Risk and Safety

in

Engineering

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Contents of Today's Lecture

- **Introduction to Bayesian Probabilistic Nets (BPN)**
- **Causality as a support in reasoning**
- **Basic theory of BPN with discrete states**
- **Risk analysis and decision making using BPN**
- **Large scale risk management using Geographic Information Systems (GIS) and BPN**

Introduction to Bayesian Probabilistic Nets (BPN)

As stated many times previously

Risk analysis supports decision making subject to uncertainty

Difficult problem
many variables
large uncertainties

Bayesian Probabilistic Nets (or Networks) (BPN) or Bayesian Belief Networks (BBN)

Rule Based Systems

What would the "expert" do when and if ?

- were developed during the last decade for purposes of decision making in artificial intelligence engineering

Not possible to treat uncertainties consistently !

Bad decisions – "Dutch Books"

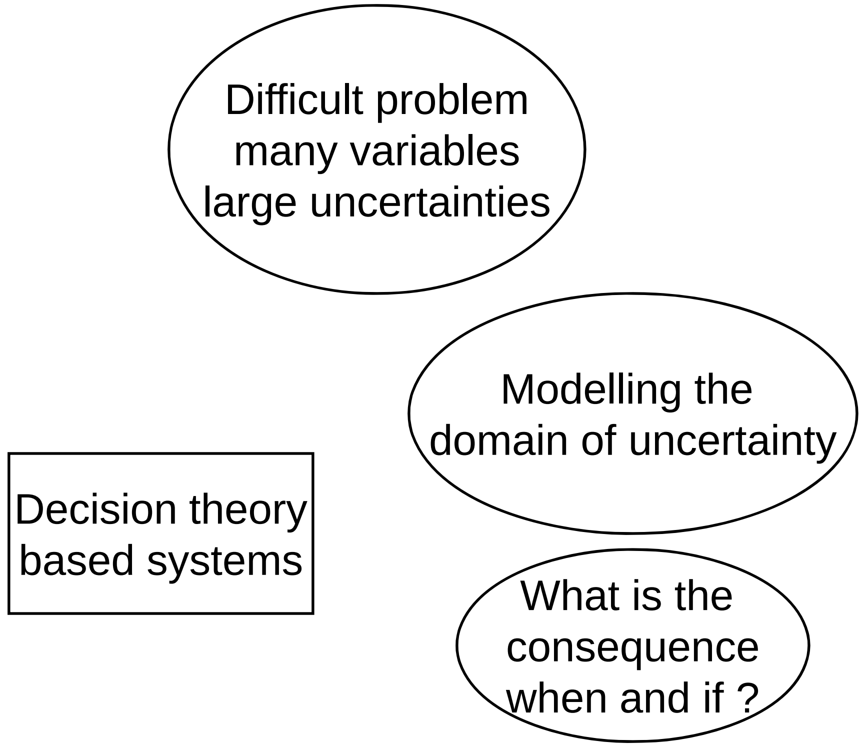
Introduction to Bayesian Probabilistic Nets (BPN)

As stated many times previously

Risk analysis supports decision making subject to uncertainty

Bayesian Probabilistic Nets (or Networks) (BPN) or Bayesian Belief Networks (BBN)

- were developed during the last decade for purposes of decision making in artificial intelligence engineering



Possible to treat uncertainties consistently !

- Supporting the expert in decision making !
- Not replacing the expert !

Introduction to Bayesian Probabilistic Nets (BPN)

The theory of Bayesian Probabilistic Nets has developed rapidly and includes

- **Establishing multi-variate joint probability structures**
- **Diagnostics of technical systems and in medicine**
- **Decision analysis subject to uncertainty**
- **Inference and data mining**

Probabilistic modelling of complex systems

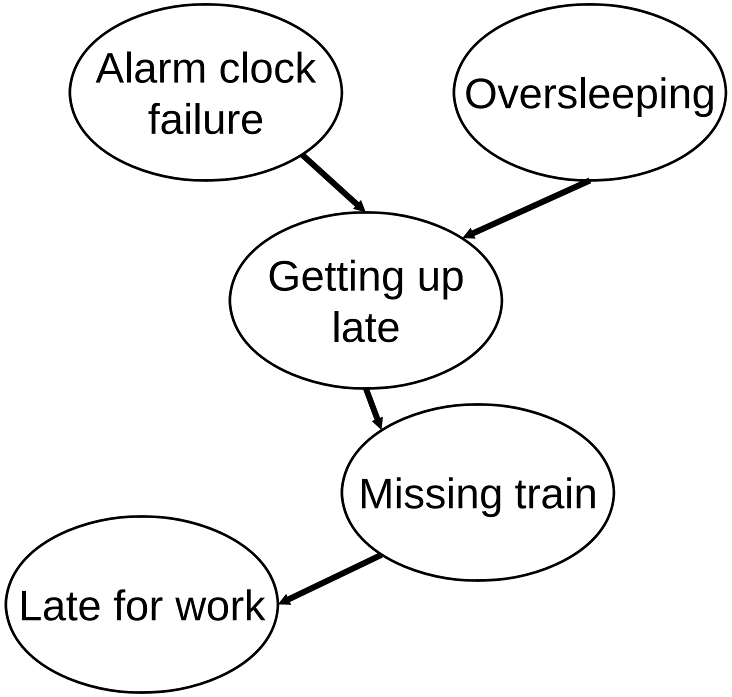
Identification of important hazard scenarios

Assessment of risk and evaluation of risk treatment measures

Identification of causal relations between states in complex systems based on data

Causality as a support in reasoning

Causality and Reasoning



Causal networks are graphical representations of causally interrelated events

Causality as a support in reasoning

Causality and Reasoning

In our daily lives we reason on the basis of causal relations

Consider the following situation:

