Uncertainty treatment in earthquake modeling using Bayesian networks

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- Probabilistic seismic hazard analysis (PSHA) using BN
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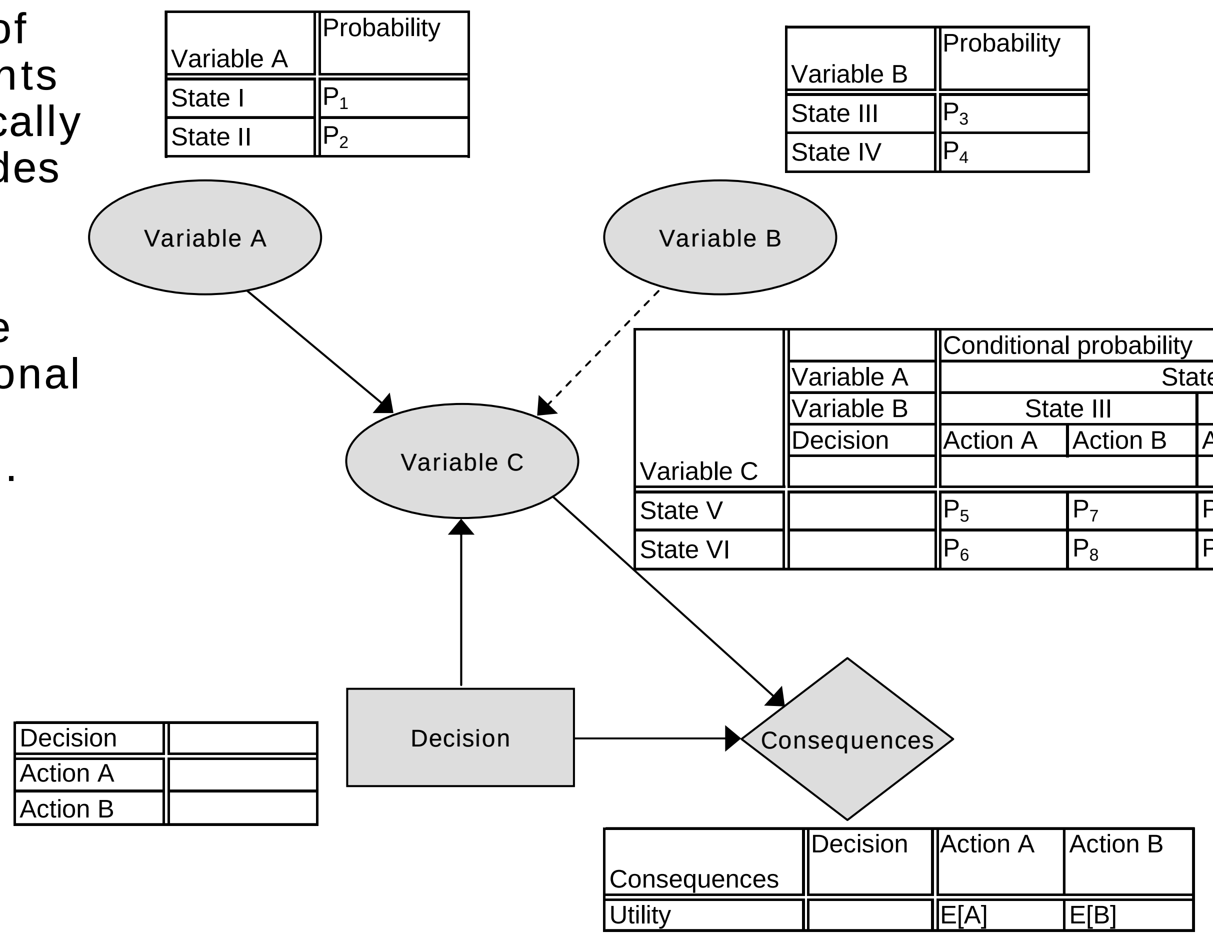
Introduction to Bayesian networks

- Causal interrelations of events leading to events of interest are graphically shown in terms of nodes connected by arrows.
- A probability structure describing the conditional state probabilities for each node is assigned.
- Consequences corresponding to the events in the BPN are assigned.



The Probabilistic seismic hazard analysis (PSHA) approach

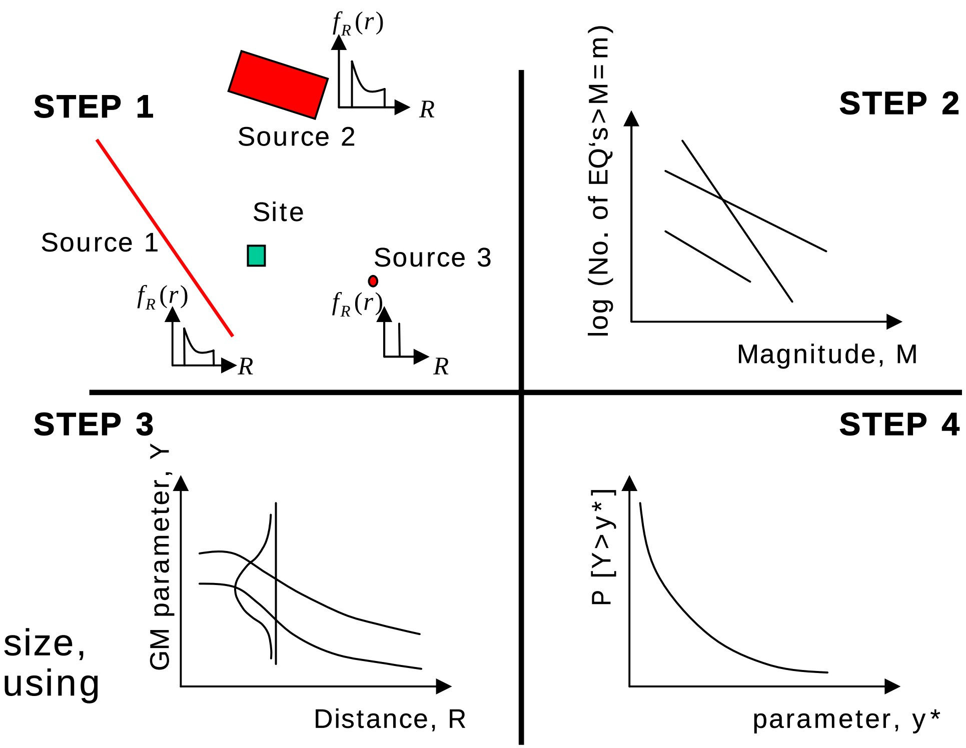
- A relationship between ground motion intensity and mean return period for engineering applications is needed.

