Integrating Bayesian Networks into a GIS for avalanche risk assessment

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Introduction & Motivation

- Avalanches cause each year significant monetary losses in mountainous regions
- Society spends high amounts of resources for mitigation measures
- In regard to societal decision-making, tools for a consistent risk assessment are crucial

Source: Kt. St. Graubünden, Switzerland
Introduction & Motivation

• Tools should
  – be based on decision theory to ensure consistency
  – include physical models
  – fully account for past observations of events and expert knowledge
  – must be spatially explicit

• Tools are required
  – for hazard mapping and zoning (land-use planning)
  – for optimization of other mitigation measures
  – to facilitate and support risk communication
Risk analysis framework

- System Exposure
- Direct consequences
- System vulnerability
- Indirect consequences
- System robustness
Bayesian Networks and Influence Diagrams

- Probabilistic models based on directed acyclic graphs
- Represent the joint probability distribution of a set of variables
- Efficient due to the factoring of the joint probability distribution into conditional distributions given the parents

\[
P(x_1, x_2, x_3) = P(x_1)P(x_2 | x_1)P(x_3 | x_1)
\]

here:

\[
P(x) = P(x_1, \ldots, x_n) = \prod_{i=1}^{n} P(x_i | pa_i)
\]

General:
Bayesian Networks and Influence Diagrams

Exposure

Vulnerability
Influence Diagram
Probabilistic Avalanche Model

- Release modelling
  - Exceedance probability of the yearly maximum snow volume
  - Five release scenarios are considered
  - A nil-scenario is introduced to model frequent avalanches with no potential for damage
Probabilistic Avalanche Model

- Avalanche modelling
  - The value of the friction $\mu$ depends on the topography and the area
  - Nine different combinations of $\mu$ values are identified
Probabilistic Avalanche Model

- **Avalanche modelling**

  - The calculation of the run-out distance is based on an existing dynamic avalanche model (AVAL-2D, Gruber 1999)

  - The model uncertainty is accounted for by an error term \( \varepsilon(u) \)

\[
P(u, \theta) = f_{AVAL}(u, \theta) + \varepsilon(u)
\]
Updating

- Available avalanche records for the past 60 years

- Spatial information is not used, instead the observed run-out distance along a line (the flowpath) is considered: $o_i$

- All observations of $o_i < o_{\text{thres}}$ are only considered as censored data

- Bayesian updating:

$$p_{\Theta|\Omega}(\Theta) \propto \left( \prod_{i=1}^{N-M} f_\delta(o_i - d_{\text{AVAL}}(\Theta)) \right) \left( \prod_{i=1+M}^{N} F_\delta(o_{\text{thres}} - d_{\text{AVAL}}(\Theta)) \right) p_\Theta(\Theta)$$
Updating

- Prior BN-Model

- Posterior BN-Model (used in the risk assessment)
Updating the friction parameter

- Prior distribution

- Posterior distribution
Results

Traditional Approach

Using Bayesian Networks

E[C] = 3850 CHF/yr

E[C] = 4970 CHF/yr
Results

- Large uncertainties in the run out zones
- Nodes with the largest impact on the expected costs
  - “pressure”
  - “house construction”
  - “people present”
Conclusions and outlook

• Combining BN and GIS provides a practical tool for the consistent risk assessment

• Expert knowledge and observations can be utilized

• Uncertainties are considered in a spatially explicit manner

• Inclusion of societal follow-up consequences

• Checking and improving the criteria for hazard mapping and land use planning

• Use of the model in risk management (e.g.- planning of evacuation, road closures etc)
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Thank you for your attention

Source: Kt. St. Gallen, Switzerland