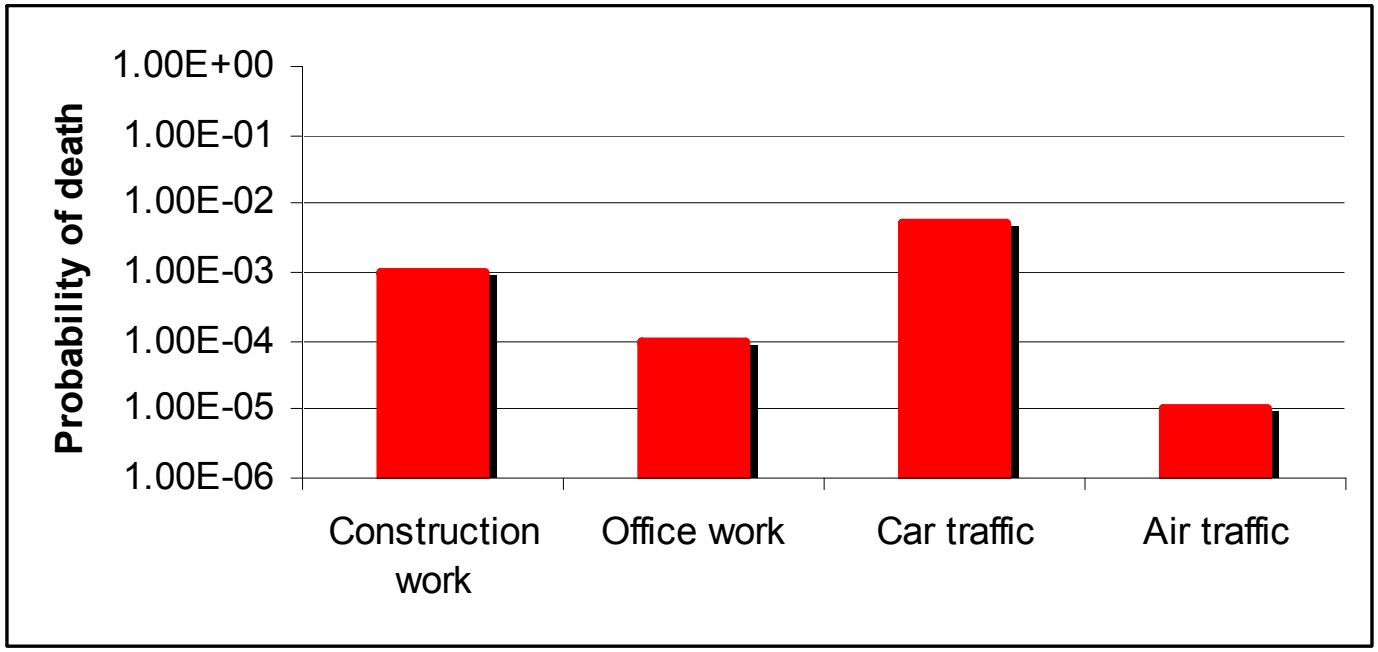
- **The SWTP criterion can be visualized**