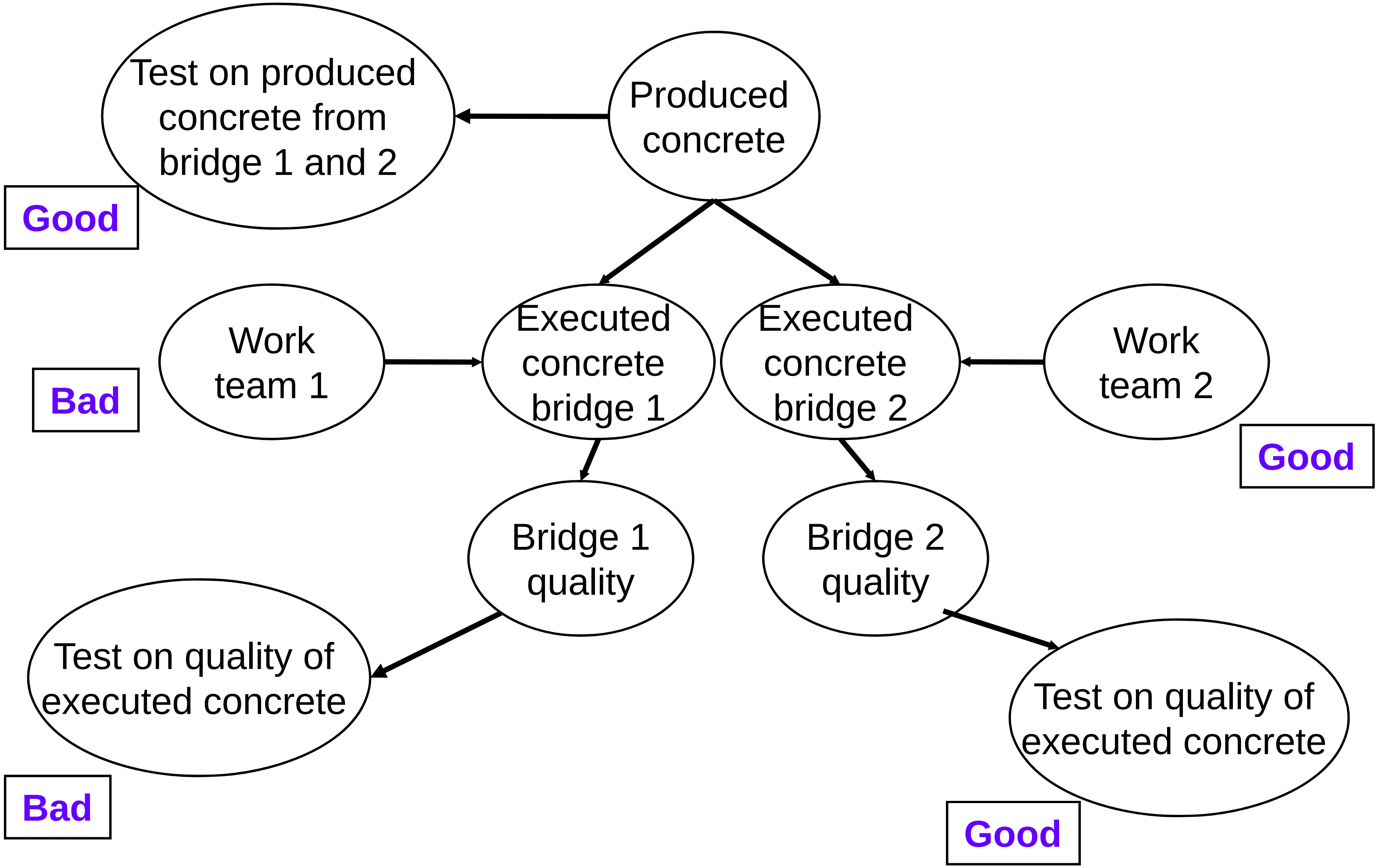
You are the owner of two new and almost identical bridges 1 and 2 made of concrete produced on site (small factory)

- Tests performed on bridge 1 indicates that the quality of the executed concrete used in bridge 1 is bad

The question is :

– What is the quality of the executed concrete of bridge 2?

Causality as a support in reasoning



Causality as a support in reasoning

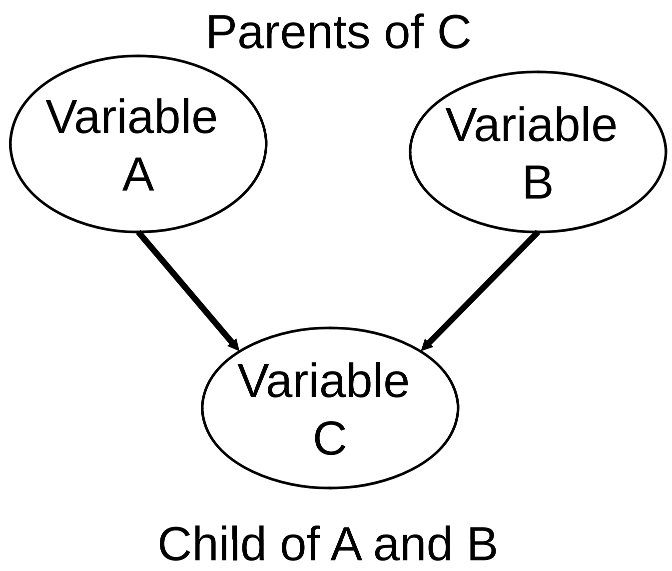
Causal Networks and BPNs

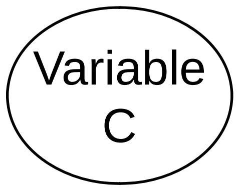
Formally speaking :

- a directed graph representing the causal interrelation between uncertain events

- interrelations expressed in terms of “family relations”

- a variable can have any number of discrete states or a continuous state space





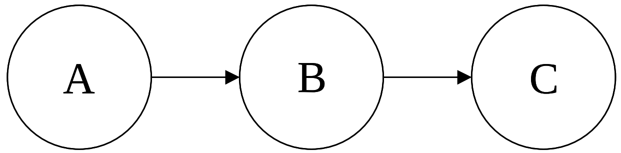
States
stress (MPa)
10-20
20-30
30-40
40-50

Basic theory of BPN with discrete states

Networks can be categorized in accordance with their configuration

For serially connected networks :

Information may be passed only if the states of the connecting variables are unknown



Serially connected network

B depends on A, C depends on B

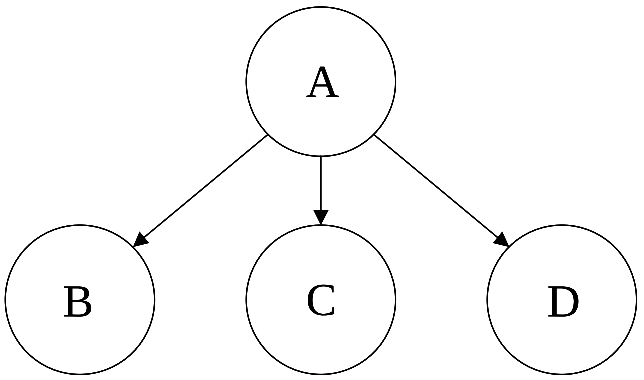
If the state of B is known with certainty variable A and variable B become independent

A and C are *d-connected* given B

Basic theory of BPN with discrete states

For diverging networks :

Information about any of the child variables will influence the uncertainty of the states of the other children as long as the state of the variable A is unknown



Diverging network

B, C and D depend on A

B, C and D are *d-connected* given A

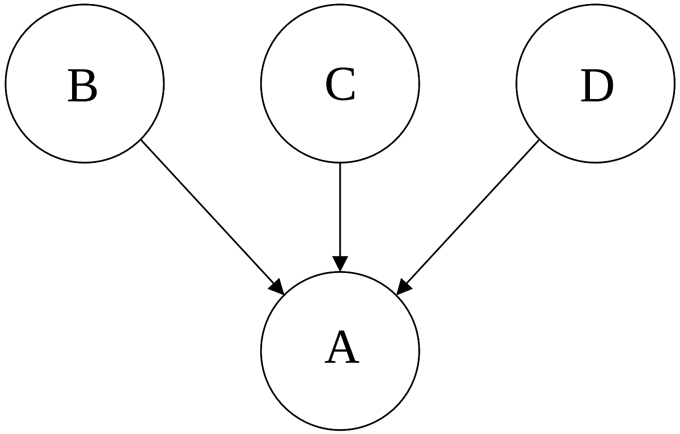
Basic theory of BPN with discrete states

For converging networks :

The parent variables remain independent as long as the state of the child variable is unknown

Given the state of the child variable or any of the parent variables, all the parent variables become dependent

This is called conditional dependence



Converging network

A depends on B, C and D

B, C and D are independent as long as the state of A is unknown

Given the state of A the variables B, C and D become dependent

Basic theory of BPN with discrete states

- **Formally a BPN is composed of:**

  - A set of variables and a set of directed *edges* (or connections) between the variables.

  - Each variable may have a countable or uncountable set of mutually exclusive states.

  - The variables together with the directed edges form a directed a-cyclic graph (DAG)

  - To each variable *A* with parents *B*, *C*, *D*, .. there is assigned a conditional probability structure $P(A|B,C,D,..)$

Basic theory of BPN with discrete states

Assume that all *n* variables A_i, $i = 1,2,..n$ of a BPN are collected in the vector $A = (A_1, A_2, \ldots A_n)^T$ - also called the *universe U*.