- STEP 1
  Identify earthquake sources

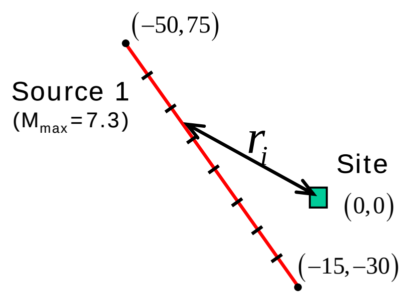
- STEP 2
  Characterize temporal distribution of earthquakes

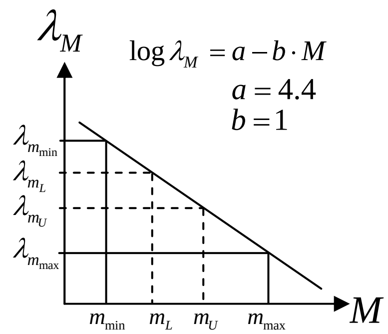
- STEP 3
  Predict ground motion intensity

- STEP 4
  Combine uncertainties in earthquake size, location and ground motion intensity using the total probability theorem

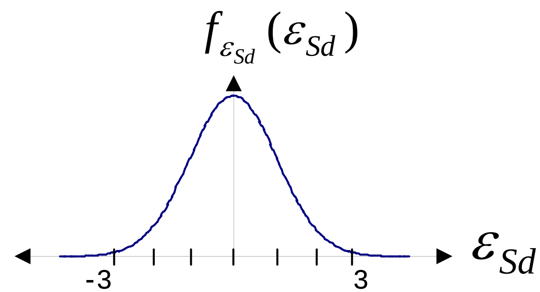


A BN for Probabilistic seismic hazard analysis

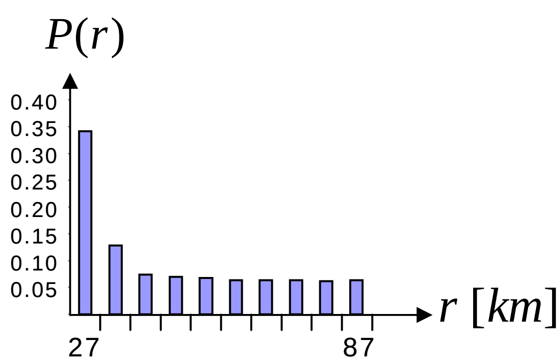




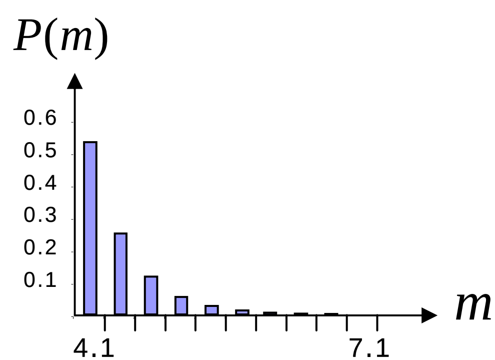
$$P\left(m_L < M < m_U \mid m_{\min} < M < m_{\max}\right) = \frac{\lambda_{m_L} - \lambda_{m_U}}{\lambda_{m_{\min}} - \lambda_{m_{\max}}}$$



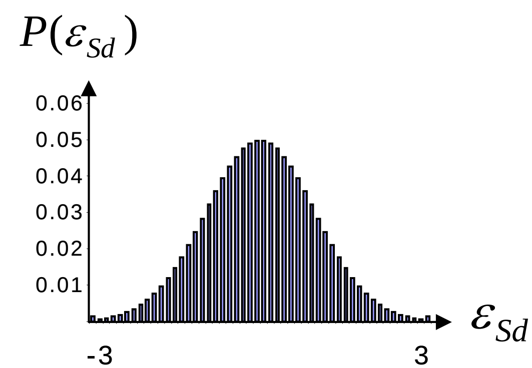
Discretisation from -3 to +3 into 50 states



Δ=6.7 km



Δ=0.33



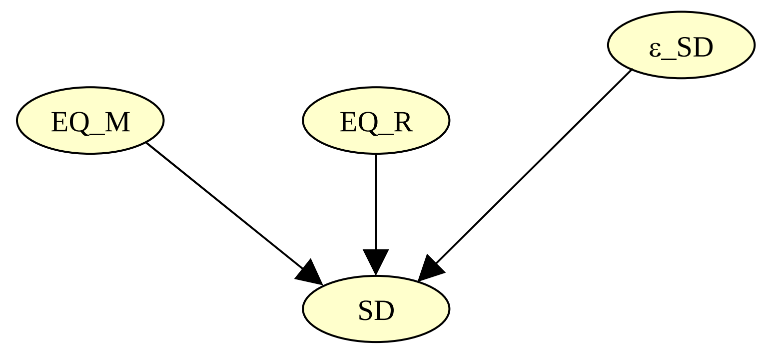
Δ=0.125

A BN for Probabilistic seismic hazard analysis

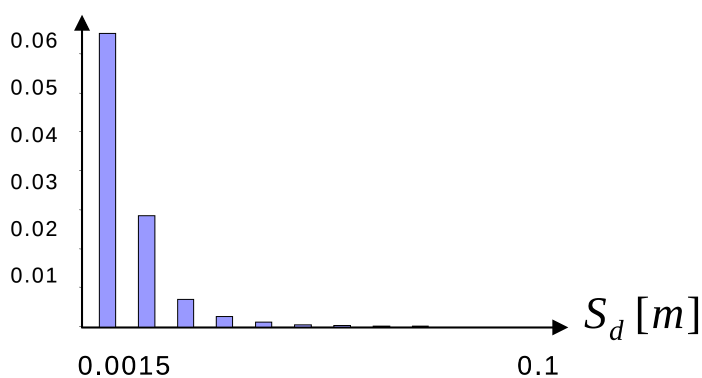
- For all combinations of (M, R, ε_{SD}) using the attenuation relation by Boore et al. (1997) the spectral displacements (SD) at a given period are calculated.

- The SD node is discretized into 16 bins.

- The conditional probability table of SD contains 1 and 0 values, depending on whether the calculated SD value falls into the bin or not.