$$dC_y(p) \geq -\frac{g}{q} C_x N_{PE} k dm(p)$$

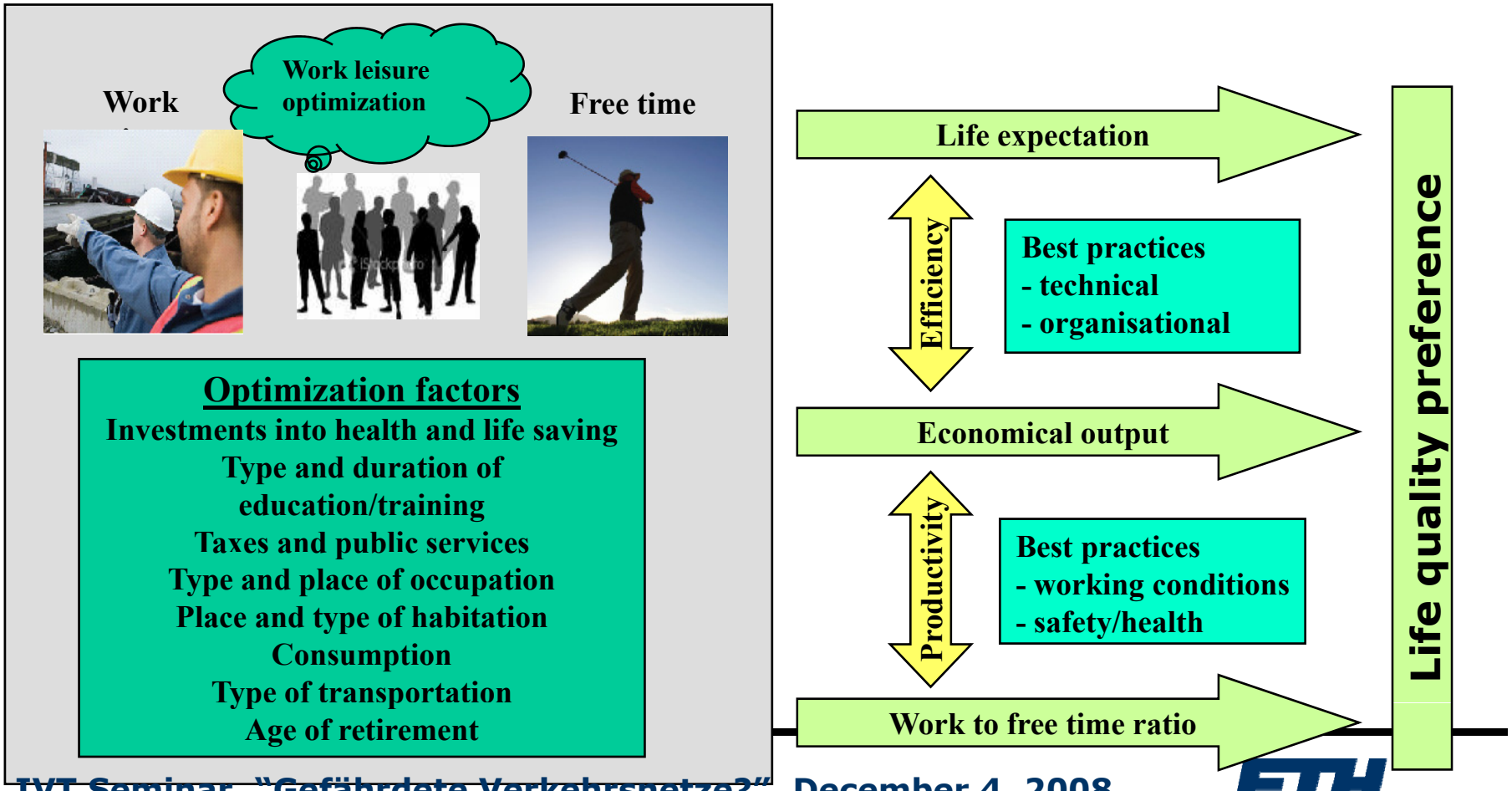
Decision optimization and life safety

- **After optimization of societal resources**



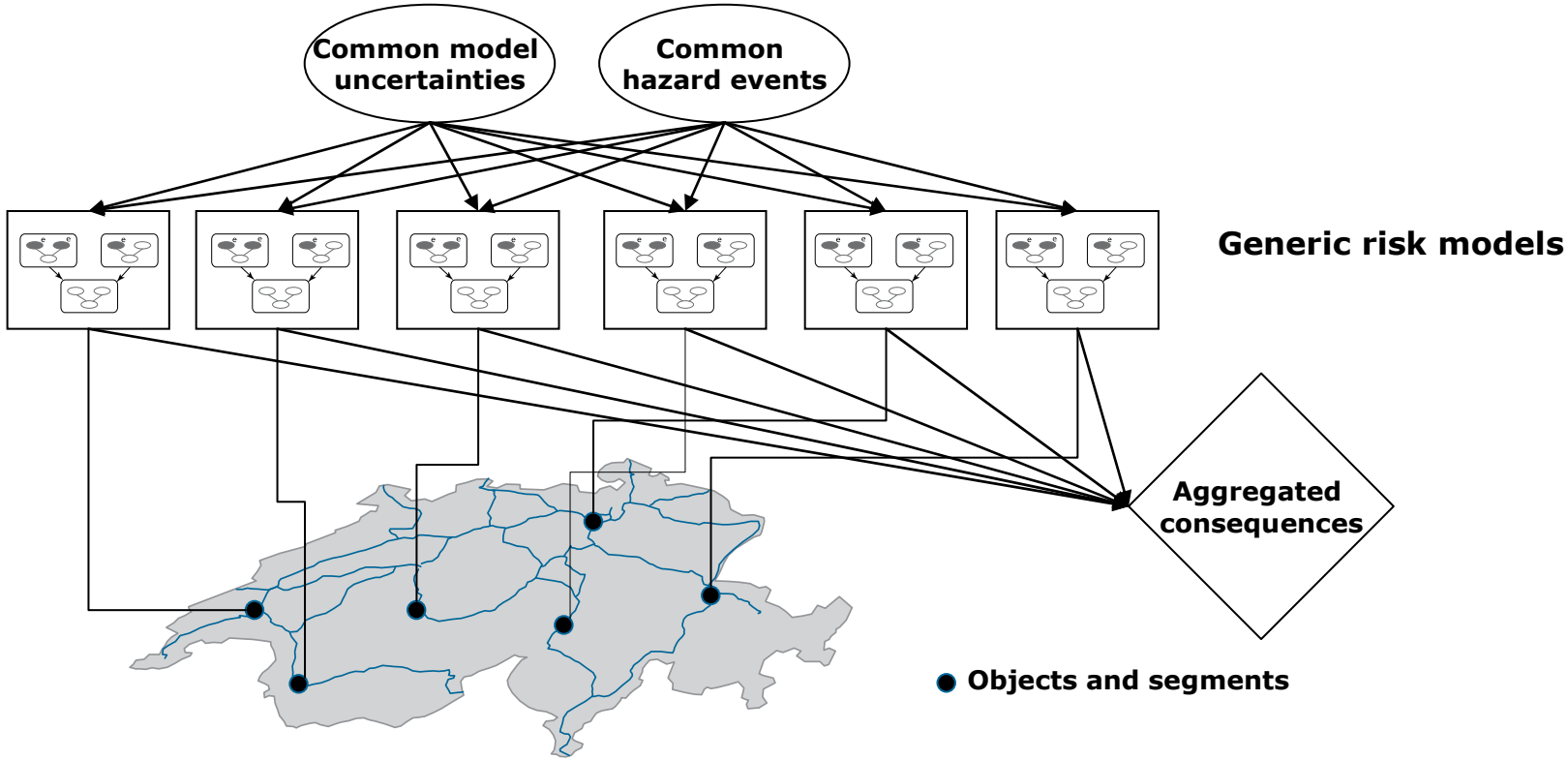
Decision optimization and life safety

- **Collective Risks vs. Individual Risks**

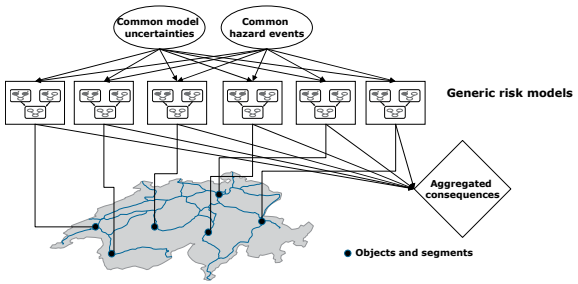


Illustrations

- **Portfolio risk assessment**

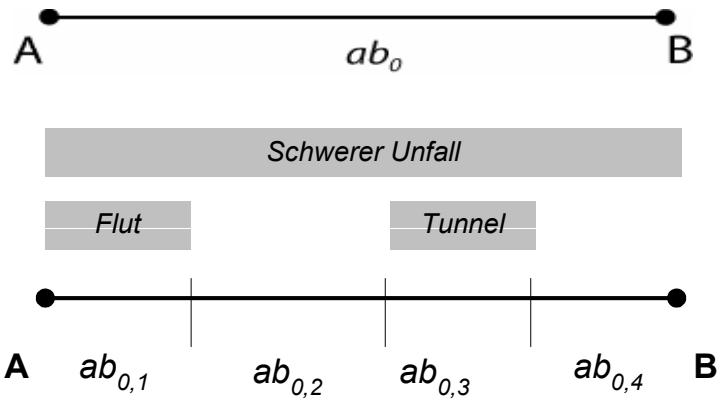


Illustrations



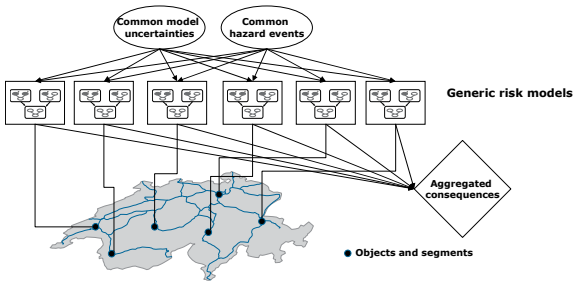
- **Road network level risk assessment**