In general it is of interest to be able to assess:

$P(\mathbf{U}) = P(A_1, A_2, ..A_n)$ **- the joint probability distribution of the universe,**

$P(A_i)$ **- any marginalized set of the universe, and**

any probability distribution subject to *evidence* with regard to the states of individual variables, e.g. $P(A_i | e)$ **.**

Basic theory of BPN with discrete states

A BPN can be considered to be a special representation of such probability distributions.

Using the chain rule of probability calculus it is possible to write the probability distribution function in the following form:

$$P(\mathbf{U}) = \prod_i P(A_i \mid pa(A_i))$$

where $pa(A_i)$ is the parent set of the variable A_i .

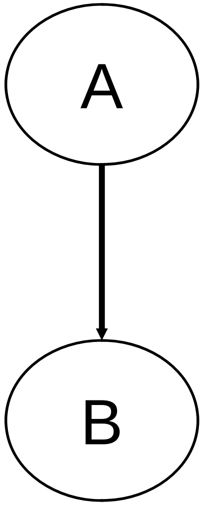
The probability distribution function for elements of $\mathbf{U}$, e.g. for A_j

can be achieved by *marginalization* i.e. $P(A_j) = \sum_{\mathbf{U} \setminus A_j} P(\mathbf{U}) = \sum_{\mathbf{U} \setminus A_j} \prod_i P(A_i \mid pa(A_i))$

Basic theory of BPN with discrete states

BPNs are sometimes referred to as **directed acyclic graphs (DAG).**

The states of each variable is allocated a conditional probability structure.



State	Probability
Wind speed	
0-10 (m/s)	0.6
10-20 (m/s)	0.4

State	Probability	
Wind force	**Wind speed (m/s)**	
	0-10	**10-20**
50-60 (kN)	0.6	0.3
60-70 (kN)	0.4	0.7

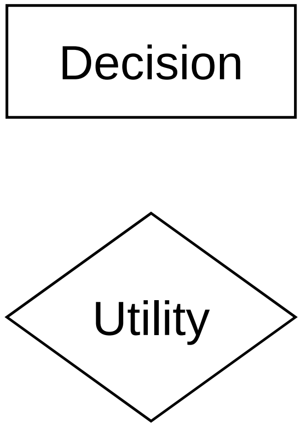
Bayesian Probabilistic Nets

BPNs may in addition to uncertain variables include

- decision nodes
- utility nodes

Decision nodes contain the various actions which may be decided

Utility nodes prescribe the consequences given the state of the variables and the decisions



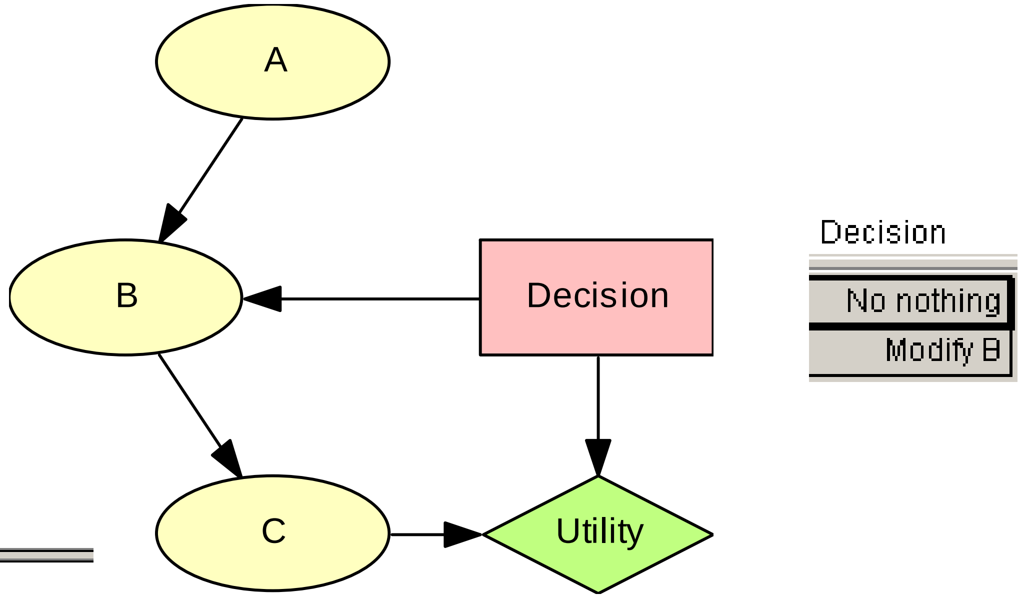
Do nothing
Modify system

Consequences
- costs
- fatalities
- injuries
- environmental impact

Bayesian Probabilistic Nets

The probabilities assigned to the states of a variable may be conditional on the decisions.

The utility may be given as a function of the states of the variables and the decisions.



B | Labelled

Decision	No nothing		Modify B	
A	fail	safe	fail	safe
fail	0.5	0.2	0.3	0.05
safe	0.5	0.8	0.7	0.95

Utility

Decision	No nothing		Modify B	
C	fail	safe	fail	safe
Utility	1000	0	1001	1

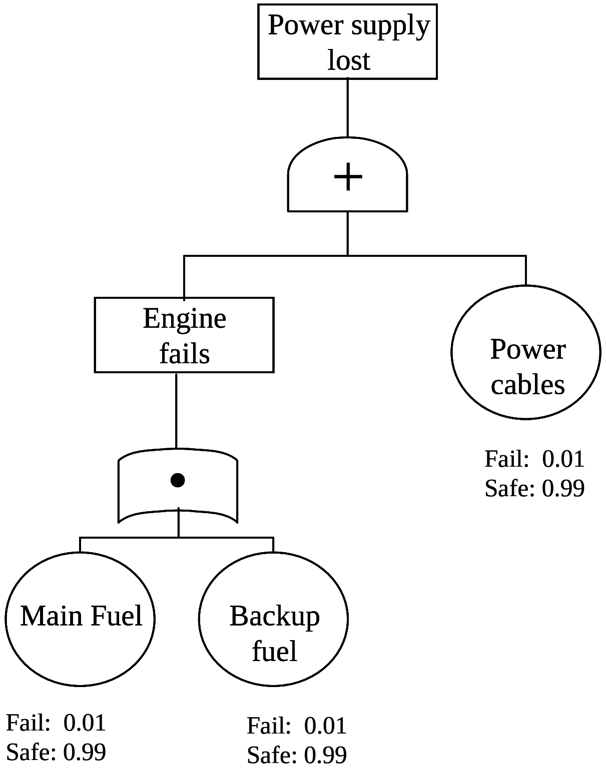
Risk analysis and decision making using BPN

BPNs for Risk Analysis

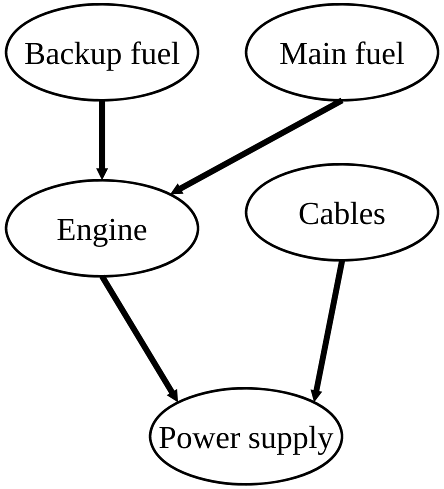
BPNs may readily substitute fault trees, event trees, cause consequence charts and decision trees in risk analysis

No problems with common cause failures when using BPN.

