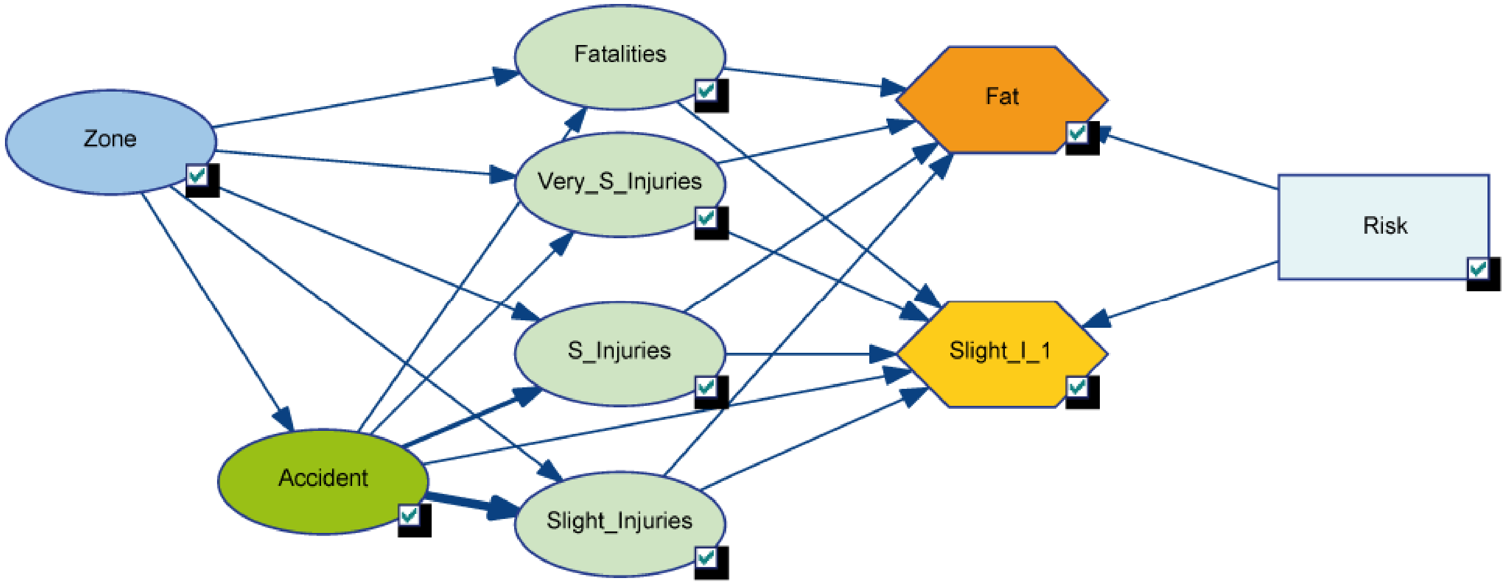
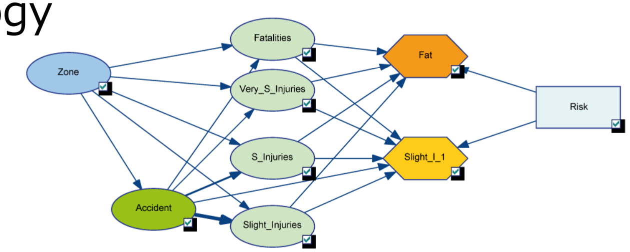
# The Probabilistic Analysis of Systems in Engineering



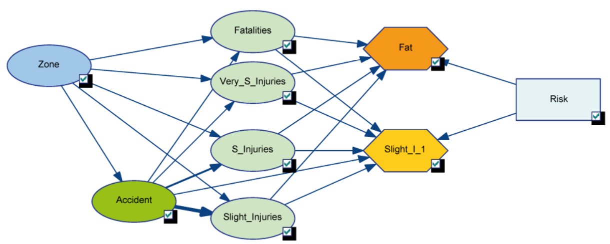

Prof. Dr. Michael Havbro Faber

Swiss Federal Institute of Technology
ETH Zurich, Switzerland



# Contents of Today's Lecture

- **Introduction of participants**
- **Motivation, overview and organization of the course**
- **Basic common definitions of systems**
- **Common characteristics of systems**
- **Focus of the present course**



# Introduction of Participants

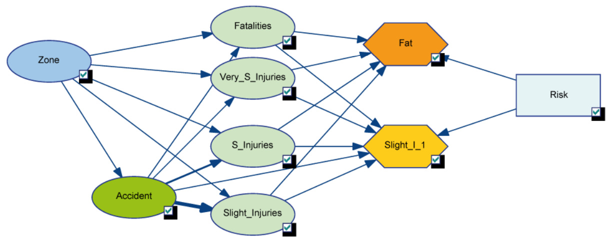
- As a first task I suggest that each of you introduce yourself and try to outline the following issues:

  - Your interest in the analysis and modeling of systems

  - Your understanding of a system

  - What examples would you like us to consider in the course

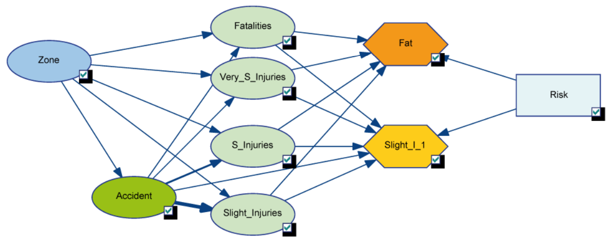




# Motivation, overview and organization of the course

- Systems are everywhere in engineering and science

  - Biology/chemistry
  - Infrastructure systems
  - Processes of natural hazards
  - Mechanical response (input/output)
  - Nervous systems
  - Climatic systems
  - Ecological systems
  - Organizational systems
  - Economical systems
  - Portfolio losses

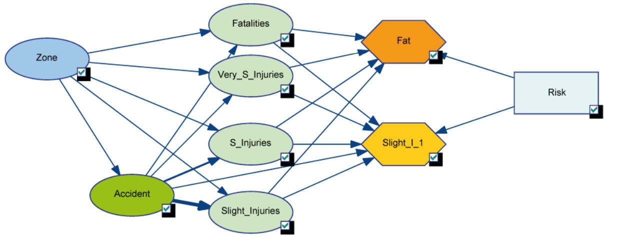


# Motivation, overview and organization of the course

- **In engineering systems are may be represented through engineering models**

  **- Top down models**
  **We attempt to assess the behavior of the system without going into the detailed modeling of its components – input output relations**

  **- Bottom up models**
  **We attempt to represent the behavior of the system through a detailed modeling of the components and their interrelations**

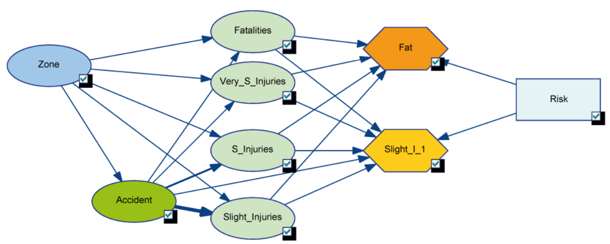


# Motivation, overview and organization of the course

- **In engineering systems are dealing with systems with rather different characteristics**

  **- Do not vary in time**
  - **Linear**
  - **Non-linear**
    - **deterministic**
    - **probabilistic**

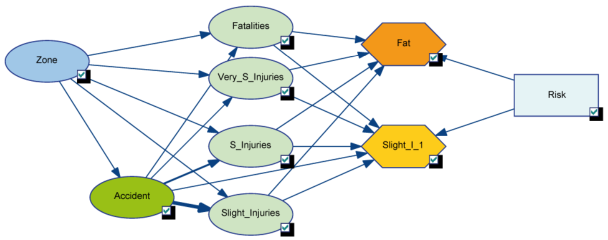
  **- Exhibit time variation**
  - **Linear**
  - **Non-linear**
    - **deterministic**
    - **chaotic (dynamic)**
    - **probabilistic**



# Motivation, overview and organization of the course

- **What we aim for in the present course is to be able to establish models for the analysis and representation of systems characteristics – subject to uncertainty**

  **- we will consider systems where not only boundary conditions are uncertain but also where the parameters of the system representation are uncertain**



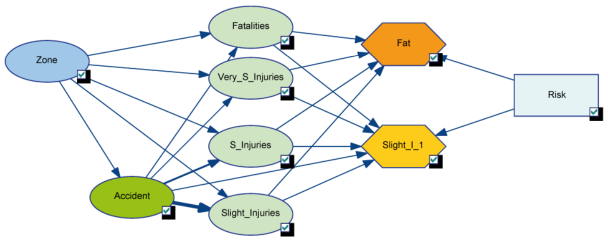
# Motivation, overview and organization of the course

- **The organization of the course will be such that the lectures will be help by the participants – YOU ! – in turn.**

  **Only a few lectures will be conducted by my self or my colleagues**

  **We will then discuss more broadly the various issues and potential problems associated with the presented material from lecture to lecture**

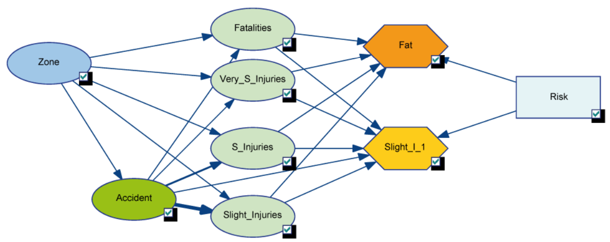
  **We will adapt examples and exercises to your interests !**