The network is discretized into segments of (quasi-)homogeneous risk characteristics, e.g. traffic, lane/surface, objects and natural hazards



EBP, ETH;
ASTRA, AGB1, TP3

Illustrations



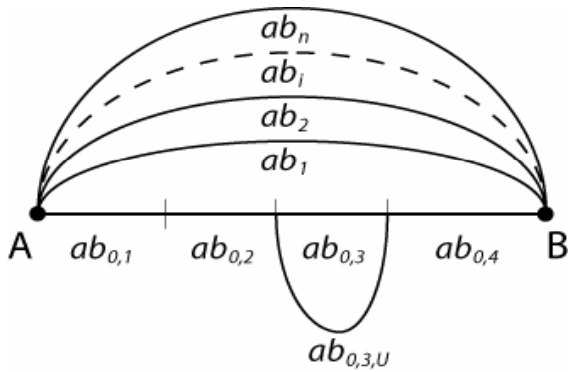
- **Road network level risk assessment**

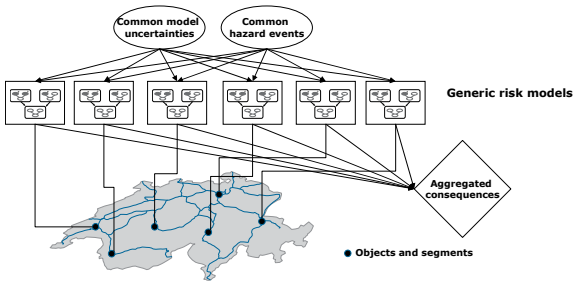
EBP, ETH;
ASTRA, AGB1, TP3

Consequences are differentiated such that

- losses on the segment where an event takes place are considered direct consequences

- other losses are considered indirect consequences





Illustrations

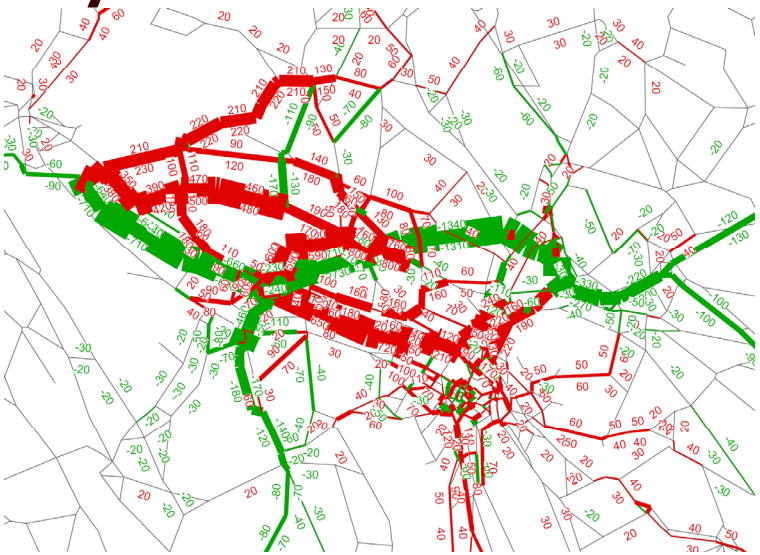
- **Road network level risk assessment**

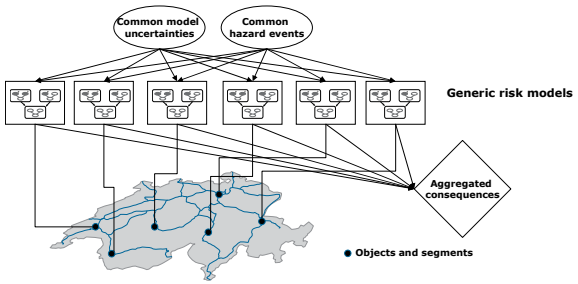
  The increase of life safety risks due redistribution of traffic after an accident/event is accounted for by traffic model analysis

  Increase in traffic accidents is explicitly accounted for on all segments which experience an increace of traffic exceeding 10%