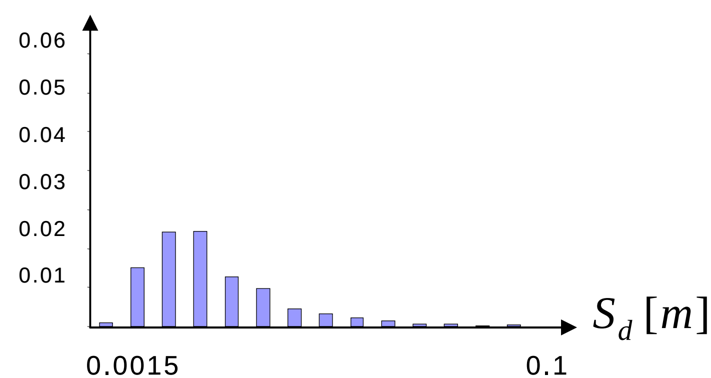


$P(S_d)$



$\Delta = 0.015$

$P(S_d \mid M = 5.8, R = 40\,km)$



$\Delta = 0.015$

Disaggregation of seismic hazard

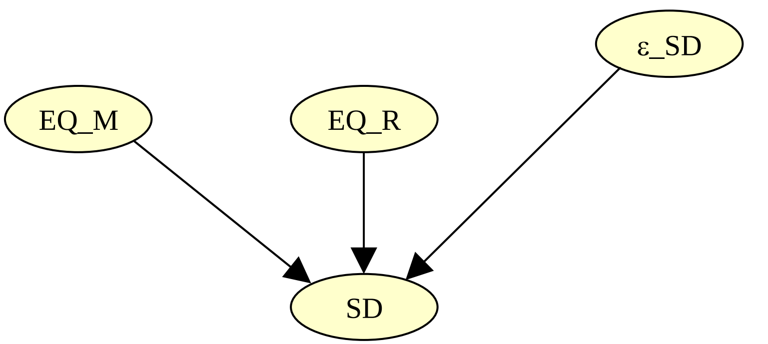
- Given that ground motion intensity level x is equalled, what type of event caused it?

$$P(M=m, R=r \mid x_1 \leq S_d \leq x_2) = \frac{P(x_1 \leq S_d \leq x_2 \mid m, r)\, f_{M,R}(m,r)}{\int\int P(IM > x \mid m, r)\, f_{M,R}(m,r)\, dm\, dr}$$

$$P(A \mid B) = \frac{P(A,B)}{P(B)}$$

Disaggregation of seismic hazard

- The probability tables are calculated using MATLAB and the Bayesian networks are assessed using the comercial software package HUGIN.
- Using the BN the marginal distribution of any variable or the conditional distribution of any variable given a specific state of any varibale can easily be calculated
- Disggregation can be calculated by instantiation of the states of the node 'SD'