# Motivation, overview and organization of the course

- **The planned program will be the following:**

| W | Date | Speaker | Topic |
|---|---|---|---|
| 1 | 26.09.07 | Prof. M.H. Faber | Basic theory of systems<br>-Definition of systems |
| 2 | 03.10.07 | Prof. M.H. Faber | Basic theory of probability<br>-Classical probability theory and Bayesian probability theory |
| 3 | 10.10.07 | K. Nishijima | Bayesian probabilistic networks<br>-Definition and use of Bayesian probabilistic networks |
| 4 | 17.10.07 | | Bayesian probabilistic networks<br>-Algorithms used in Bayesian probabilistic networks |
| 5 | 24.10.07 | | Bayesian probabilistic networks<br>-Introduction of available software tools<br>-Statistical inferences |
| 6 | 31.10.07 | | Bayesian probabilistic networks<br>-Hierarchical modeling |
| 7 | 07.11.07 | | Assessment of system reliability and robustness |
| 8 | 14.11.07 | J. Qin | Application example<br>-Performance of structural systems |
| 9 | 21.11.07 | | Application example<br>-Propagation of degradation |
| 10 | 28.11.07 | Y. Bayraktarli | Application example<br>-Analysis of portfolio losses |
| 11 | 05.12.07 | | Application example<br>-Process of natural hazards |
| 12 | 12.12.07 | | Application example<br>-Electricity distribution systems |
| 13 | 19.12.07 | | Application to other fields |

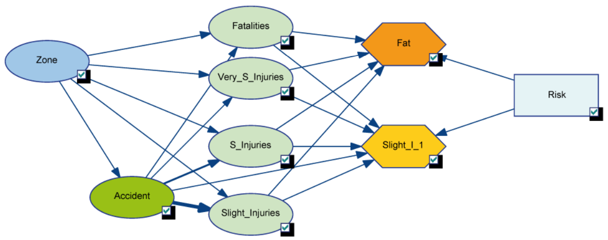


# Basic common definitions of systems

- **System:**

  **A system is a set of entities, real or abstract, comprising a whole where each component interacts with or is related to at least one other component and they all serve a common objective.**

  **Any object which has no relation with any other element of the system is not part of that system but rather of the system environment. A subsystem then is a set of elements, which is a system itself, and a part of the whole system.**

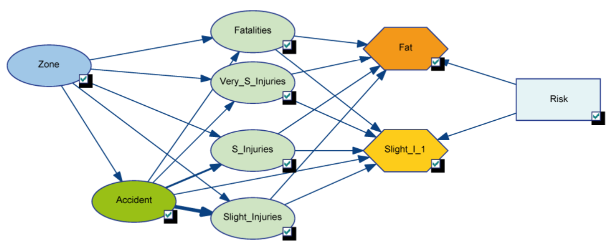


# Basic common definitions of systems

- **Complex systems:**

  **"There are many definitions of complexity, therefore many natural, artificial and abstract objects or networks can be considered to be complex systems, and their study (complexity science) is highly interdisciplinary.**

  **Examples of complex systems include ant-hills, ants themselves, human economies, climate, nervous systems, cells and living things, including human beings, as well as modern energy or telecommunication infrastructures."**



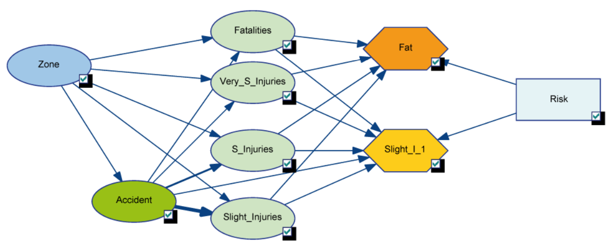
# Common characteristics of systems

- **The research into the behavior of systems has gained increased interest over the last decades**

**The general perspective being that it is not always possible to describe the behavior of the real "world" in terms of a "reductionistic" perspective**

**"More is different!"**

**Systems exhibit what is referred to as: "Emergence"**



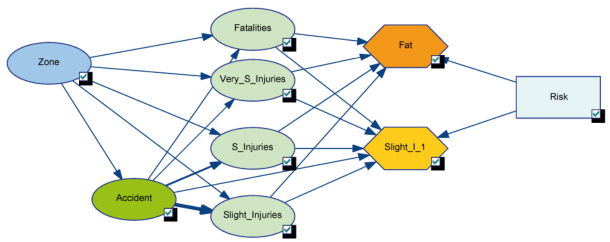
# Common characteristics of systems

- **Emergence**

  **Emergence refers to the way complex systems and patterns arise out of a multiplicity of relatively simple interactions**

  **Weak emergence describes new properties arising in systems as a result of the interactions at an elemental level**

  **Strong emergence refers to properties not directly traceable to the system's components, but rather to how those components interact; the whole is greater than the sum of its parts**

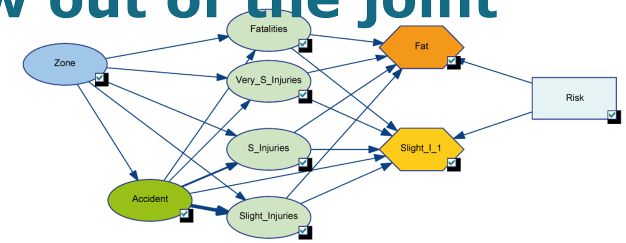


# Common characteristics of systems

- **Systems are often defined in terms of components which are interrelated logically (causally) and which jointly exhibit attributes beyond the attributes of the components**

- **In physics such a constellation is only understood to be a system if the constellation does not loose joint the attributes subject to a minor change in the constellation Robustness is required for a system to be considered a system**

- **Emergence – is a word often utilized to describe system characteristics/attributes which grow out of the joint behavior of components**