  User costs caused by detours

EBP, ETH;
ASTRA, AGB1, TP3



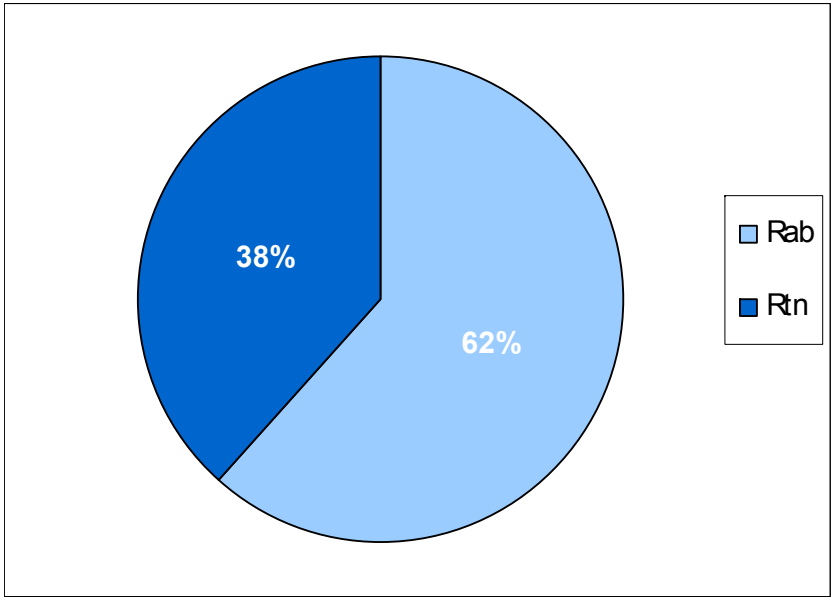


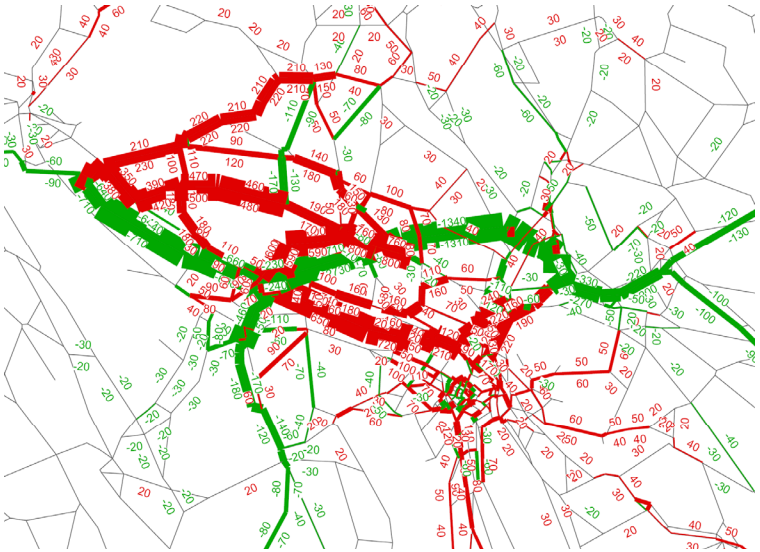
Illustrations

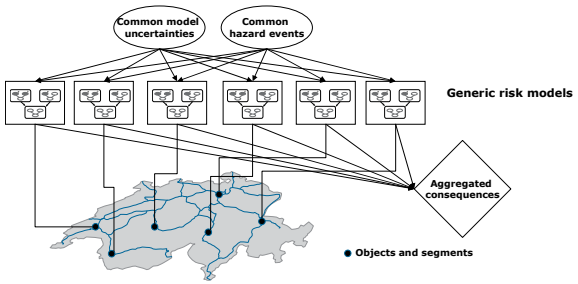
- **Road network level risk assessment**

The calculated risks may be compared

EBP, ETH;
ASTRA, AGB1, TP3



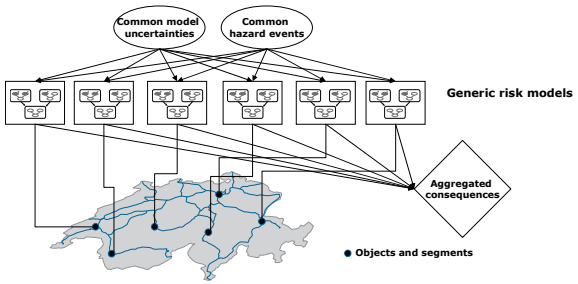




Illustrations

- **Segments and tunnels**

Generic representation of risks



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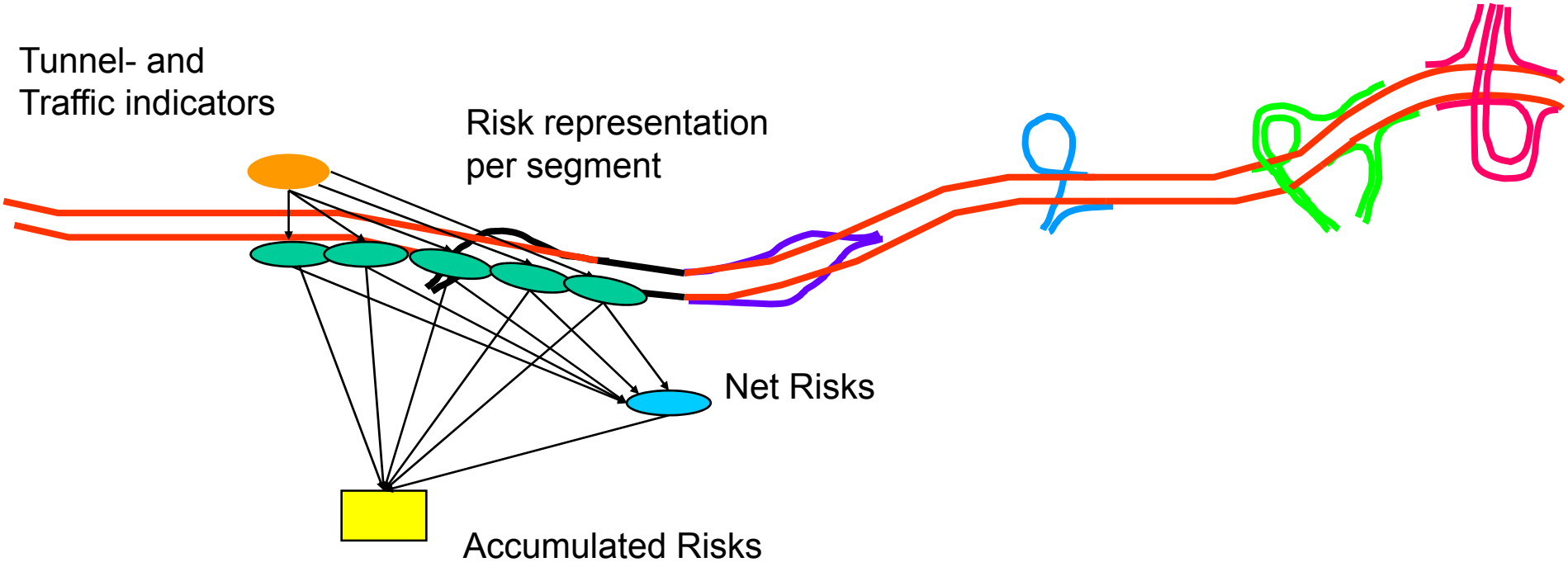

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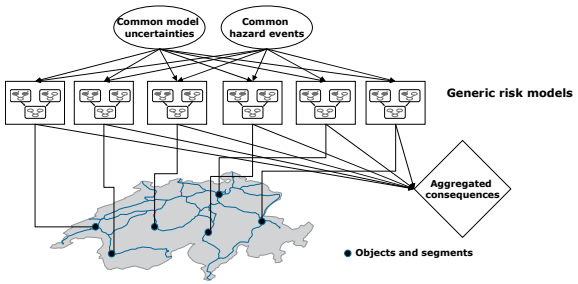
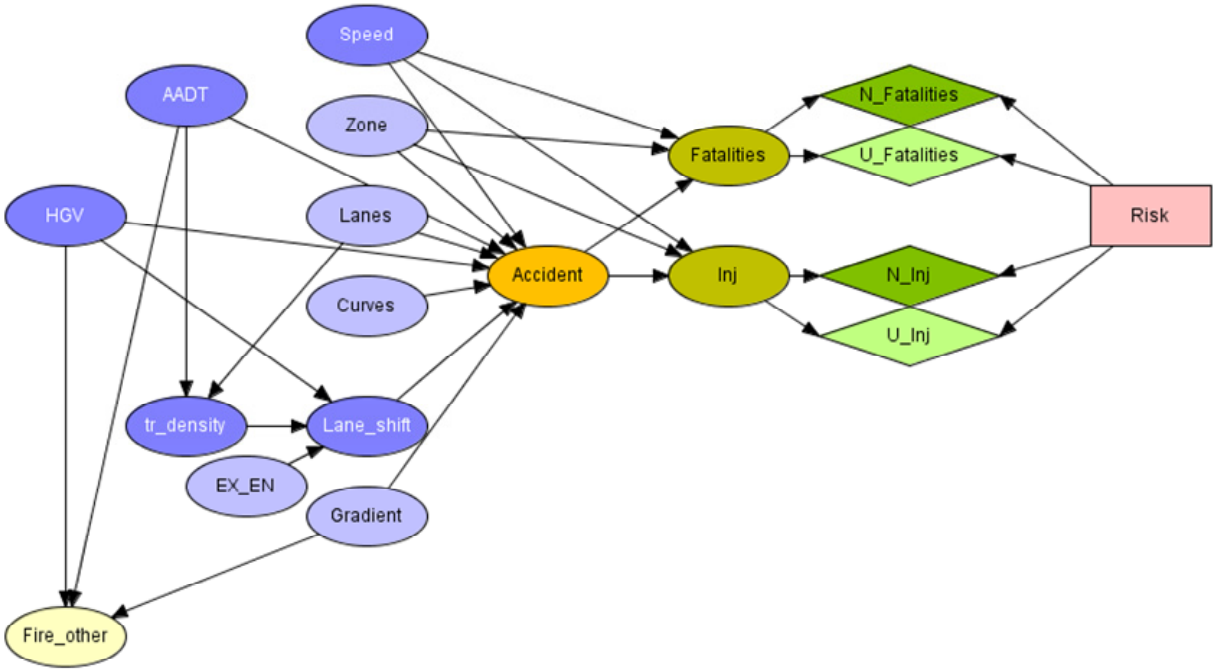
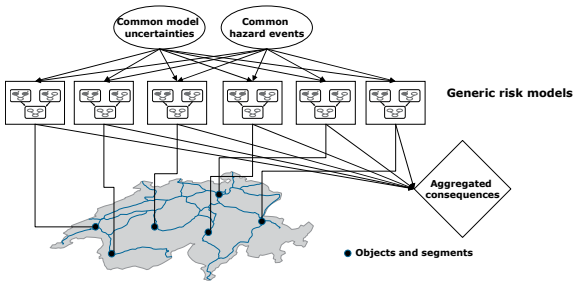