Let us consider the simple power supply example again



Fault tree

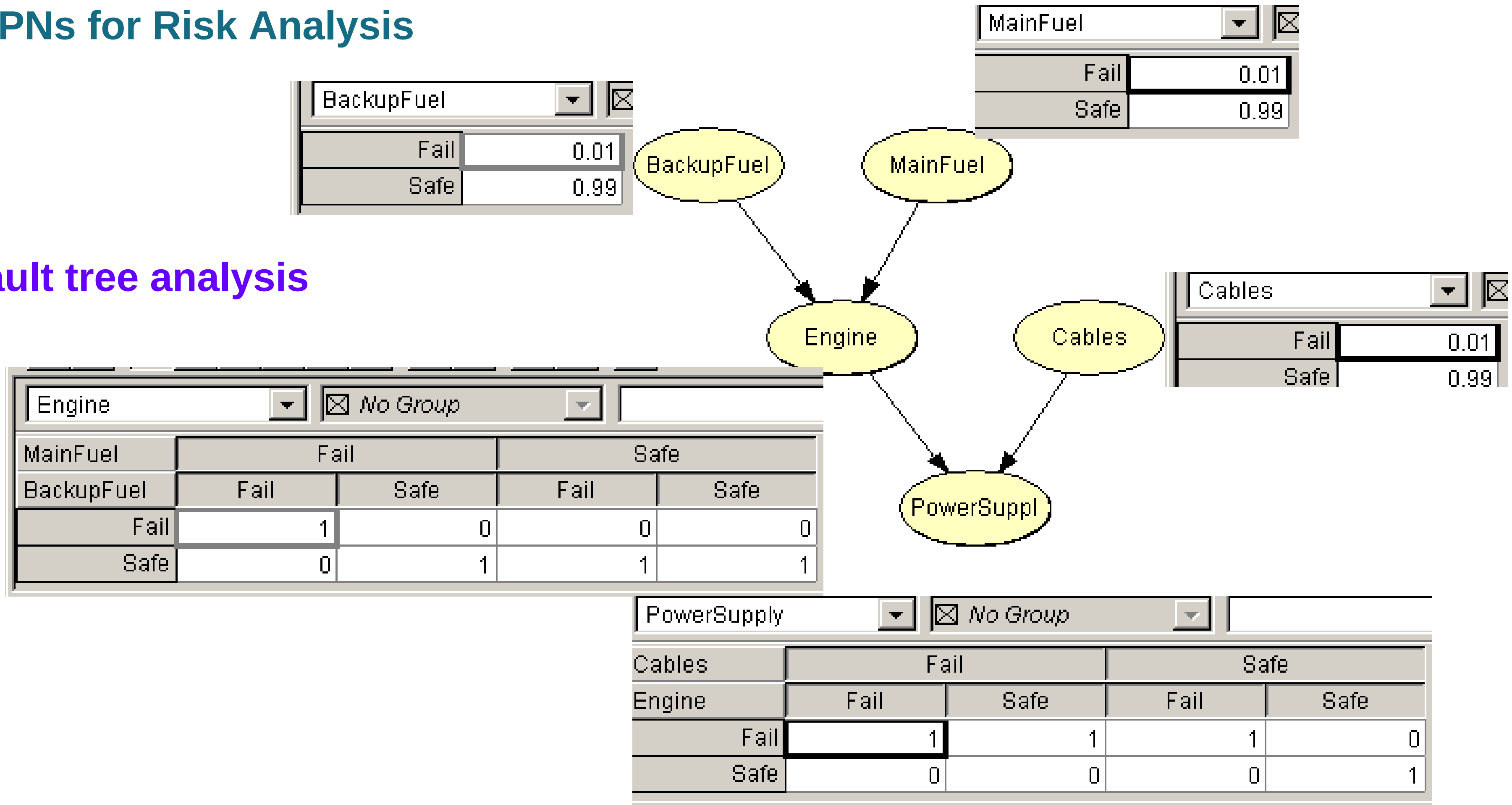


BPN

Risk analysis and decision making using BPN

BPNs for Risk Analysis

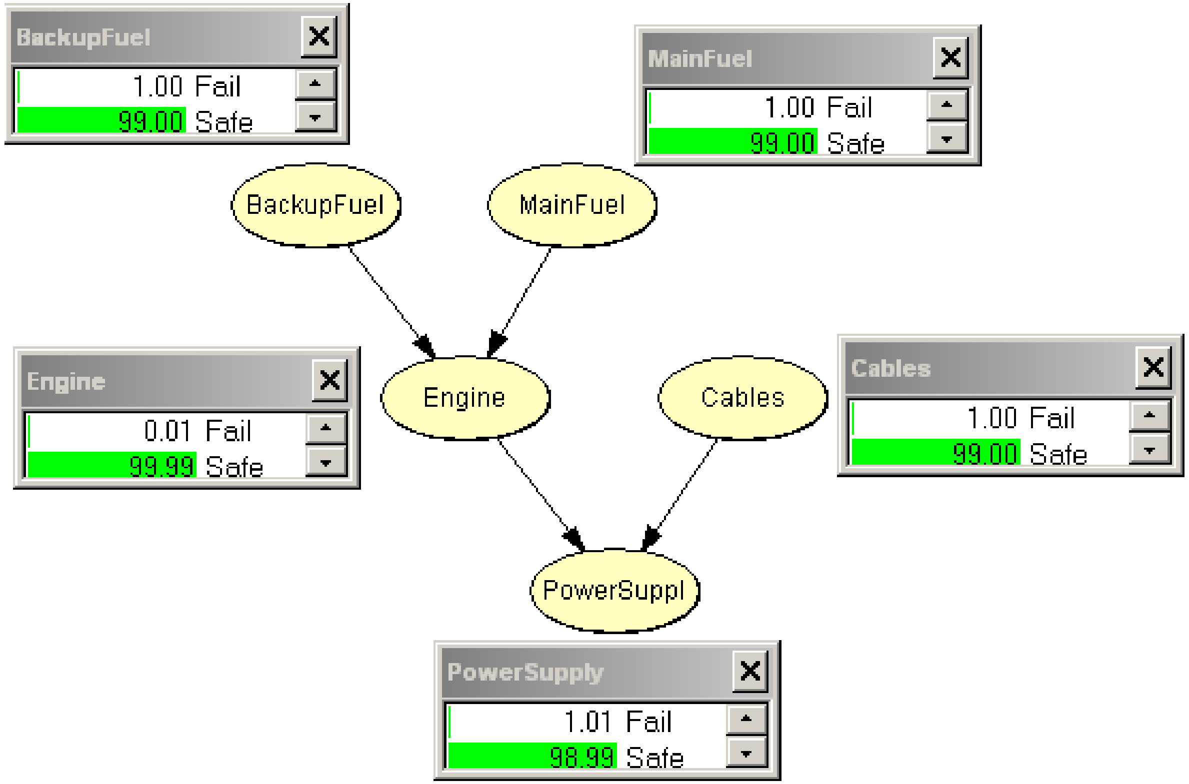
Fault tree analysis



Risk analysis and decision making using BPN

BPNs for Risk Analysis

Fault tree analysis

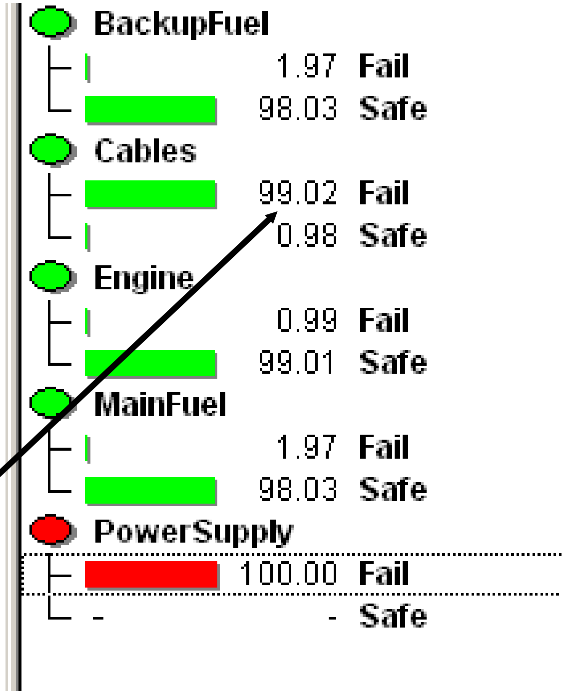


Risk analysis and decision making using BPN

BPNs for Risk Analysis

Identification of important hazard scenarios

Conditioning on the event of failure of power supply



Most likely scenario is cable failure
- this scenario should be detailed further in the modelling