# Common characteristics of systems

- **Characteristics often associated to systems include**

**Robust**

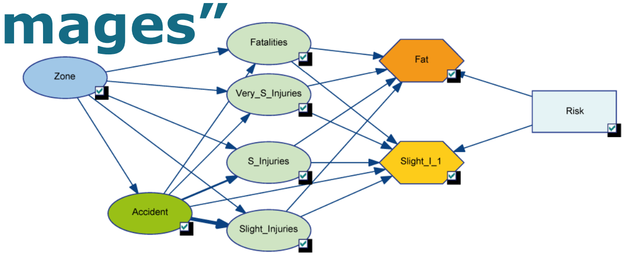
- response of a system does not change significantly subject to a change of the system components

**Adaptive**

- the system is able to maintain its attributes by adapting to new boundary conditions

**Resilient**

- the system is able to recuperate into its original condition/performance after "damages"



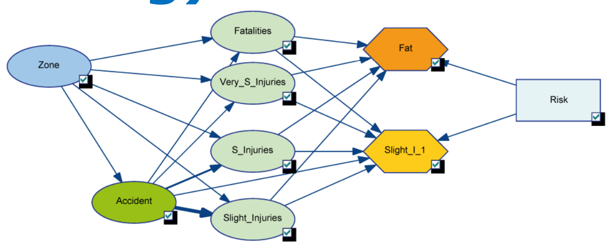
# Focus of the present course

- **Here we will look into the modeling and analysis of natural and man made systems**

  **in particular we will address systems subject to uncertainties and/or lack of knowledge**

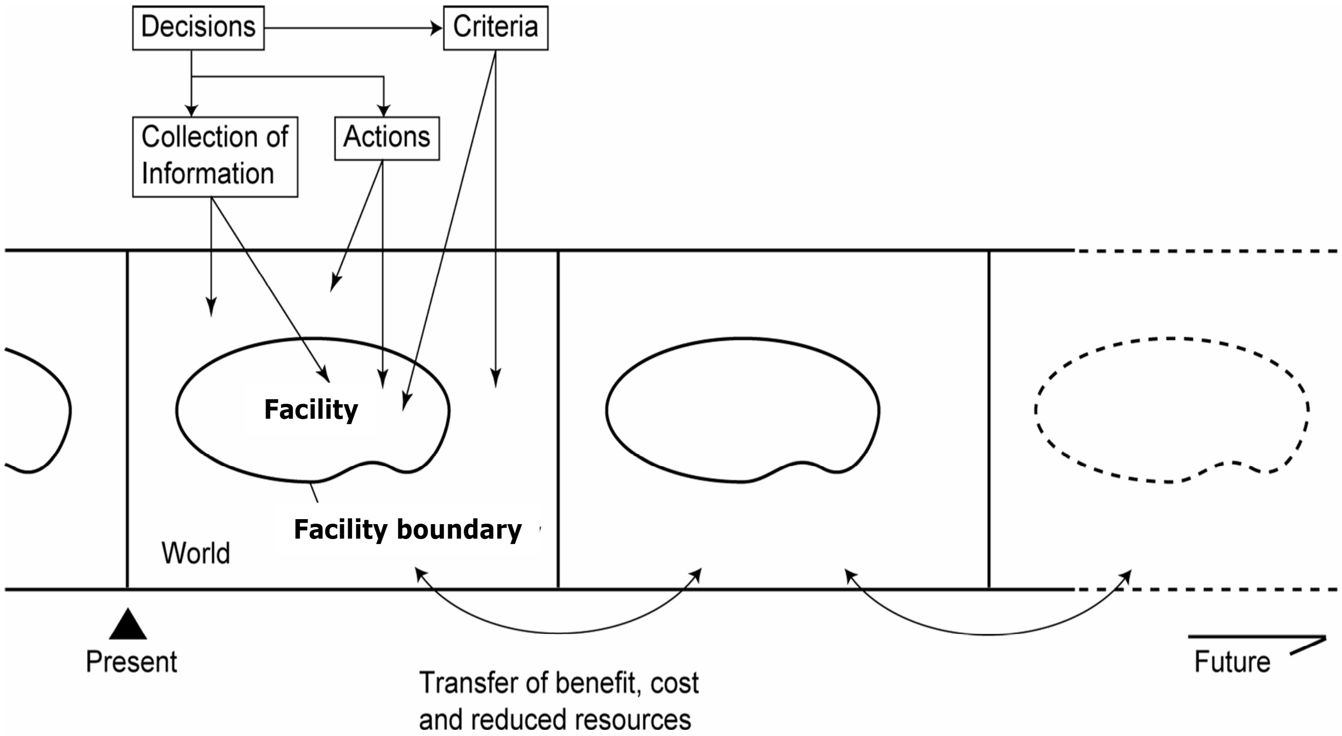
- **An appropriate framework to represent and analyze such systems is the Bayesian statistics**

- **Bayesian Probabilistic Nets will be employed for the modeling and analysis**
  **- Top down approaches (data mining)**
  **- Bottom up approaches (physical modeling)**
  **- Combinations**