Illustrations

- **Segments and tunnels**

Each segment catagory is modelled by Bayesian Probabilistic Nets

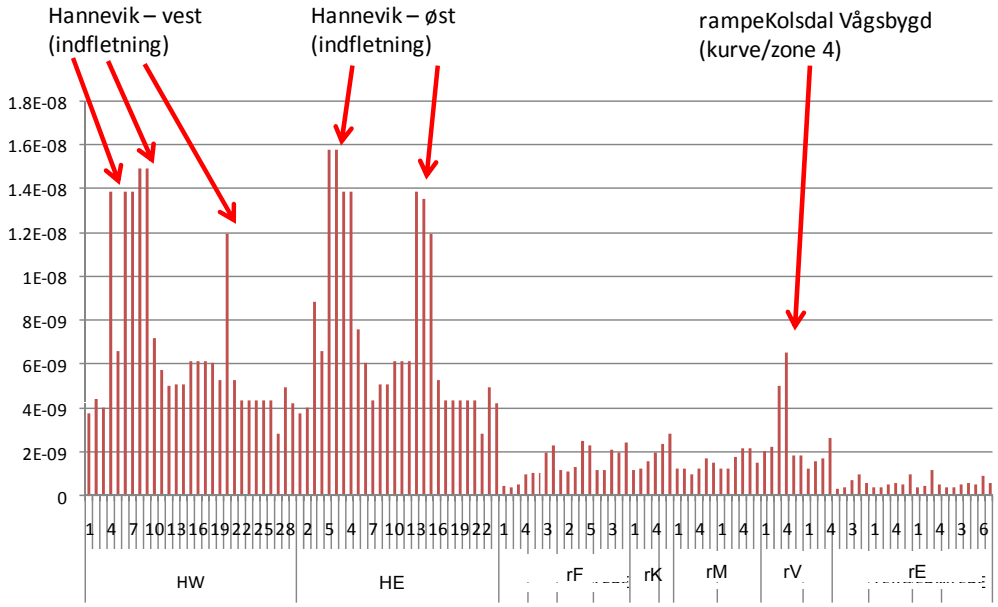




Illustrations

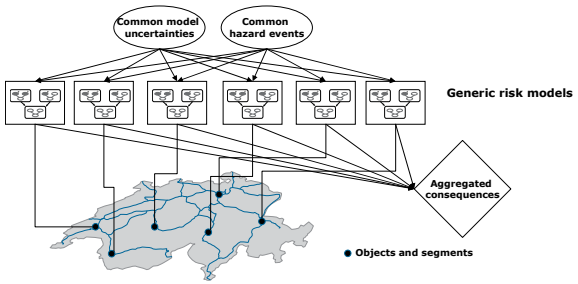
- **Segments and tunnels**

Risks can be visualized over the length of tunnel segments



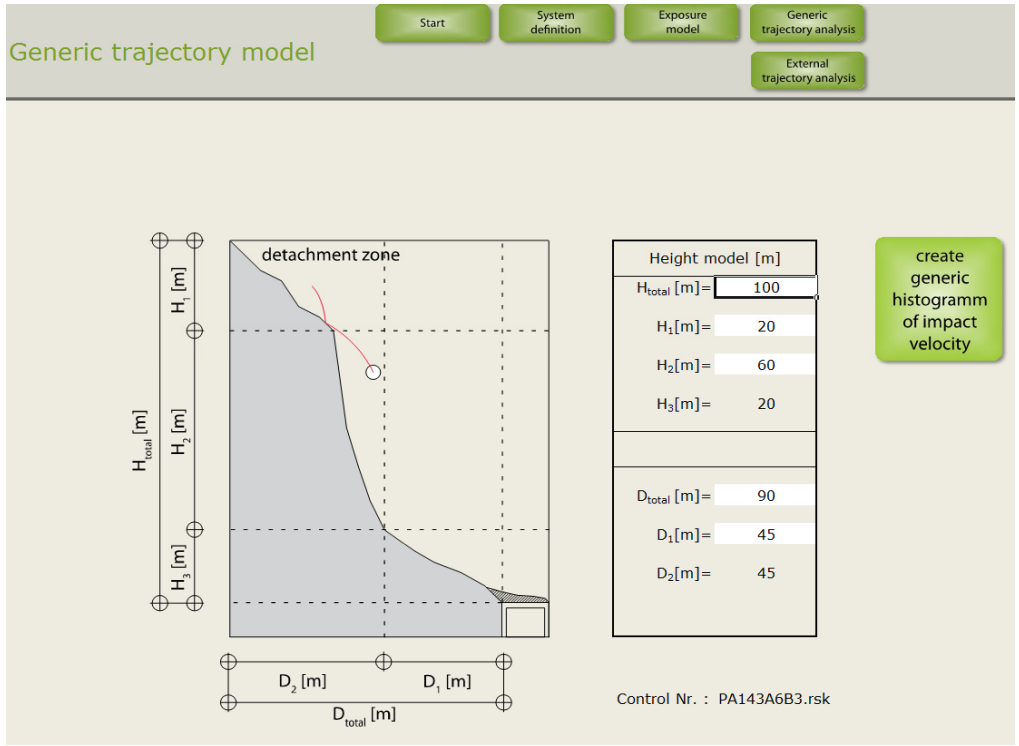
Frequenz pro Mio. Fz-km

Illustrations



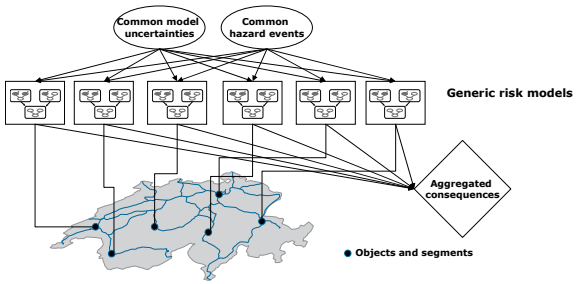
- **Galleries**

Generic models for assessing risk due to rock-fall



ASTRA/ETHZ, 2008

Illustrations



