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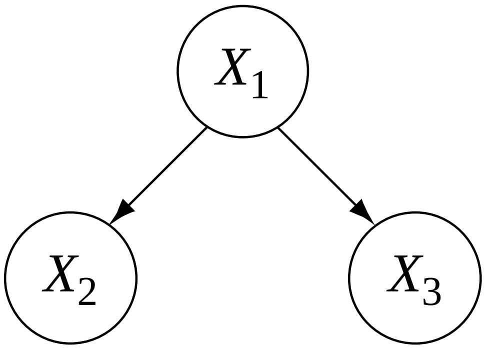
Natural hazards risk assessment using Bayesian networks



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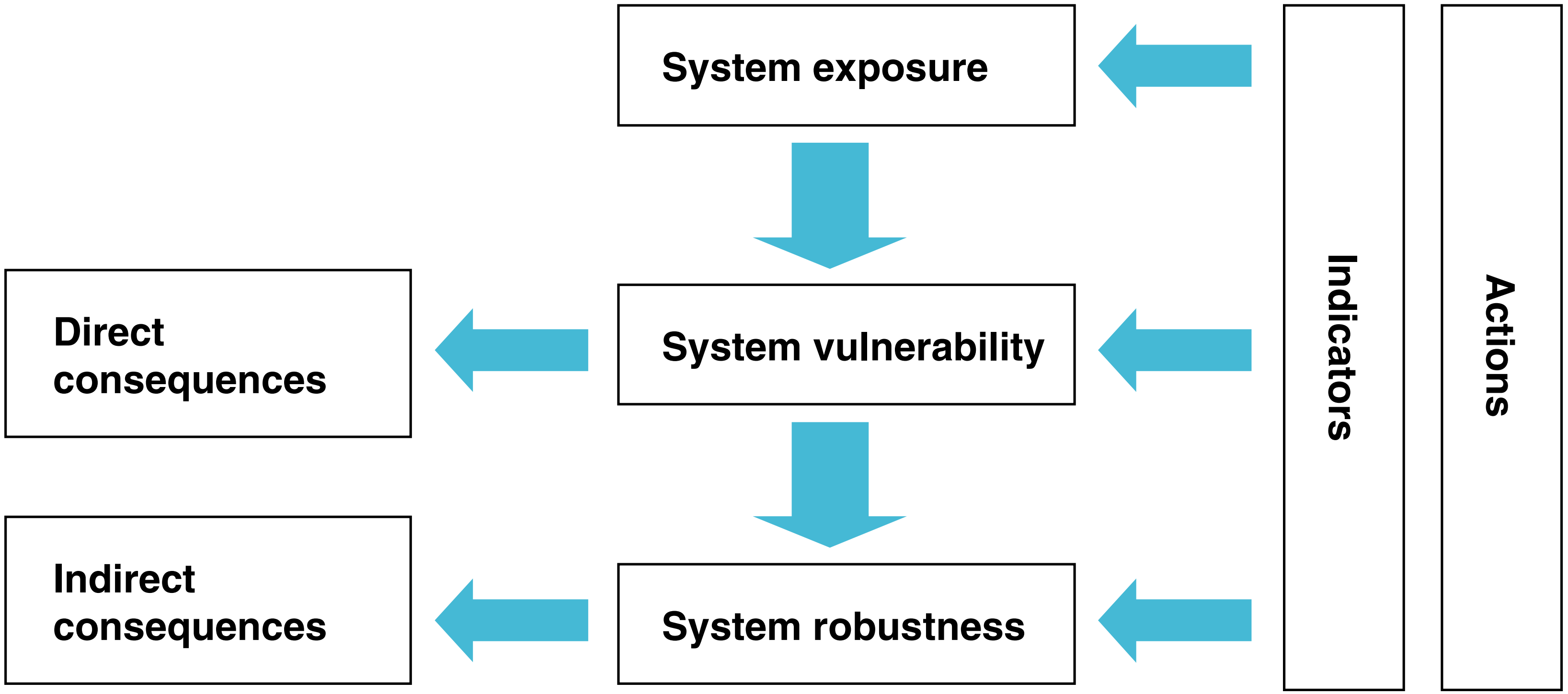
Problem statement