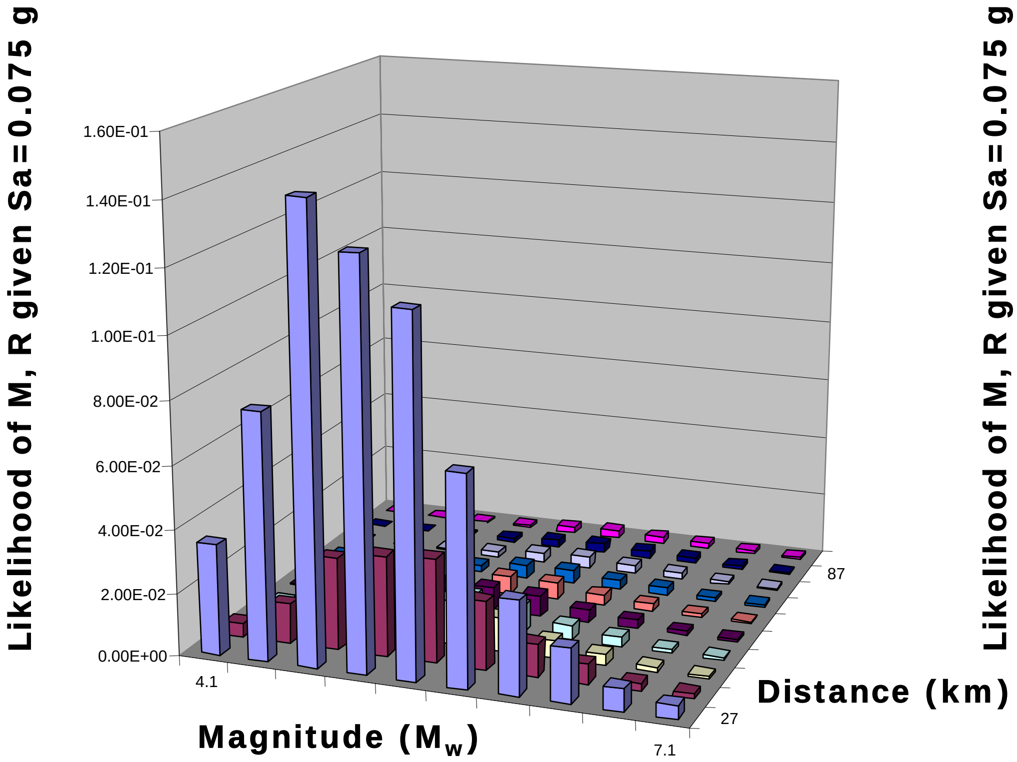
Disaggregation of seismic hazard

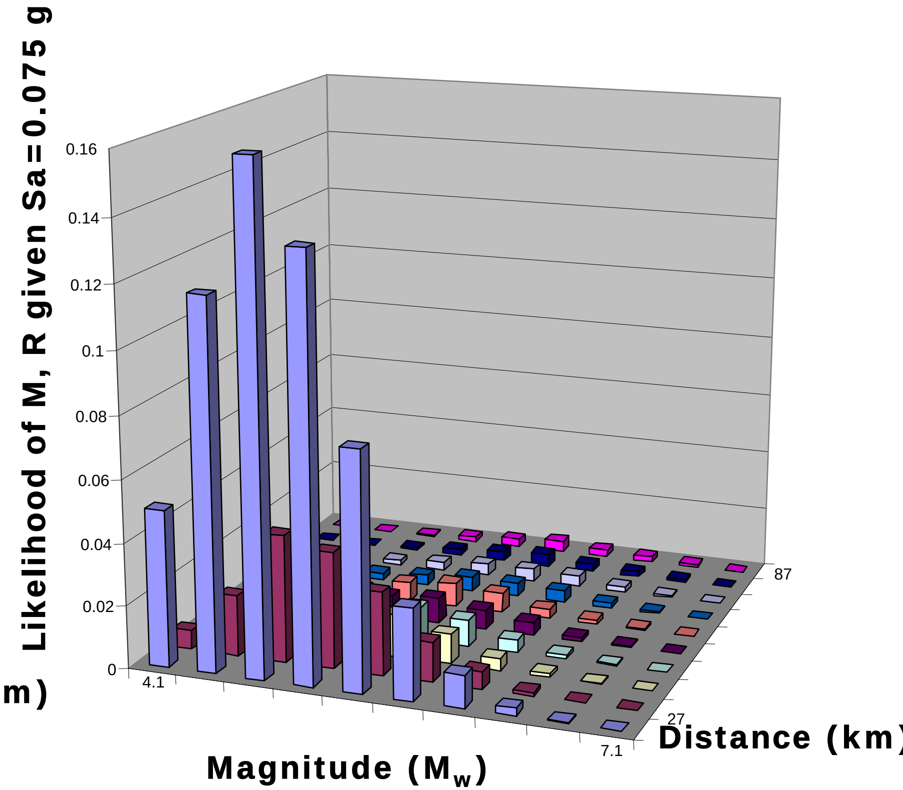
Traditional PSHA

Calculated with HAZ31 by Abrahamson

Bayesian network

Calculated with HUGIN using MATLAB as client.





Correlation of ground motion intensity parameters

- Structural and geotechnical responses may require different ground motion intenisty parameters. E.g. spectral acceleration for structural damage and peak ground acceleration for liquefaction failure.
- For reliability assessments considering simultaneously both types of failures, the probabilistic characterization of the joint occurrence of these parameters are needed.
- The needed correlation coefficient model is obtained using a set of 517 recorded ground motions.

Correlation of PGA and SA

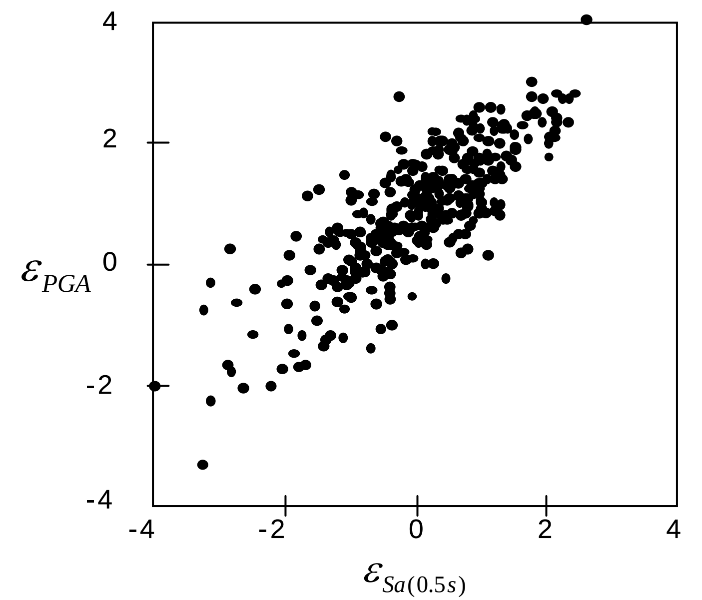
- Using the attenuation model of Boore et al. (1997) a normalized residual for each of the ground motion is computed.

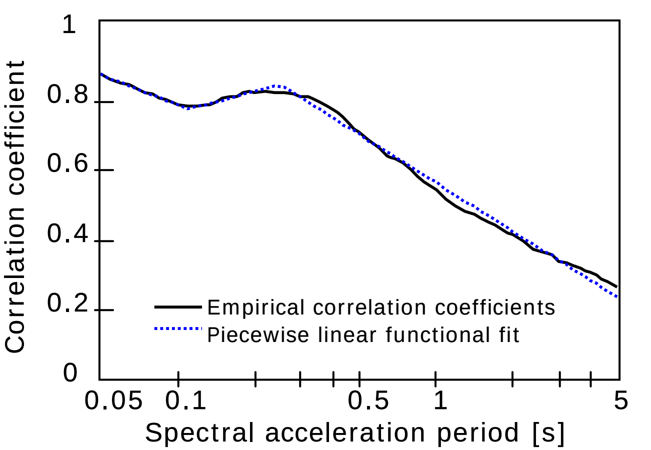
$$\varepsilon_{PGA_i} = \frac{\ln PGA_i - \mu_{\ln PGA}}{\sigma_{\ln PGA}}$$

$$\varepsilon_{Sa(T)_i} = \frac{\ln Sa(T)_i - \mu_{\ln Sa(T)}}{\sigma_{\ln Sa(T)}}$$

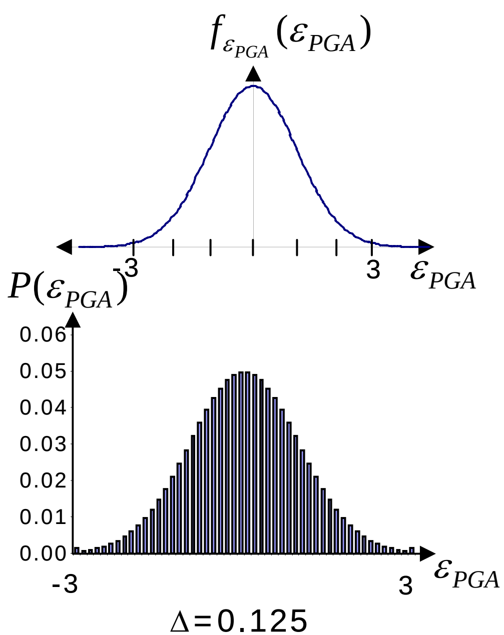
- Correlation between PGA and SA

$$\rho_{PGA,Sa(T)} = \begin{cases} 0.500 - 0.127 \cdot \ln(T) & \text{if } 0.05 \le T < 0.11 \\ 0.968 + 0.085 \cdot \ln(T) & \text{if } 0.11 \le T < 0.25 \\ 0.568 - 0.204 \cdot \ln(T) & \text{if } 0.4 \le T \le 5 \end{cases}$$





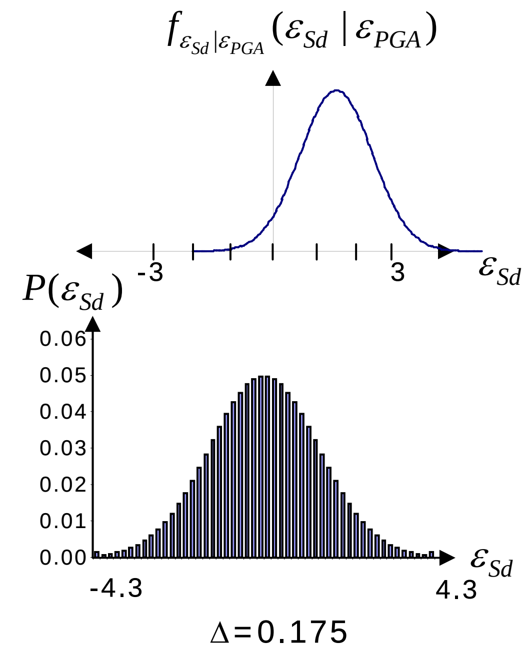
Correlation of ground motion intensity parameters