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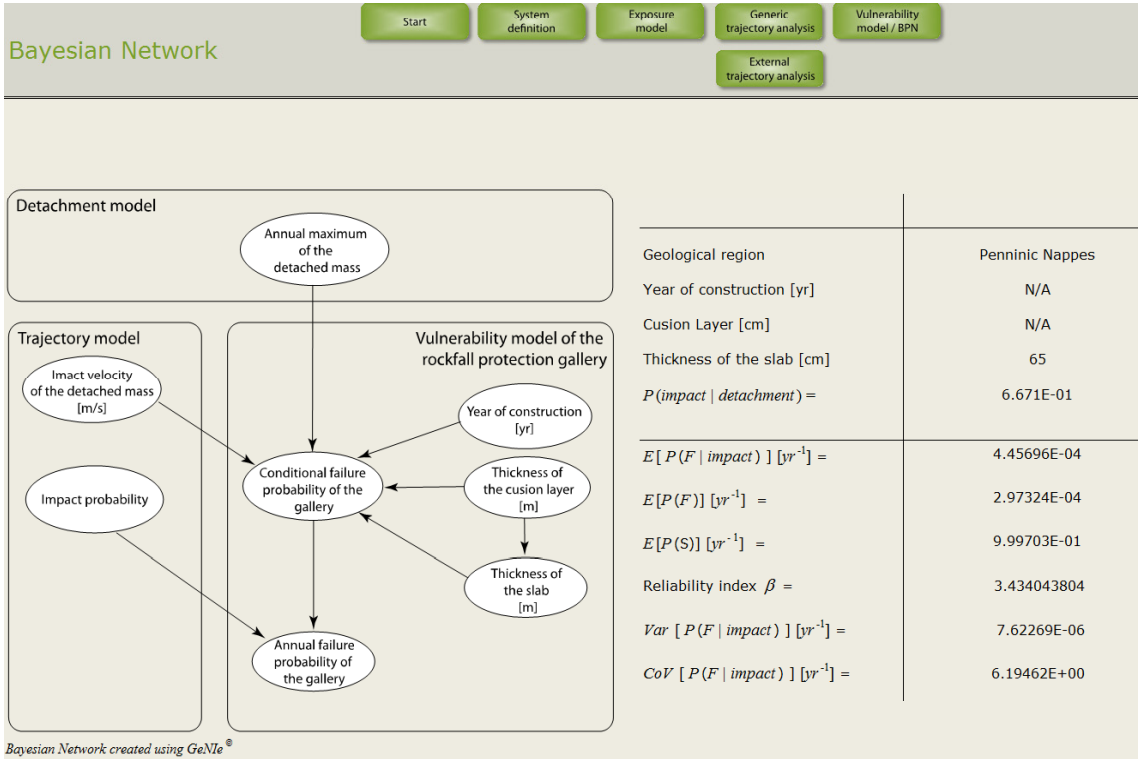
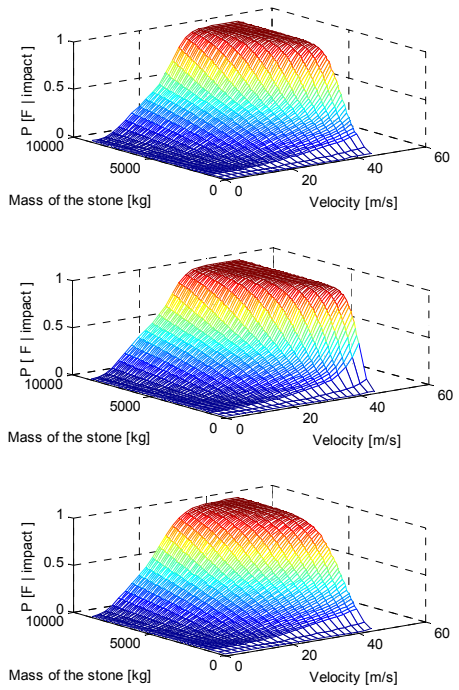


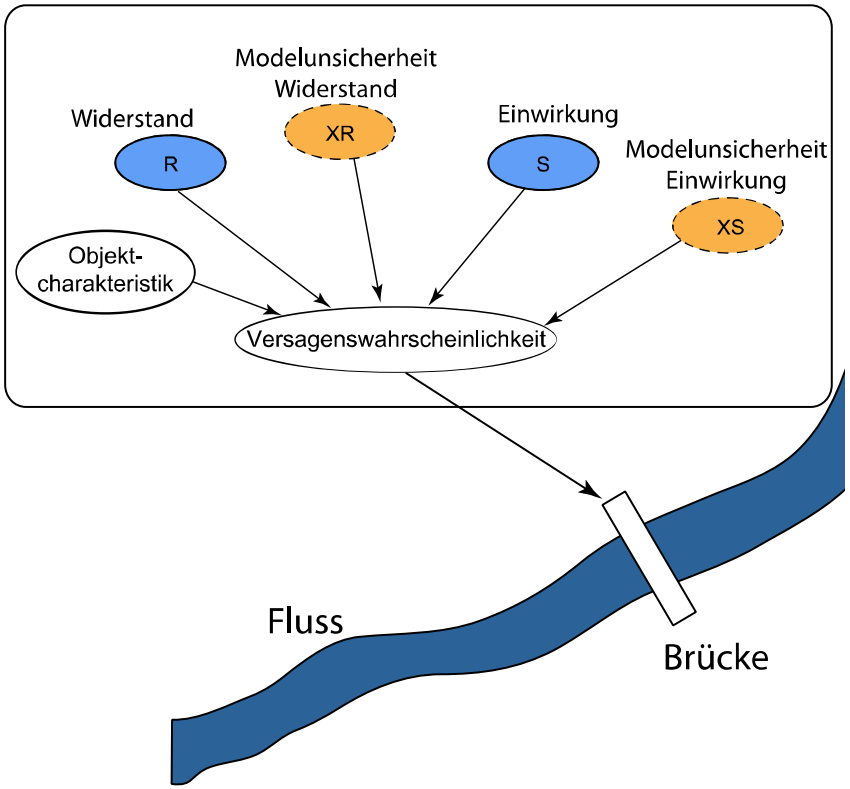
Geological region	Penninic Nappes
Year of construction [yr]	N/A
Cusion Layer [cm]	N/A
Thickness of the slab [cm]	65
$P(impact \mid detachment) =$	6.671E-01
$E[P(F \mid impact)]\ [yr^{-1}] =$	4.45696E-04
$E[P(F)]\ [yr^{-1}] =$	2.97324E-04
$E[P(S)]\ [yr^{-1}] =$	9.99703E-01
Reliability index $\beta =$	3.434043804
$Var\ [P(F \mid impact)]\ [yr^{-1}] =$	7.62269E-06
$CoV\ [P(F \mid impact)]\ [yr^{-1}] =$	6.19462E+00