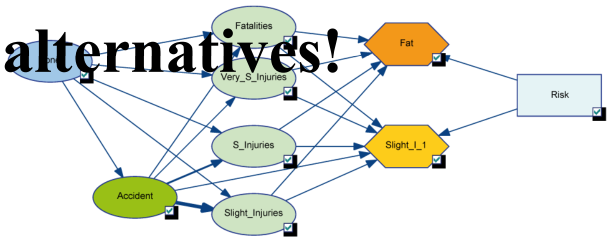


# A Systems Model in Engineering Decision Making

- **System representation in risk assessment**

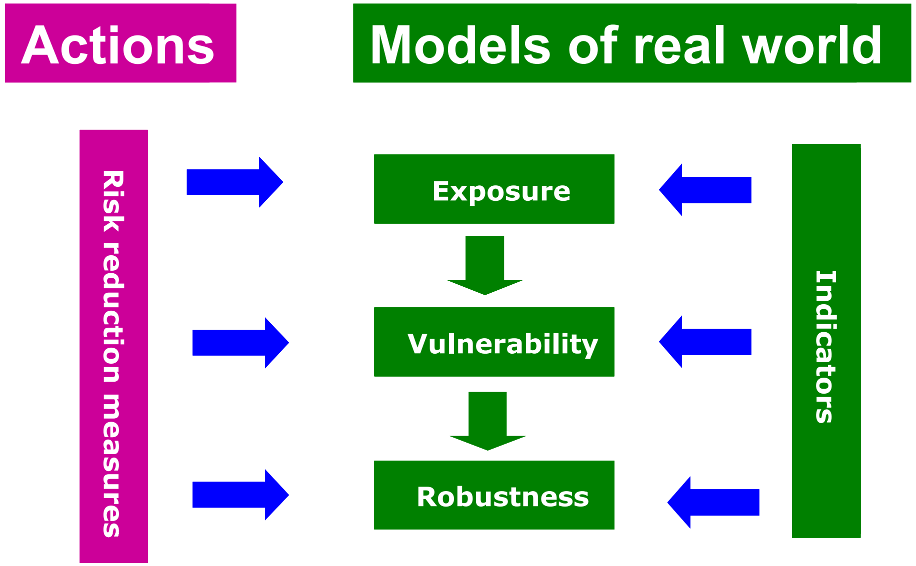


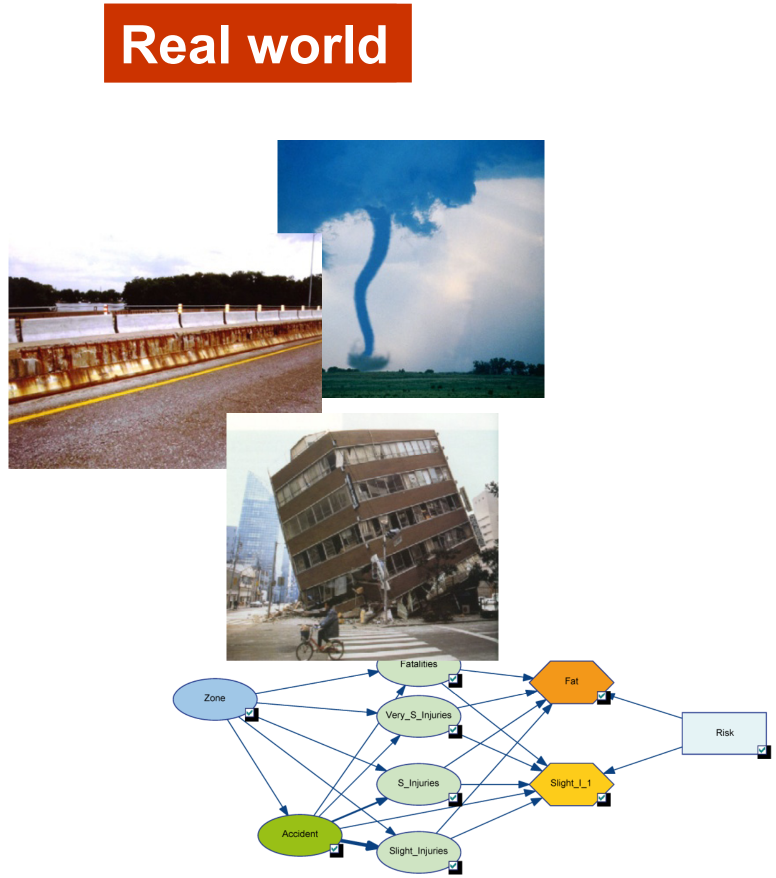

**Detailing to facilitate ranking of decision alternatives!