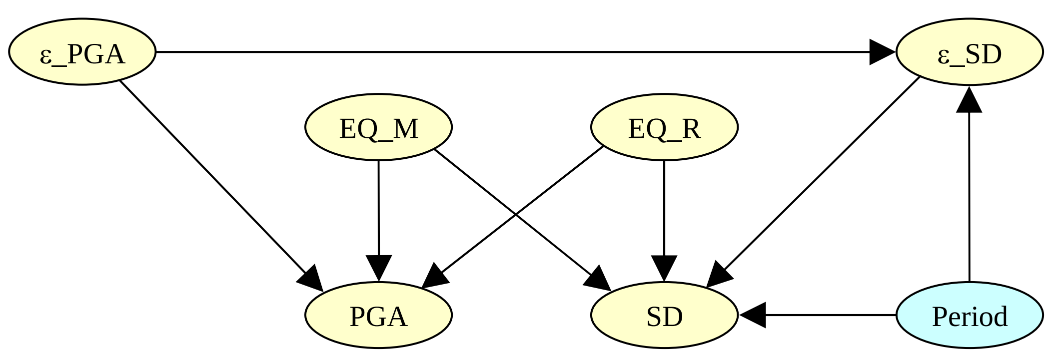


$$\rho_{PGA,Sa(0.49)} = 0.568 - 0.204 \cdot \ln(T) = 0.71$$

$$\varepsilon_{PGA} \sim N(0,1)$$

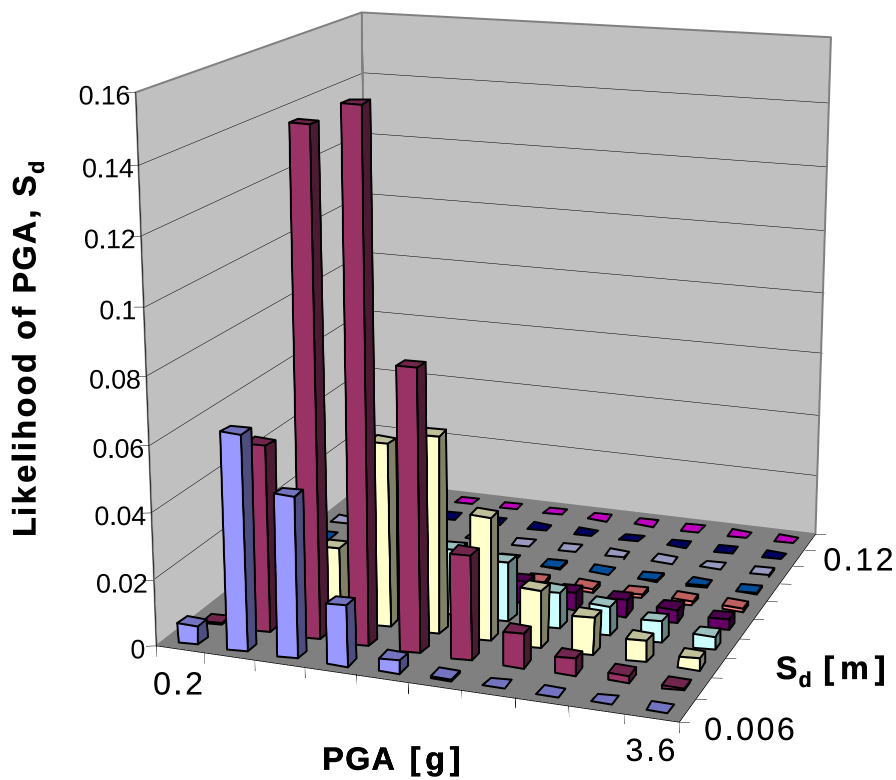
$$\varepsilon_{Sd} \mid \varepsilon_{PGA} \sim N(\rho \cdot \varepsilon_{PGA}, \sqrt{1-\rho^2})$$