Risk analysis and decision making using BPN

BPNs for Risk Analysis

Common cause failures

BackupFuel ☒

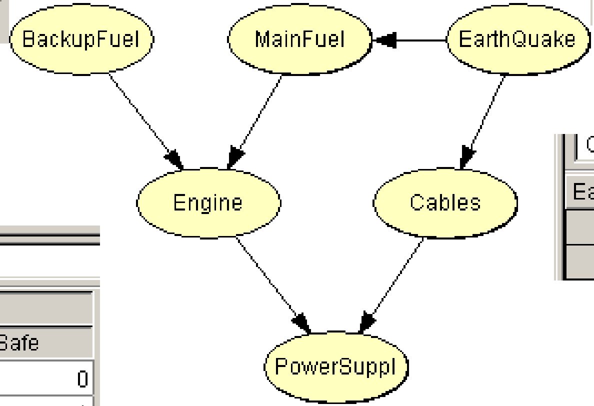
Fail	0.01
Safe	0.99

MainFuel ☒ No Group

EarthQuake	yes	No
Fail	0.1	0.01
Safe	0.9	0.99

EarthQuake ☒

yes	0.0001
No	0.9999



Cables ☒ No Group

EarthQuake	yes	No
Fail	0.1	0.01
Safe	0.9	0.99

Engine ☒ No Group

MainFuel	Fail		Safe	
BackupFuel	Fail	Safe	Fail	Safe
Fail	1	0	0	0
Safe	0	1	1	1

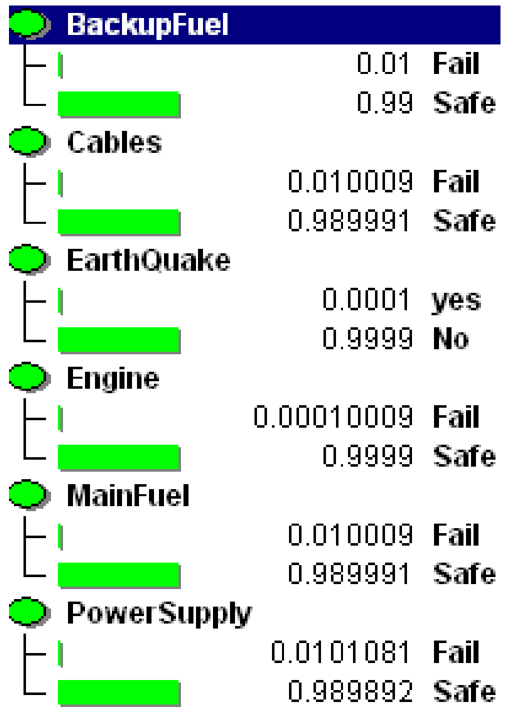
PowerSupply ☒ No Group

Cables	Fail		Safe	
Engine	Fail	Safe	Fail	Safe
Fail	1	1	1	0
Safe	0	0	0	1

Risk analysis and decision making using BPN

BPNs for Risk Analysis

Common cause failures

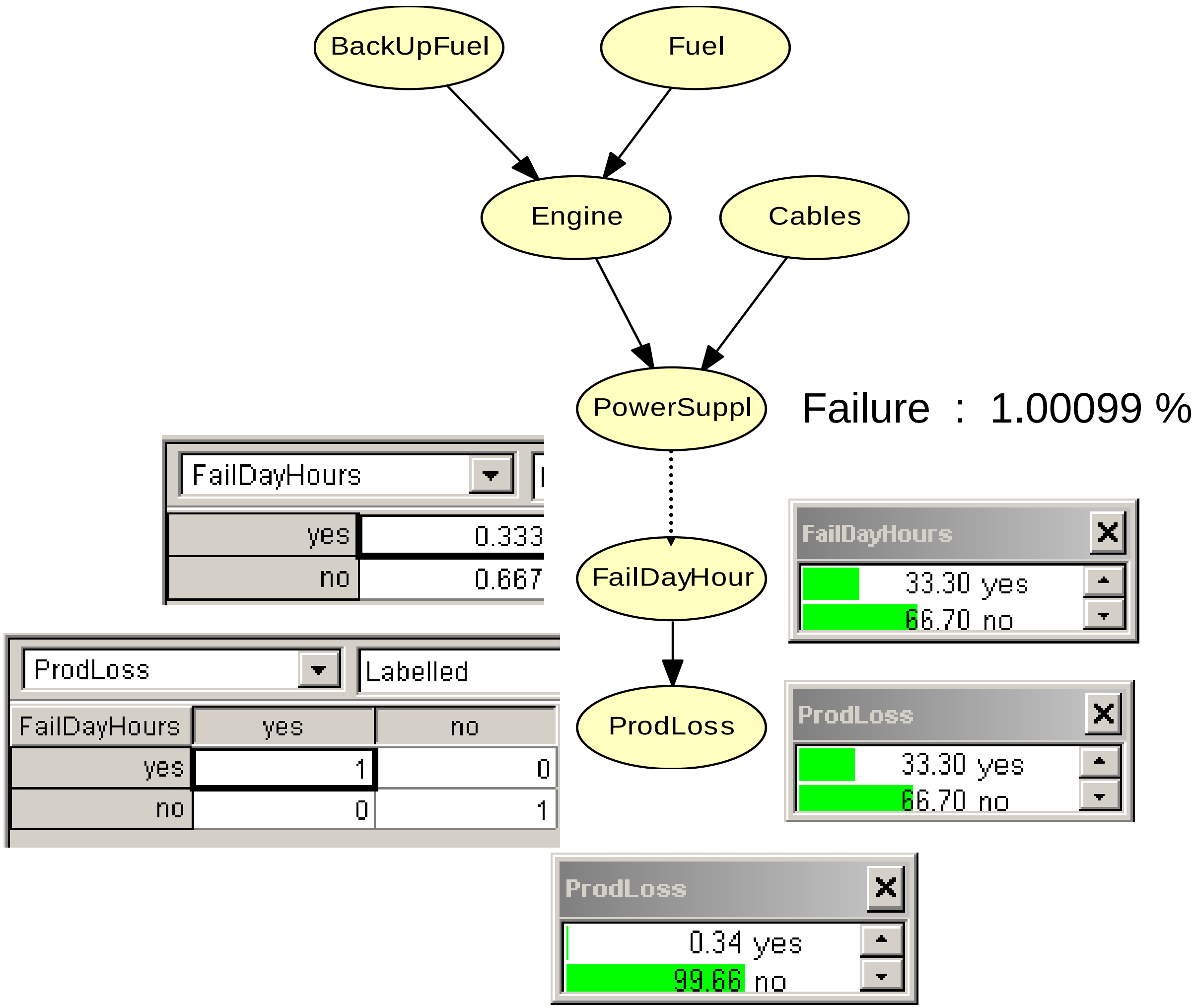