- Experienced damages from natural hazards increase worldwide
- (Financial) resources for protection are limited
- Suitable tools are required for risk assessment & management
- A risk assessment (& management) framework and tool should have the following properties:
  - Include entire systems & networks with dependent elements
  - It should allow for combining different models and data
  - It should be applicable to different types of hazards
  - Easy to understand and communicate

Contents

- Presentation of a general framework
- Short introduction to Bayesian networks (BN)
- Demonstration of the capabilities of BN for natural hazards risk assessment

A general framework



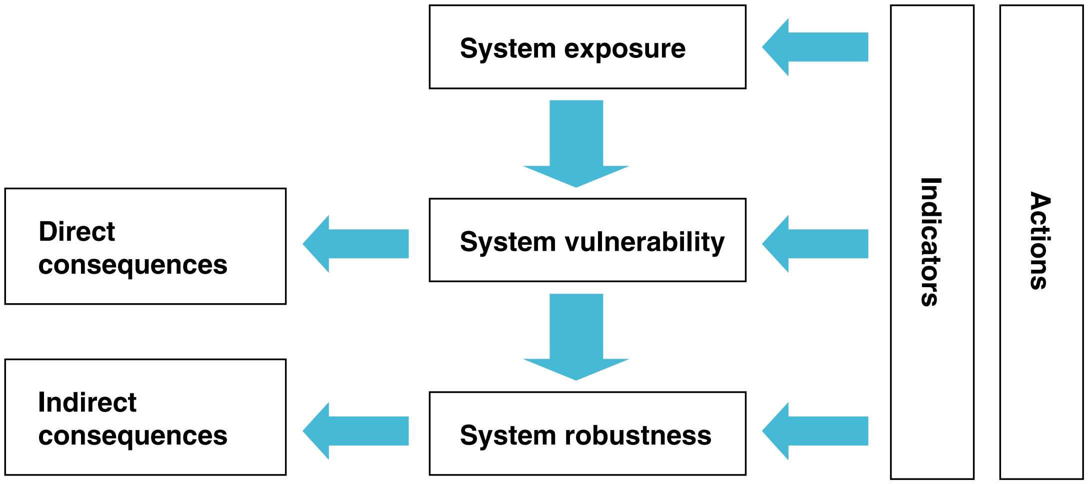
A general framework

- Multidisciplinary:

Natural scientist

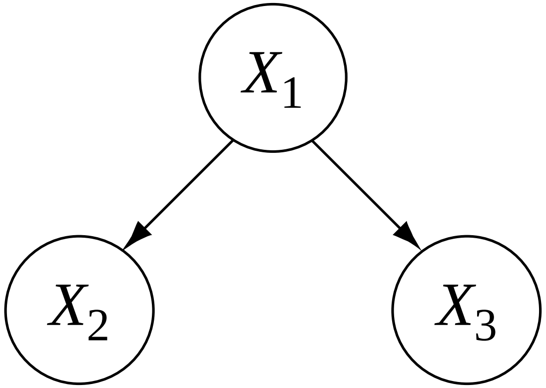
Engineer

Economist



Bayesian networks

- 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 (local) distributions given the parents



here:

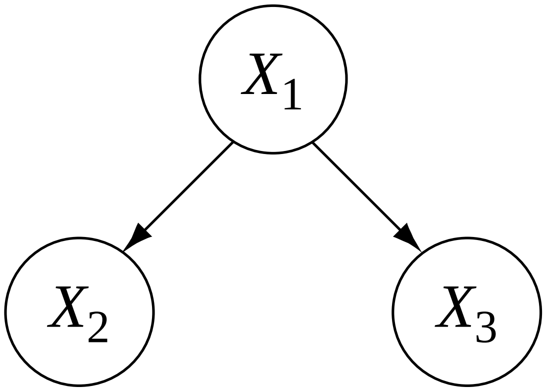
$$P(x_1, x_2, x_3) = P(x_1)\,P(x_2 \mid x_1)\,P(x_3 \mid x_1)$$

general:

$$P(\mathbf{x}) = P(x_1, \ldots, x_n) = \prod_{i=1}^{n} P(x_i \mid pa_i)$$

Bayesian networks

- Facilitates updating when additional information (evidence) is available



$$P(x_1, x_3 | e) = \frac{P(x_1, e, x_3)}{P(e)}$$

$$= \frac{P(x_1) P(e|x_1) P(x_3|x_1)}{\sum_{X_1} P(x_1) P(e|x_1)}$$

- BN are (in general) restricted to variables with discrete states

Example – Rockfall hazard risk rating system

Example – Rockfall hazard risk rating system

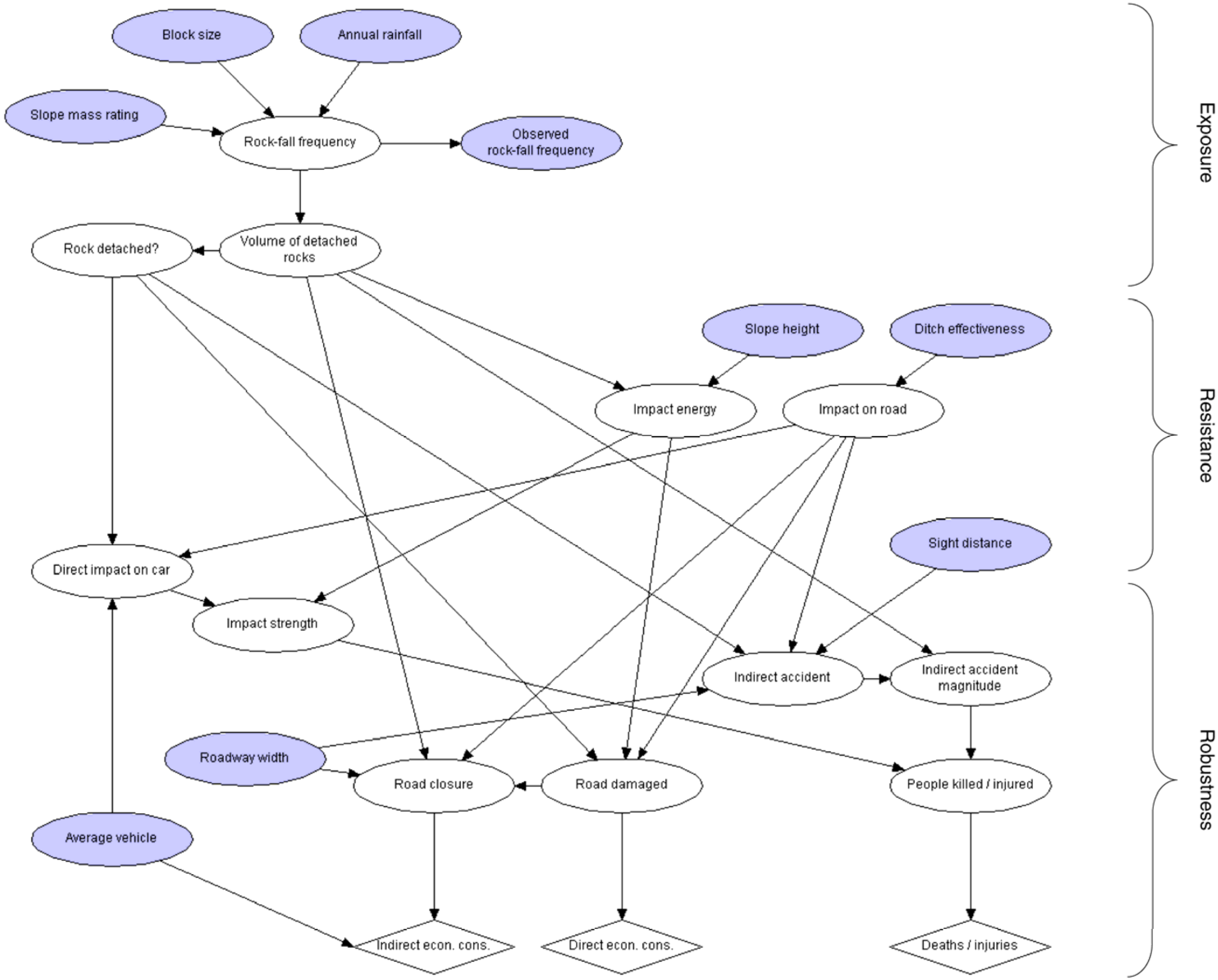
- A typical rating system from the literature:
- Nine indicators are considered for rockfall risk along a road:
  - Slope height
  - Ditch effectiveness
  - Average vehicle risk (the traffic volume)
  - Decision sight distance
  - Roadway width
  - Slope Mass Ratio (A description of the geological character)
  - Block size / Volume of rock-fall per event
  - Annual rainfall and freezing periods
  - Observed rock-fall frequency
- Each indicator has 4 intervals
- Points are assigned for each indicator: 3, 9, 27 or 81
- The points from all indicators are summed up