**



# A Systems Model in Engineering Decision Making

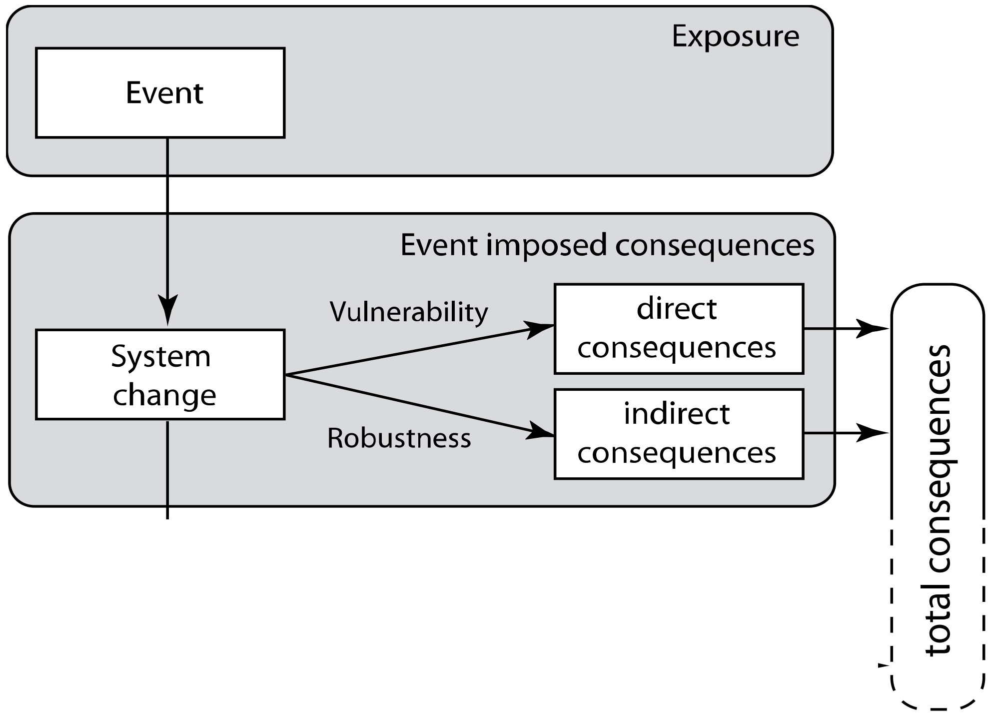
- System representation

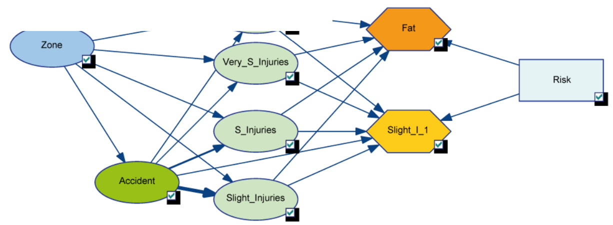


# A Systems Model in Engineering Decision Making

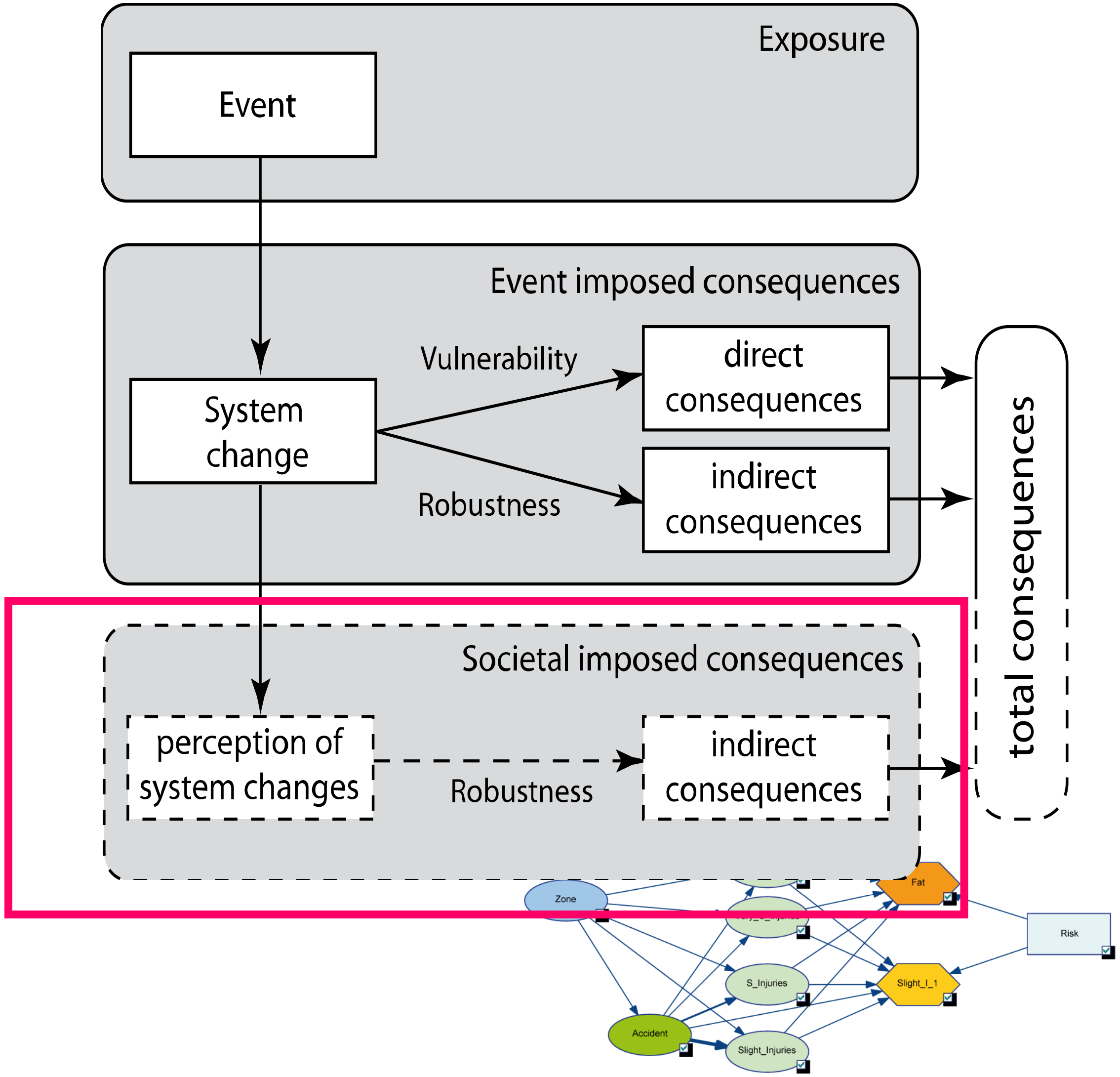
- **System representation – evolution of consequences**