With common cause	1.01081 %
Without common cause	1.00099 %

Risk analysis and decision making using BPN

BPNs for Risk Analysis

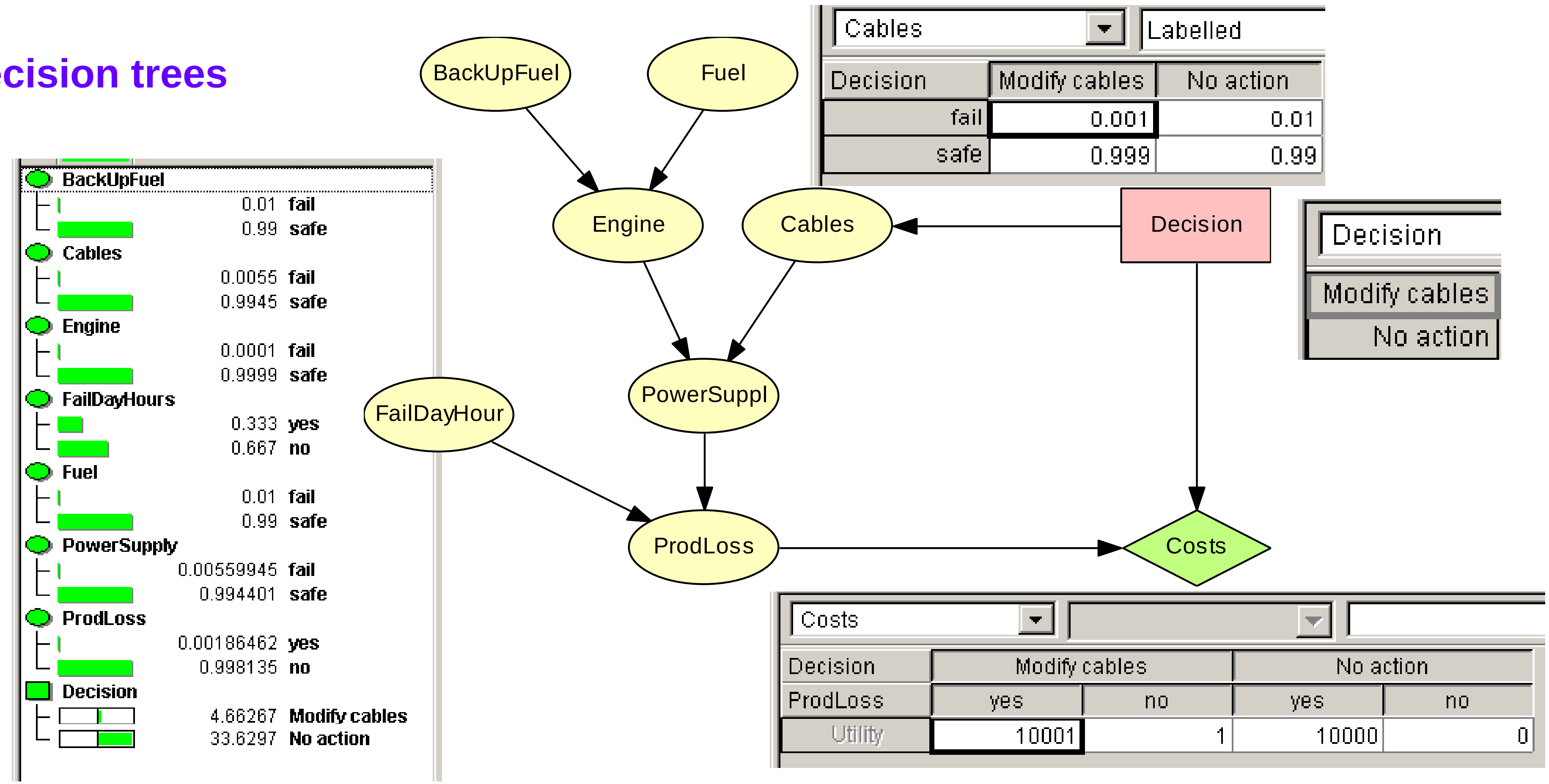
Event trees



Risk analysis and decision making using BPN

BPNs for Risk Analysis

Decision trees

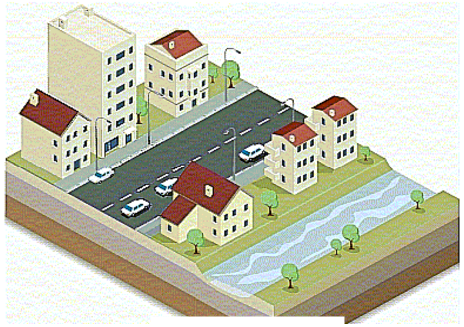


Large Scale Risk Assessment using GIS and BPN

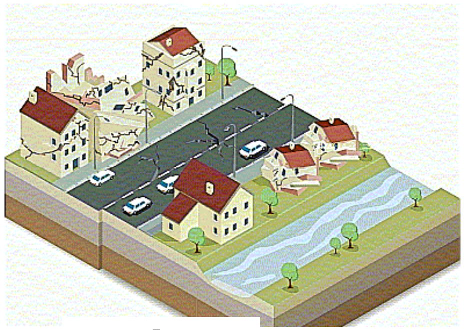
- **Risk management concerning natural hazards often involves large geographical areas**

Large Scale Risk Assessment using GIS and BPN

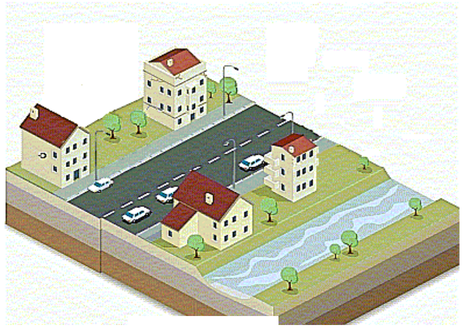
- **It is important to be able to provide decision support in the situations before, during and after the occurrence of natural hazards**