Example – Rockfall hazard risk rating system

Category	Rating criteria by score			
	Points 3	Points 9	Points 27	Points 81
Slope height	7.5 m	15 m	22.5 m	> 30 m
Ditch effectiveness	Good catchment	Moderate catchment	Limited catchment	No catchment
Average vehicle risk (% of time)	25%	50%	75%	100%
Decision sight distance (% of design value)	Adequate (100%)	Moderate (80%)	Limited (60%)	Very limited (40%)
Roadway width (including paved shoulders)	13.20 m	10.80 m	8.40 m	6 m
Geologic characteristics, Case 1: Structural condition	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
Geologic characteristics, Case 1: Friction	Rough, irregular	Undulating	Planar	Clay infilling or slickensided
Geologic characteristics, Case 2: Structural condition	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
Geologic characteristics, Case 2: Difference in erosion rates	Small	Moderate	Large	Extreme
Block size	0.3 cm	0.6 m	0.9 m	1.20 m
Volume of rockfall per event	2.3 m^3	4.6 m^3	6.9 m^3	9.2 m^3
Climate and presence of water on slope	Low to moderate precipitation; no freezing periods; no water on slope water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope and long freezing periods	High precipitation and long freezing periods or continual
Rockfall history	Few falls	Occasional falls	Many falls	Constant falls