# A Systems Model in Engineering Decision Making

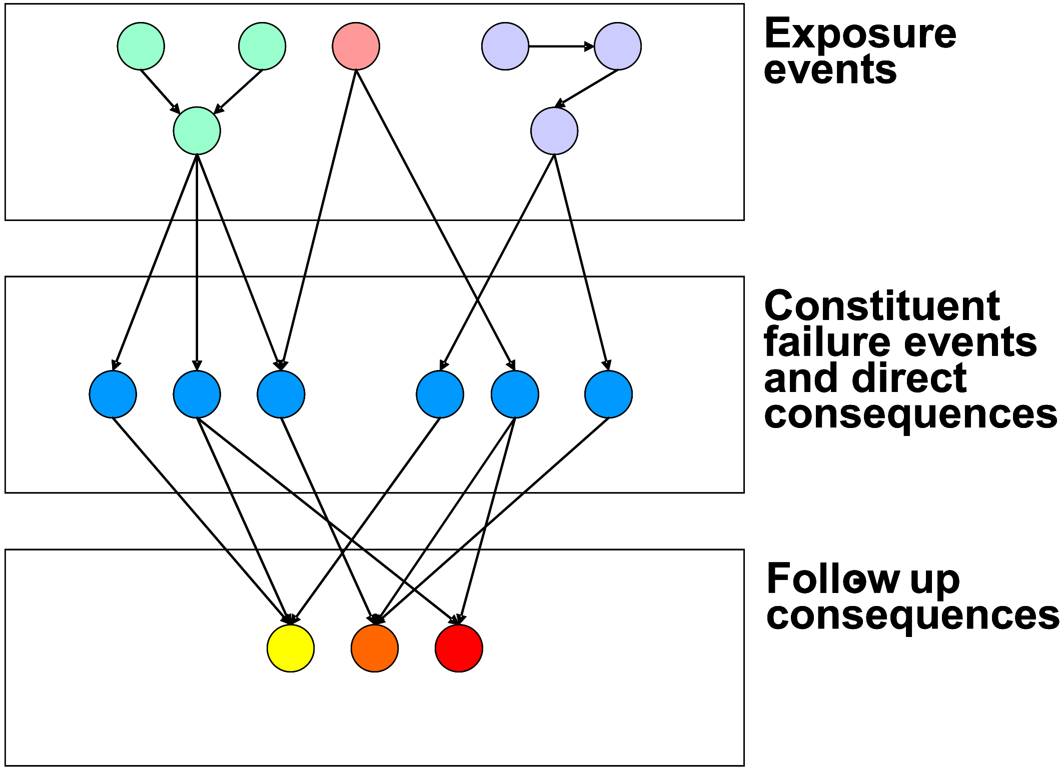
- **Risk perception**



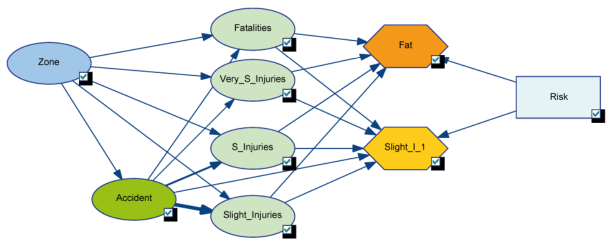

**Due to perception of possible events**

# A Systems Model in Engineering Decision Making

- System representation – scenarios of events

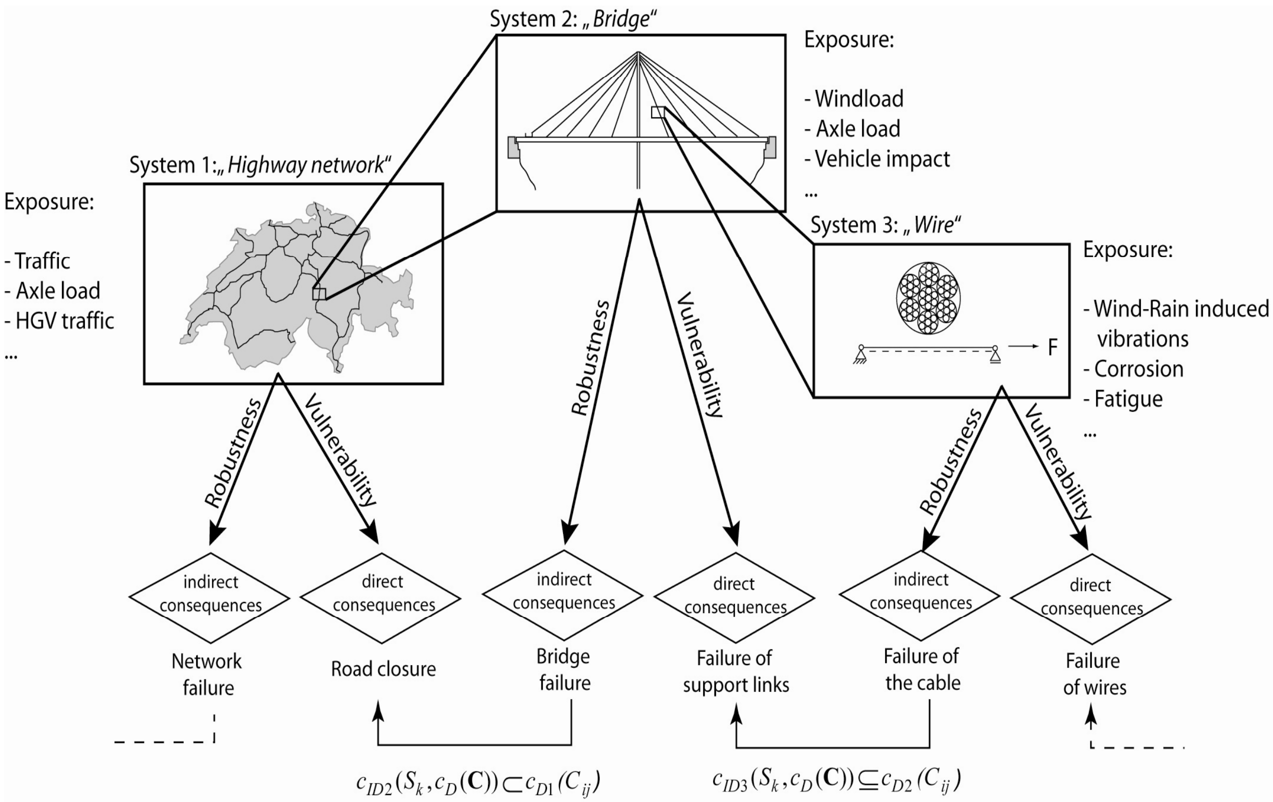


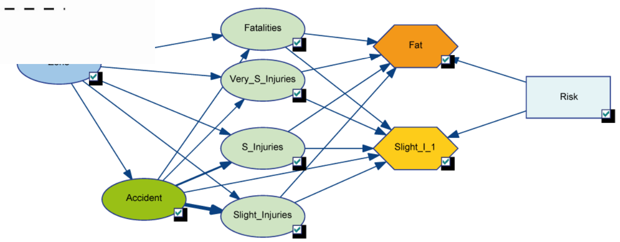

**System representation must be refined enough to enable a comparison of the risks or benefits of different decision alternatives**



# A Systems Model in Engineering Decision Making

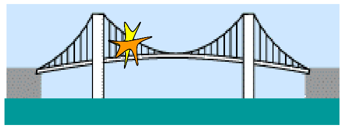
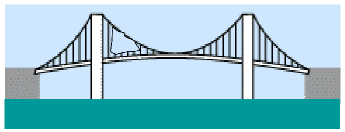
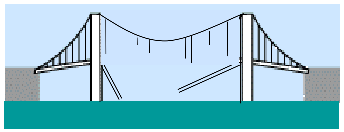
- ## System representation – multiple scales



# A Systems Model in Engineering Decision Making

## • Indicators of risks

| Scenario representation | Physical characteristics | Indicators | Potential consequences |
|---|---|---|---|
| **Exposure**<br> | Flood<br>Ship impact<br>Explosion/Fire<br>Earthquake<br>Vehicle impact<br>Wind loads<br>Traffic loads<br>Deicing salt<br>Water<br>Carbon dioxide | Use/functionality<br>Location<br>Environment<br>Design life<br>Societal importance | |
| **Vulnerability**<br> | Yielding<br>Rupture<br>Cracking<br>Fatigue<br>Wear<br>Spalling<br>Erosion<br>Corrosion | Design codes<br>Design target reliability<br>Age<br>Materials<br>Quality of workmanship<br>Condition<br>Protective measures | **Direct consequences**<br>Repair costs<br>Temporary loss or reduced functionality<br>Small number of injuries/fatalities<br>Minor socio-economic losses<br>Minor damages to environment |
| **Robustness**<br> | Loss of functionality<br>partial collapse<br>full collapse | Ductility<br>Joint characteristics<br>Redundancy<br>Segmentation<br>Condition control/monitoring<br>Emergency preparedness | **Indirect consequences**<br>Repair costs<br>Temporary loss or reduced functionality<br>Mid to large number of injuries/fatalities<br>Moderate to major socio-economic losses<br>Moderate to major damages to environment |