Illustrations

- **Risk aggregation**

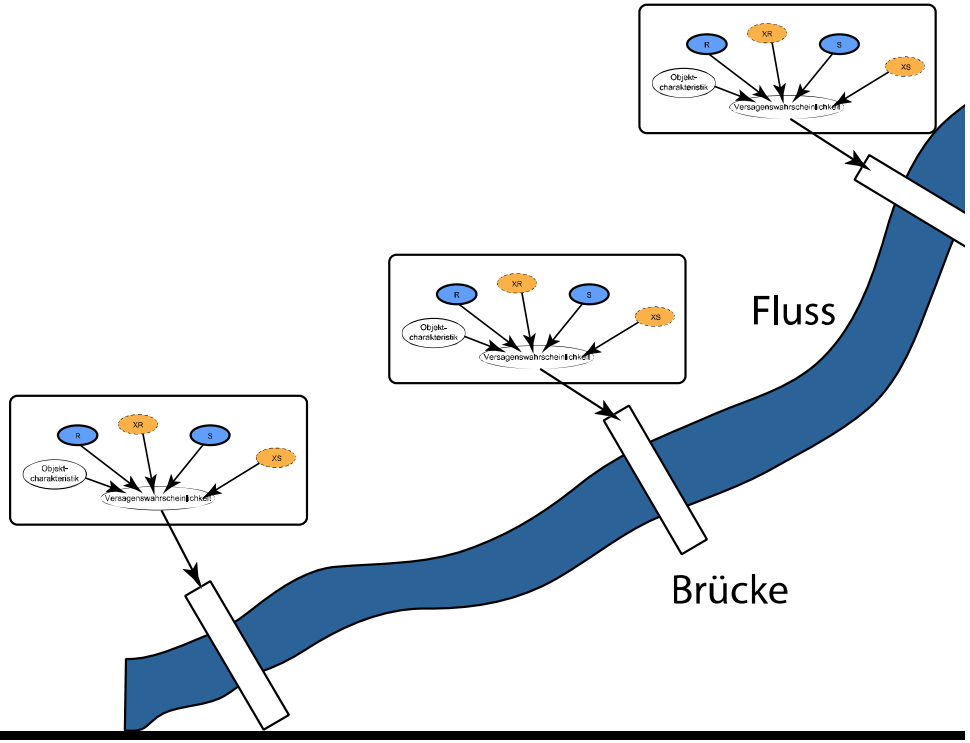
Risk models might be established for individual objects



Illustrations

- **Risk aggregation**

If there are more objects these can be treated individually using the same principal model



Illustrations

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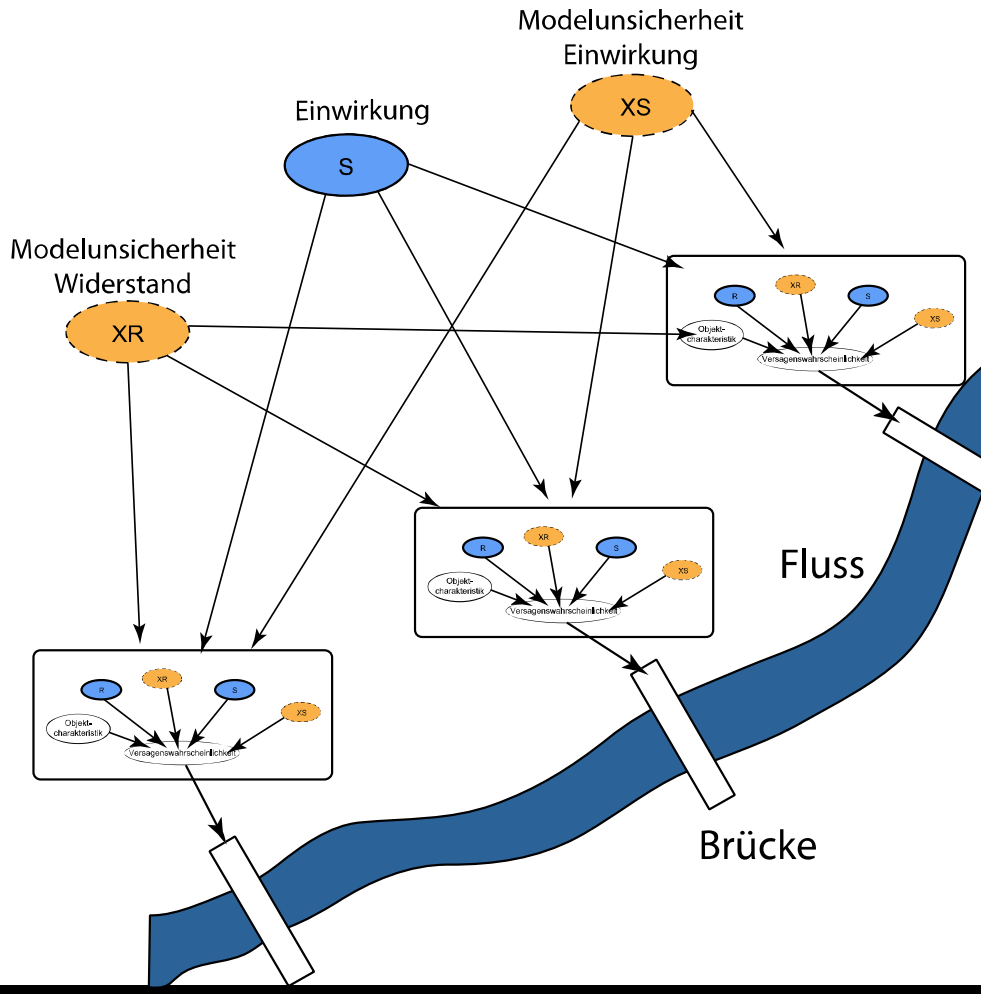
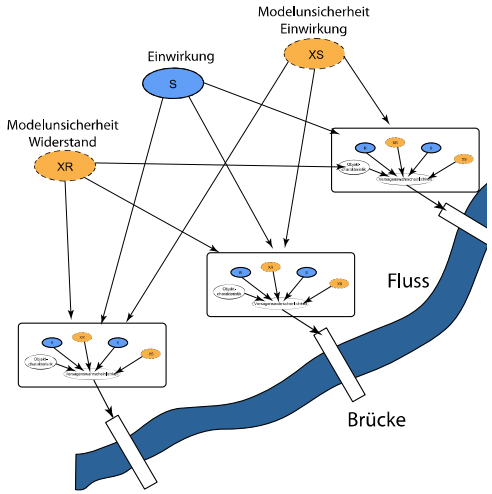