Before



During



After

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

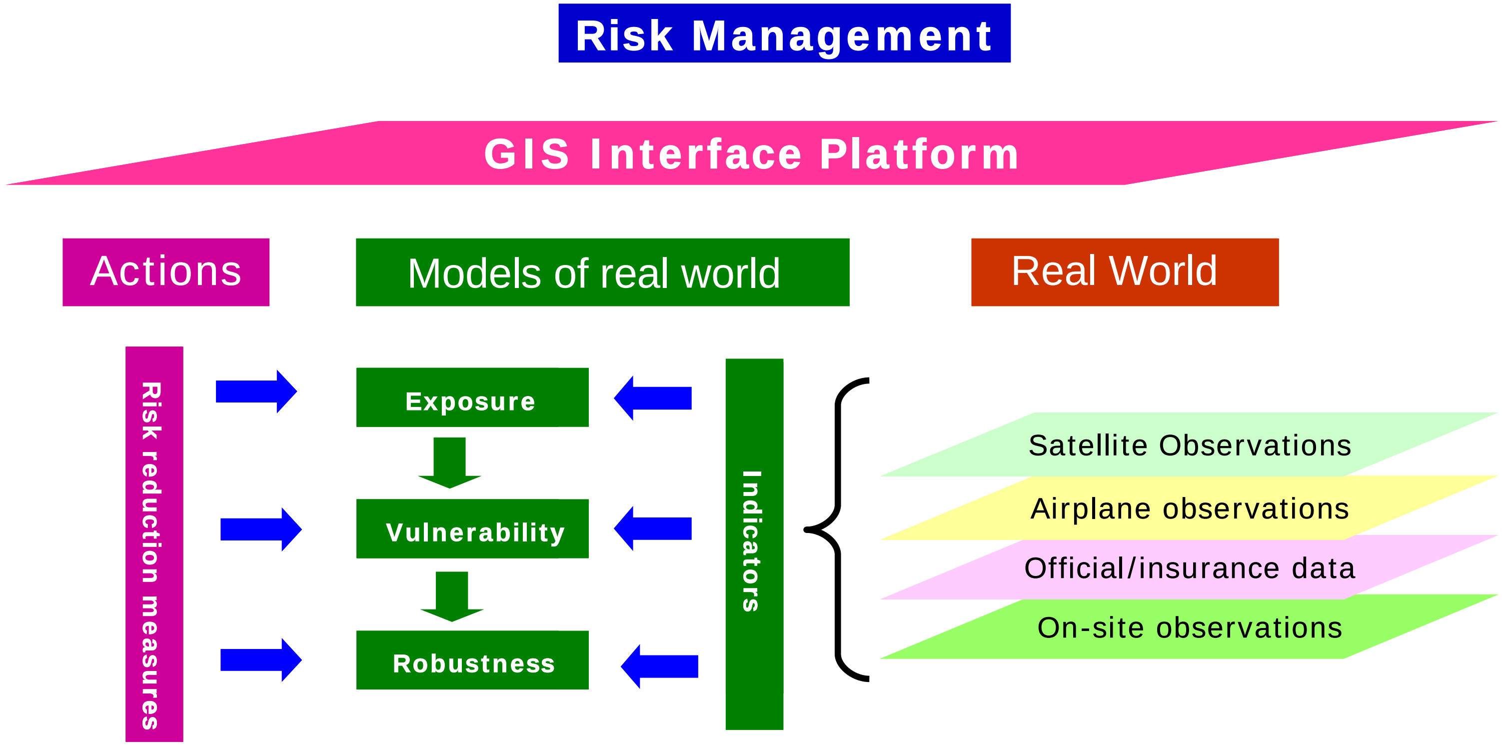
Rehabilitation of infrastructure functionality

Condition assessment and updating of reliability and risks

Optimal allocation of ressources for rebuliding and strengthening

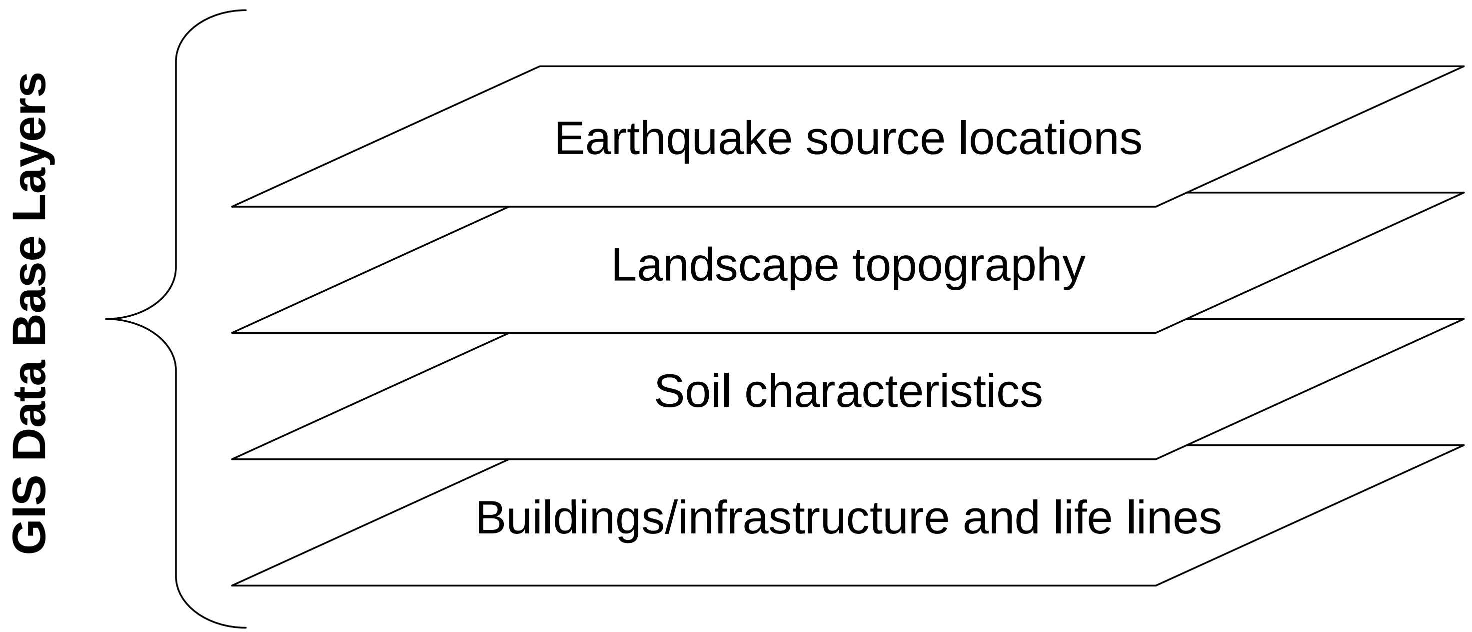
Large Scale Risk Assessment using GIS and BPN

- **A general framework for natural hazards risk management using GIS can be visualized as:**



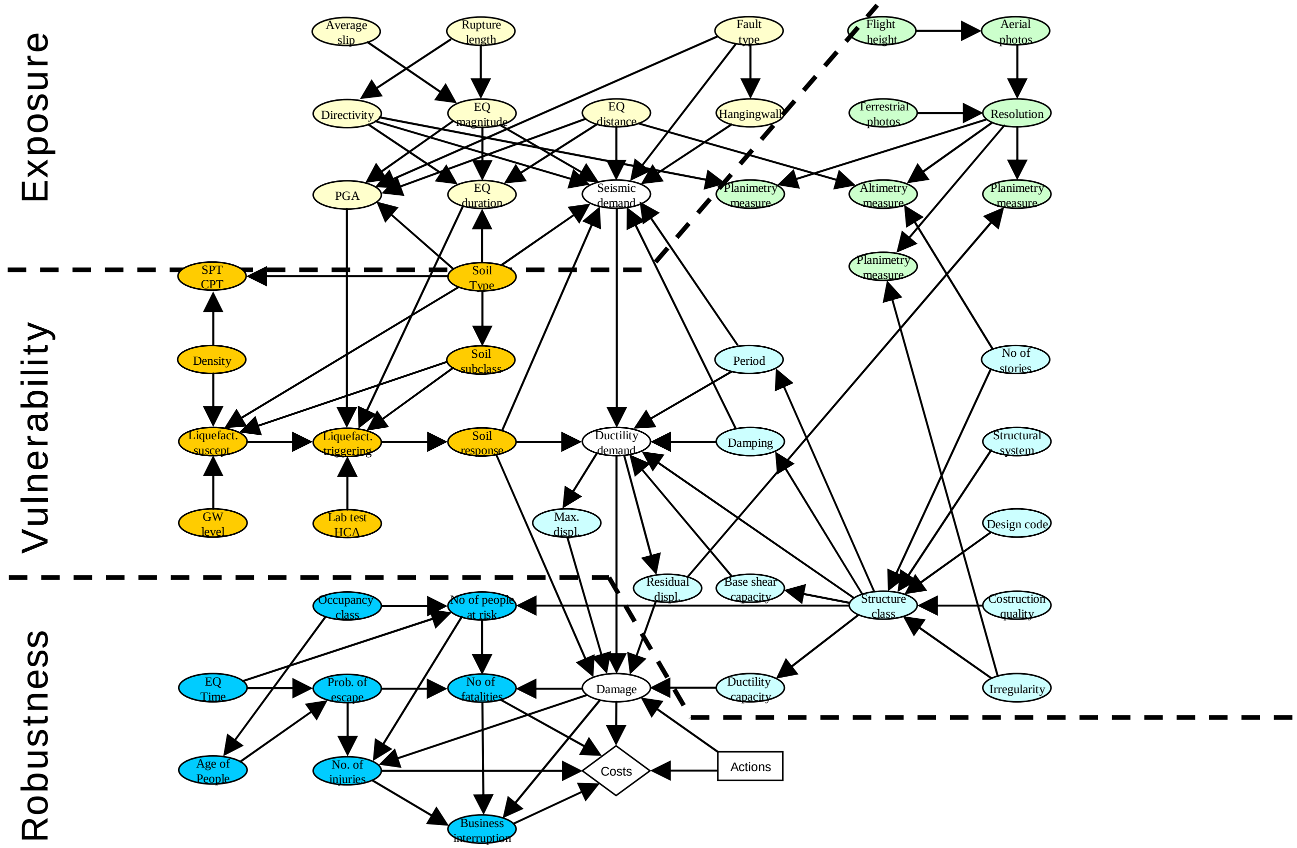
Large Scale Risk Assessment using GIS and BPN