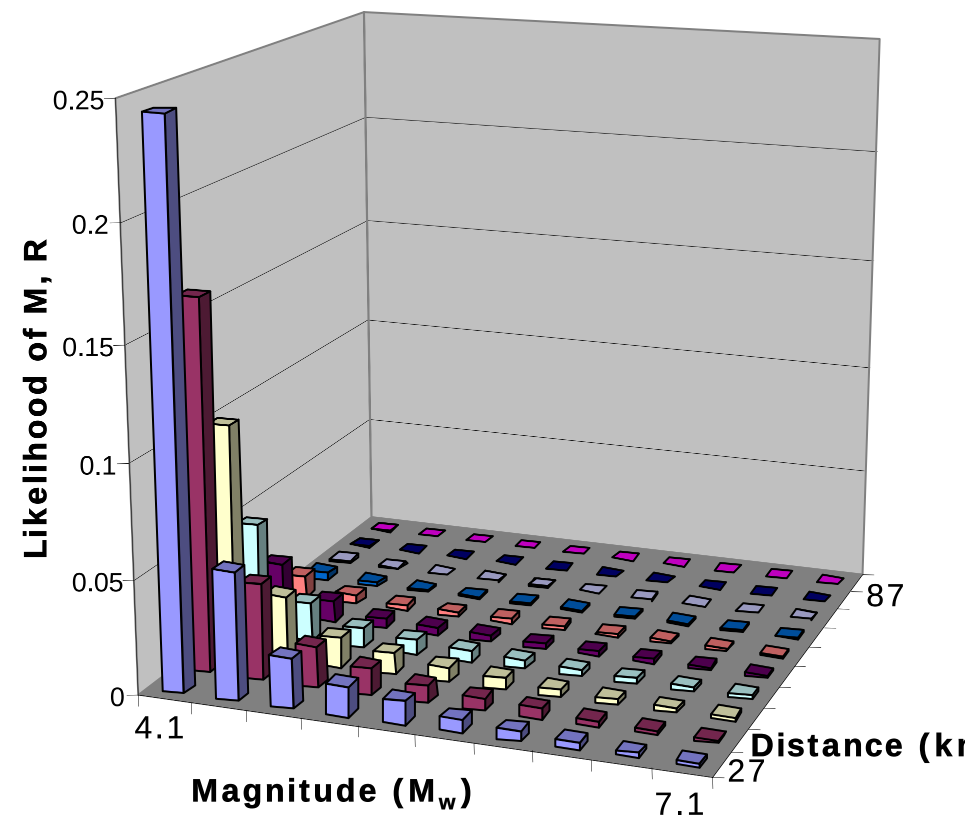


Results

7<M<7.3
23.7 km<R<30.3 km



0.4 g<PGA<0.8 g
0< S_d <0.012 m

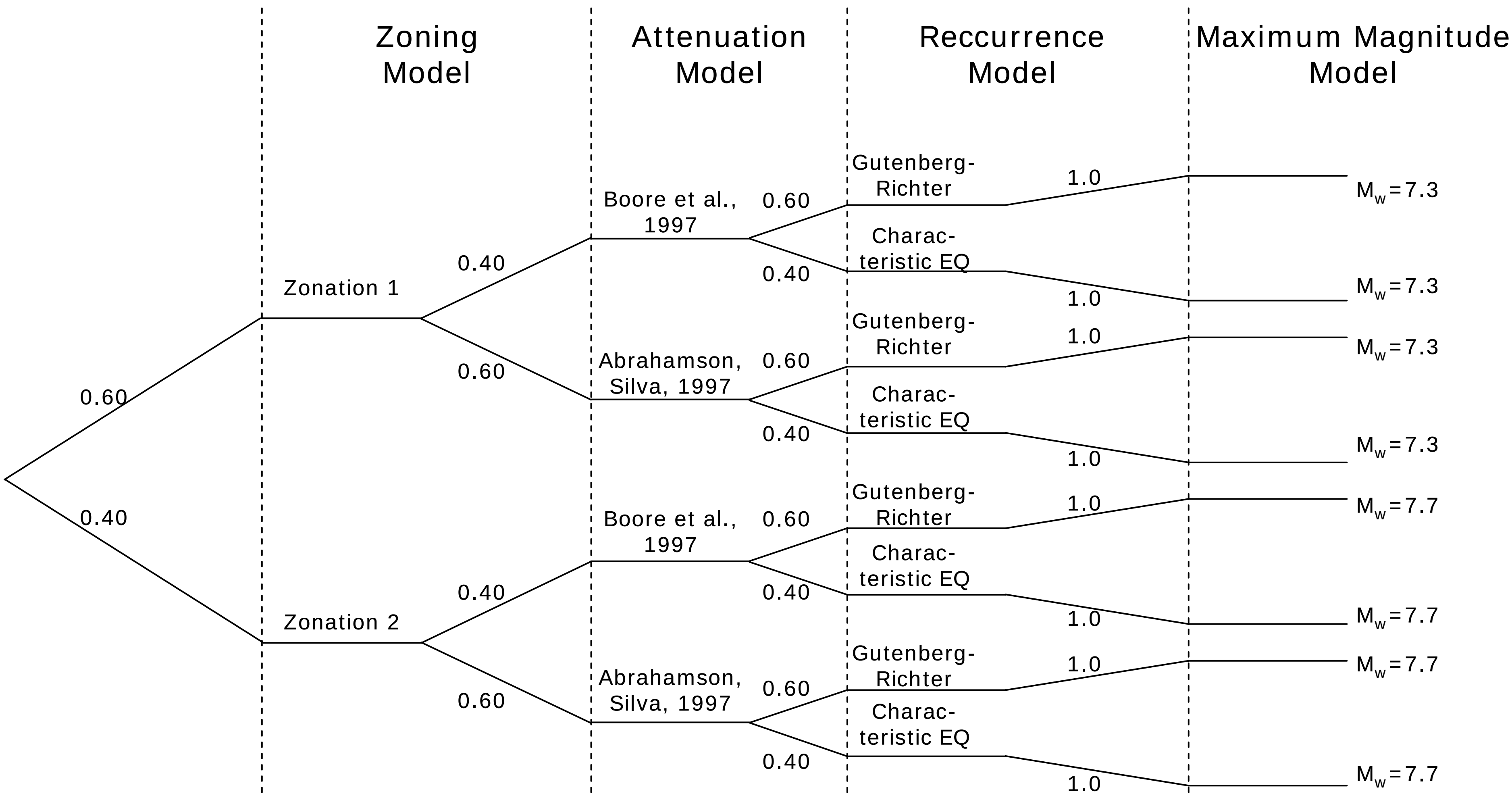


Incorporating model (epistemic) uncertainty

- A systematic consideration of uncertainty in the values of the parameters of a particular seismic hazard model can be described by PSHA.

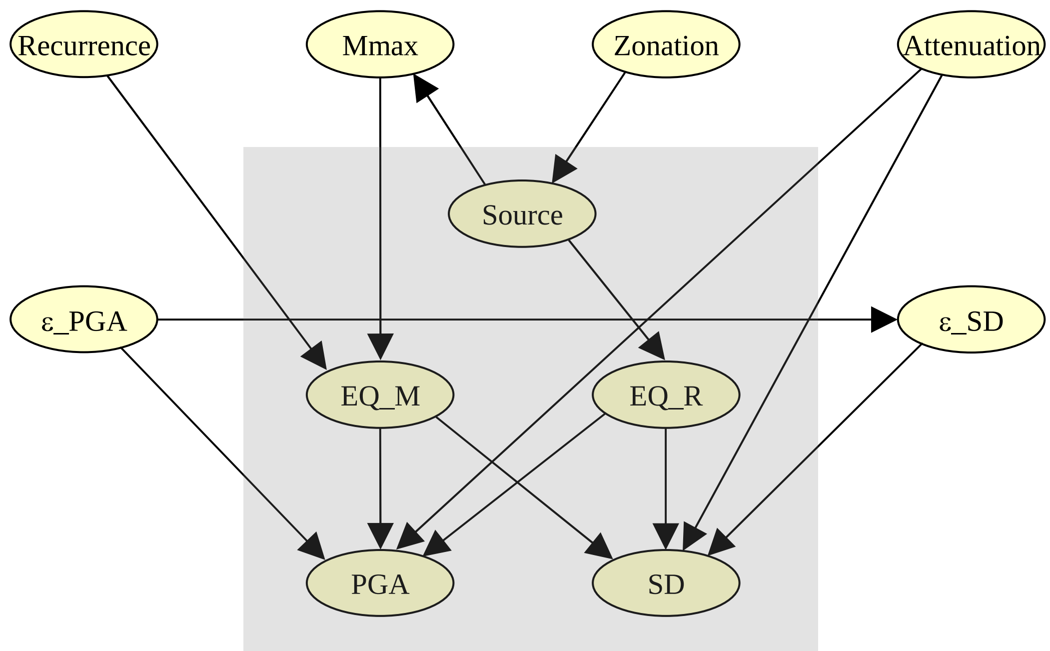
- But the correct choices for elements of the seismic hazard model are uncertain. Logic trees provide a convenient framework for the treatment of model uncertainty.