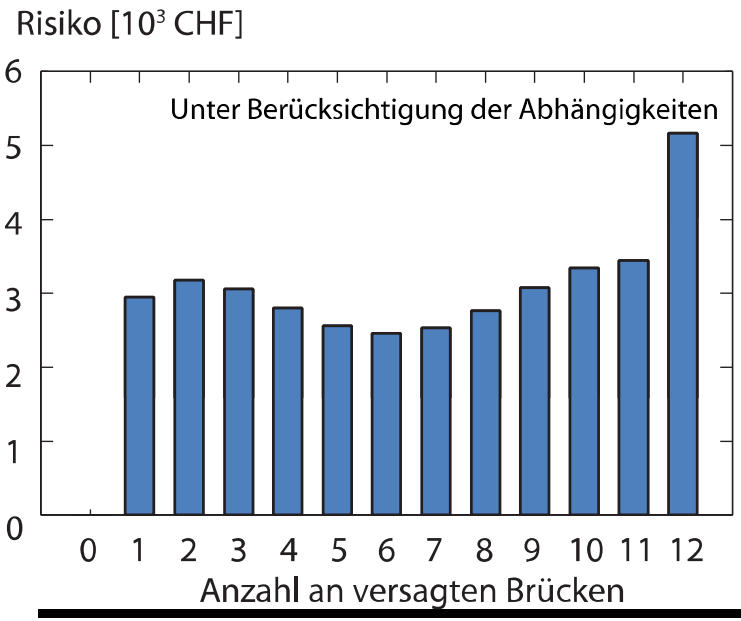
However, it is important to take into account dependencies!

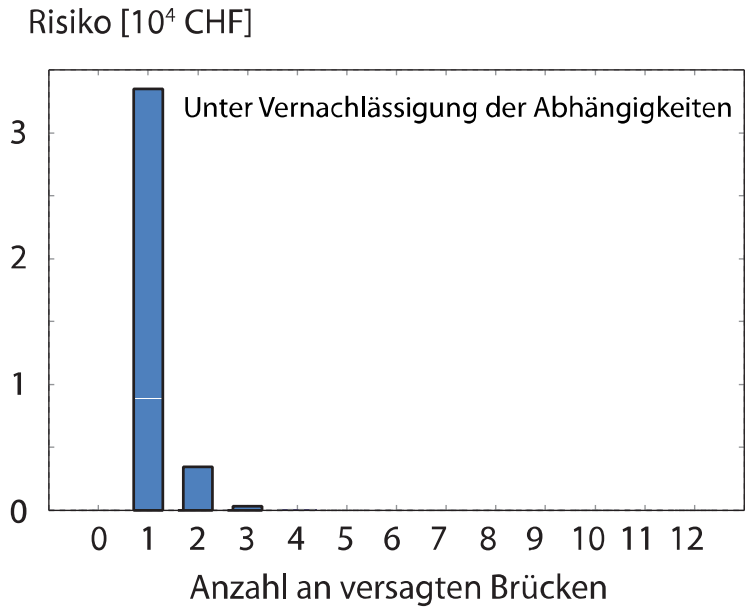
Illustrations

- **Risk aggregation**

  However, it is important to take into account dependencies!







Outlook

- How might we improve the assessment of the performance of roadway traffic system

  Consistently account for uncertainties
  - utilize Bayesian probabilistic modeling
  - utilize decision theoretical concepts

  Improve systems modeling
  - account for indirect consequences
  - account for dependencies
  - utilize generic risk models
  - utilize indicators and Bayesian updating

Outlook

- How might we reduce risks by improved understanding? – which are the major knowledge gaps?

  By assessing and quantifying risks homogeneously we might achieve a “real picture” of the risk contributions

  Using the concept of value of information and sensitivity analysis we might quantify the effect of improving

  - models, and

  - data bases

Needs and Prospects

- How might we advance? – which are the big questions in need for research and development?

  In the overall prioritization the assessment of the benefit of societal infrastructure should be a focus issue

  so far only very crude models have been developed to represent the economical societal benefit of e.g. roadway extensions or capacity increases of electricity distribution networks

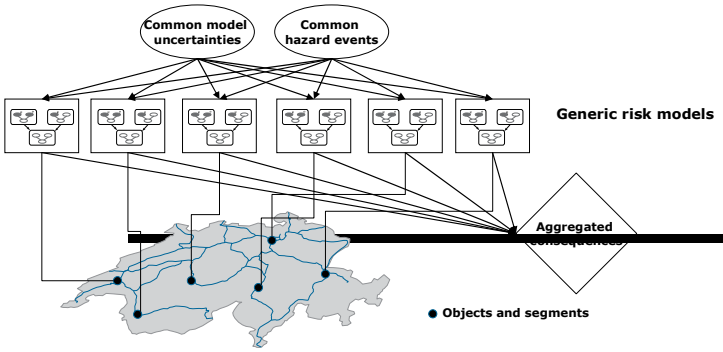
  Development of generic standardized indicator based risk assessment models for the assessment of common systems and objects

Needs and Prospects

- How might we advance? – which are the big questions in need for education and dessimination?

  Education and information about strategic management of risks of decision makers and stakeholders

  Requiring that decisions in the public domain shall be based on a tractable, transparent and documented basis

IVT Seminar, "Gefährdete Verkehrsnetze?"
ETHZ, December 4, 2008.

Thanks for your attention!