- **The GIS database is important as most of the required data generally are spatially distributed for the considered system, e.g. city or region**



Large Scale Risk Assessment using GIS and BPN

- Utilizing that indicators of exposures (hazards) and consequences (vulnerability and robustness) can efficiently be stored and managed in the GIS data base, BPN risk models may be established and linked to each asset in the considered system



Large Scale Risk Assessment using GIS and BPN

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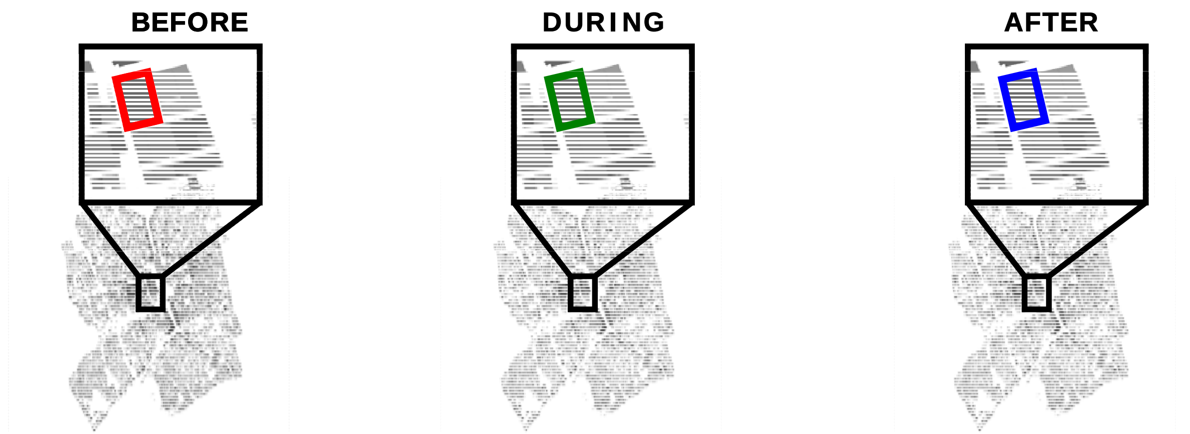
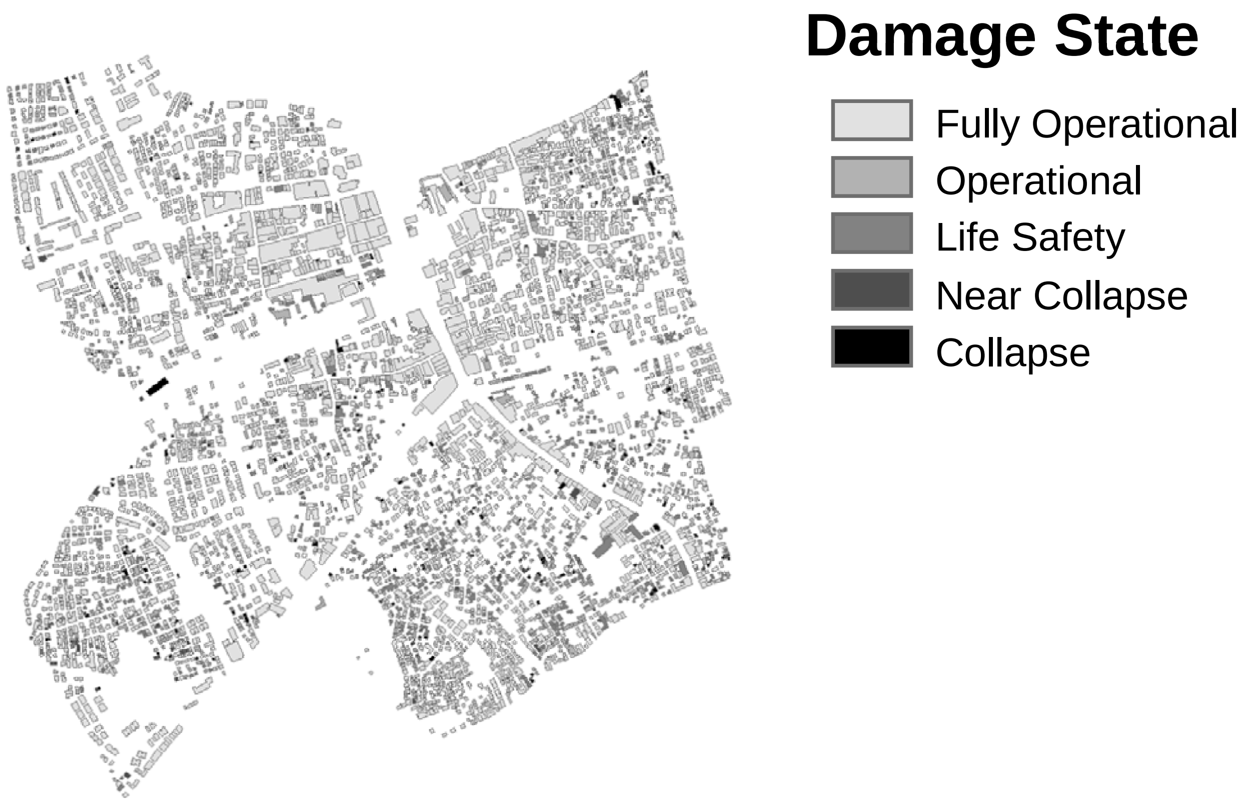
Typical Outputs



BEFORE	DURING	AFTER
Generic BPN + structure and site specific information	Generic BPN + structure and site specific information + new data (e.g. aerial photogrammetrical measurements	Generic BPN + structure and site specific information + new data + updating models

Large Scale Risk Assessment using GIS and BPN

- **The generic BPN risk models linked with the GIS database facilitate the efficient risk assessment for large numbers of buildings and other assets**



Large Scale Risk Assessment using GIS and BPN

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