Example application

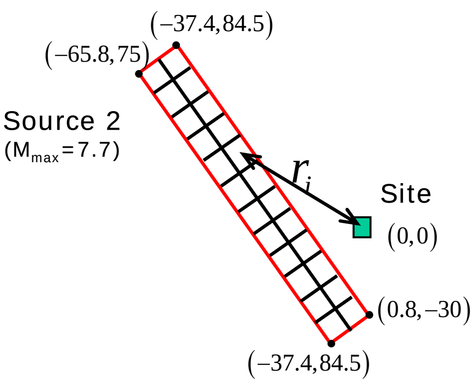


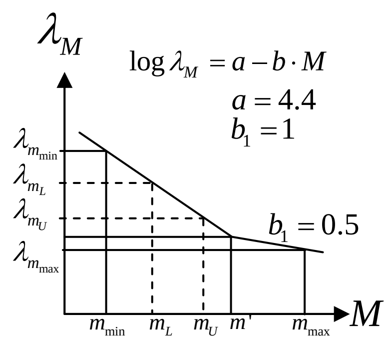
Incorporating model (epistemic) uncertainty

- The conditional probabilities for the nodes with the new parent nodes are to be recalculated

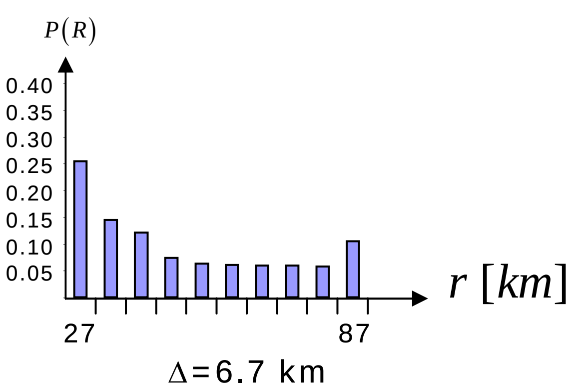


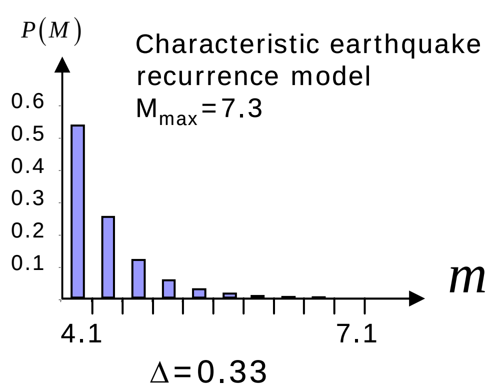
Incorporating model (epistemic) uncertainty





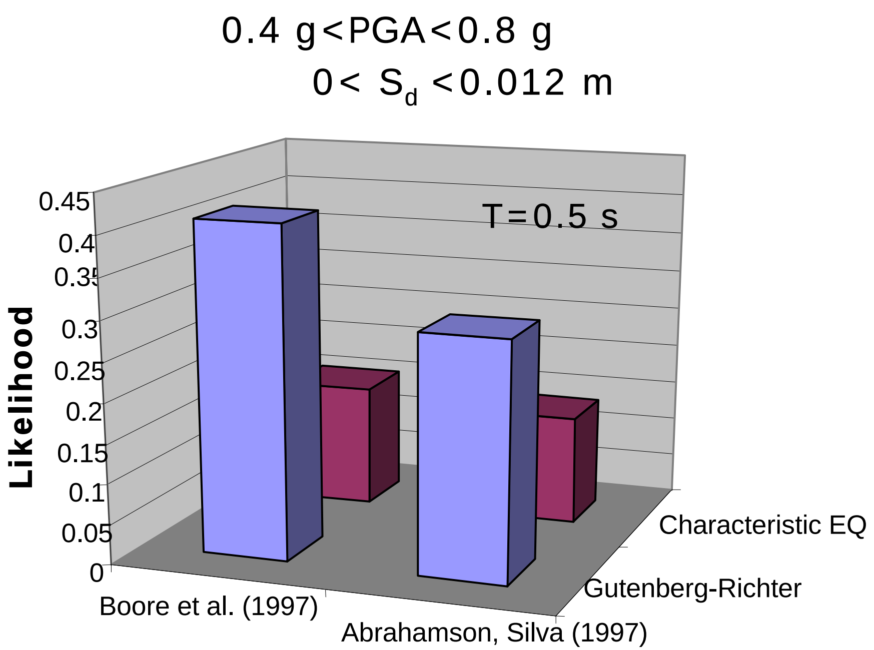
$$P\left(m_L < M < m_U \mid m_{\min} < M < m'\right) = \frac{\lambda_{m_L} - \lambda_{m_U}}{\lambda_{m_{\min}} - \lambda_{m'}}$$

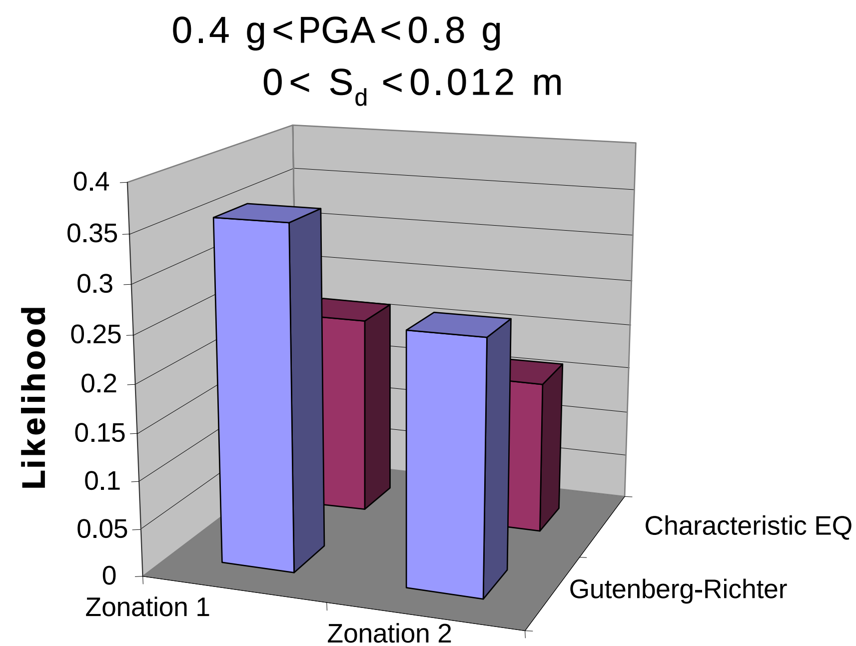


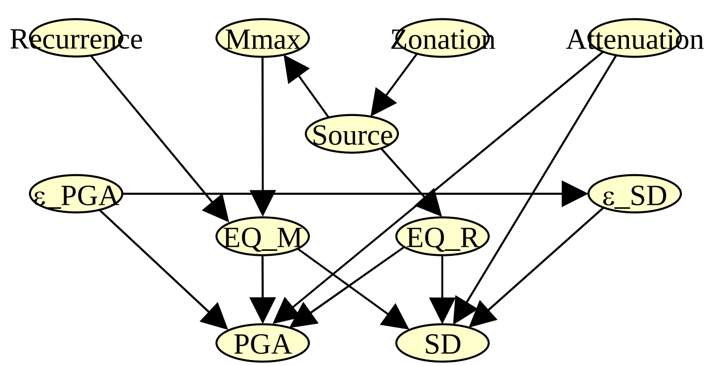


- For all combinations of (m, r, ε_{SD}) using the attenuation relation by (Boore et al., 1997) and by Abrahamson & Silva (1997) the spectral displacements (SD) are calculated.

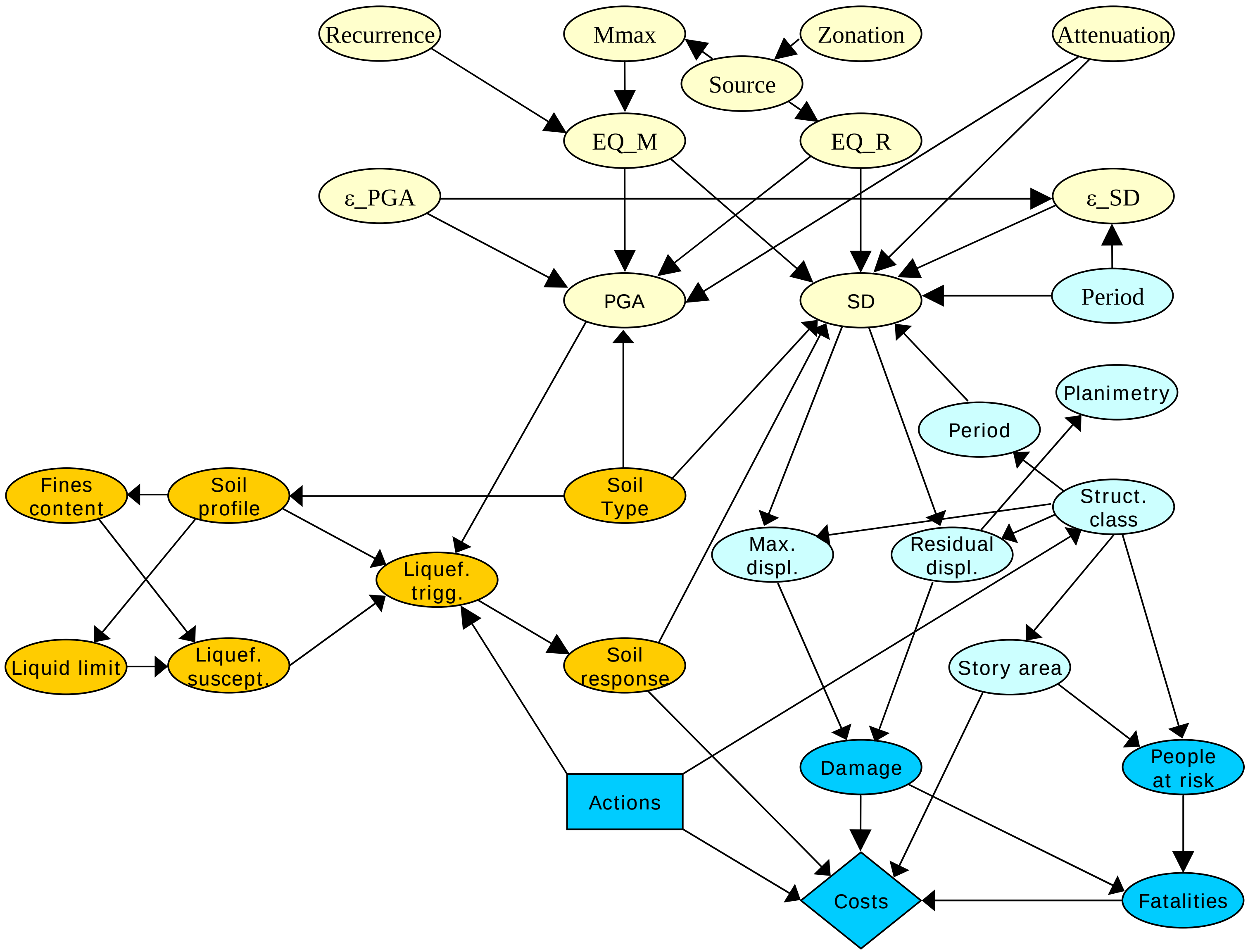
Dependence of results on model uncertainty







Outlook


Recurrence
Mmax
Zonation
Attenuation
Source
EQ_M
EQ_R
ε_PGA
ε_SD
PGA
SD
Period
Planimetry
Period
Fines content
Soil profile
Soil Type
Struct. class
Max. displ.
Residual displ.
Liquef. trigg.
Liquid limit
Liquef. suscept.
Soil response
Story area
Damage
People at risk
Actions
Costs
Fatalities

Summary

- Application of Bayesian networks (BN) for PSHA is illustrated. Uncertainties in earthquake size, location and ground motion intensity are considered as in PSHA.
- Seismic hazard disaggregation is performed.
- The joint occurrence of correlated ground motion intensity parameters is outlined.
- Uncertainties regarding the model choices are incorporated.
- Using a procedure similar to disaggregation, dependence of the results on model uncertainty assumptions is investigated.

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Thank you for your attention

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