Example – BN for hazard rating

- Use the same indicators to model the rockfall risk using a BN



Block size
Annual rainfall
Slope mass rating
Rock-fall frequency
Observed rock-fall frequency
Rock detached?
Volume of detached rocks
Slope height
Ditch effectiveness
Impact energy
Impact on road
Sight distance
Direct impact on car
Impact strength
Indirect accident
Indirect accident magnitude
Roadway width
Road closure
Road damaged
People killed / injured
Average vehicle
Indirect econ. cons.
Direct econ. cons.
Deaths / injuries
Exposure
Resistance
Robustness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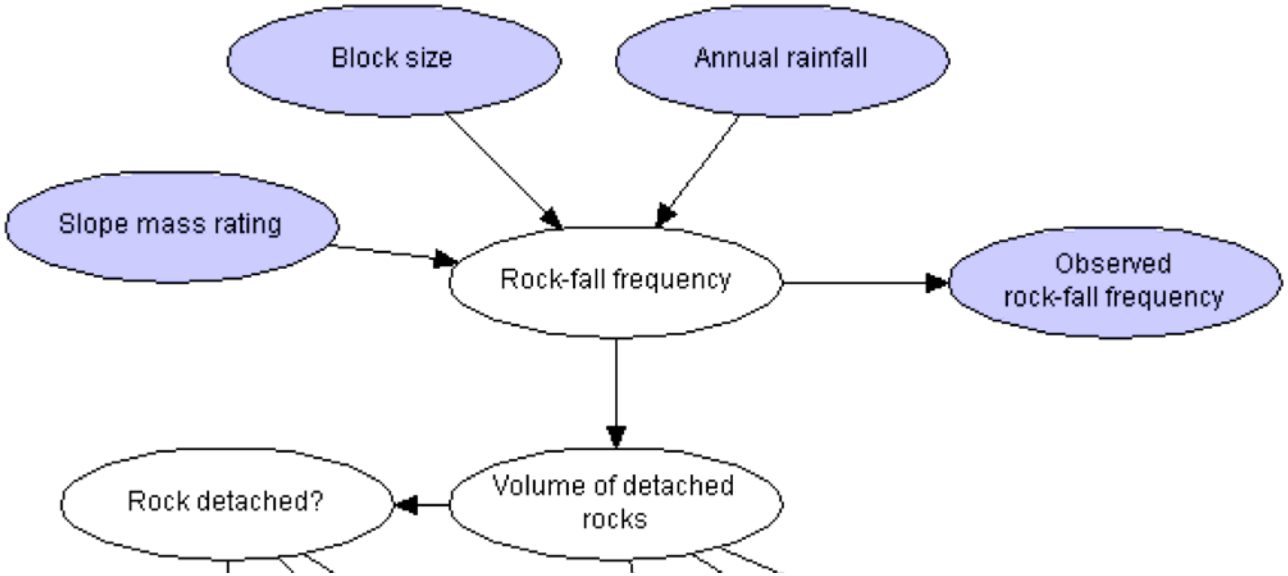
A part of the net – exposure



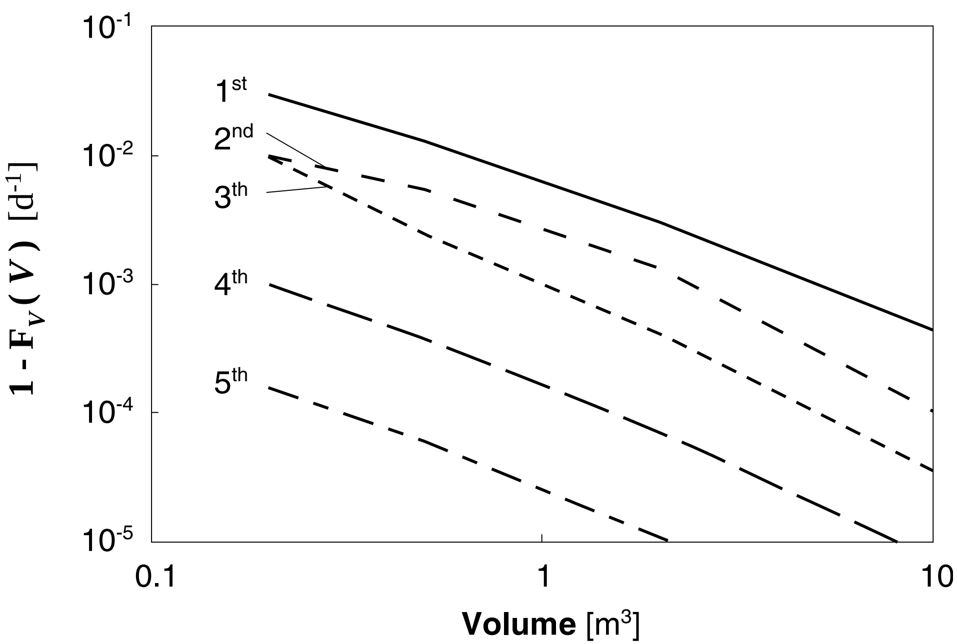
- The causal relations are correctly modelled
- As a consequence, the dependencies between indicators is consistently accounted for
- The node rock-fall frequency has five states, each representing a different exceedance frequency curve

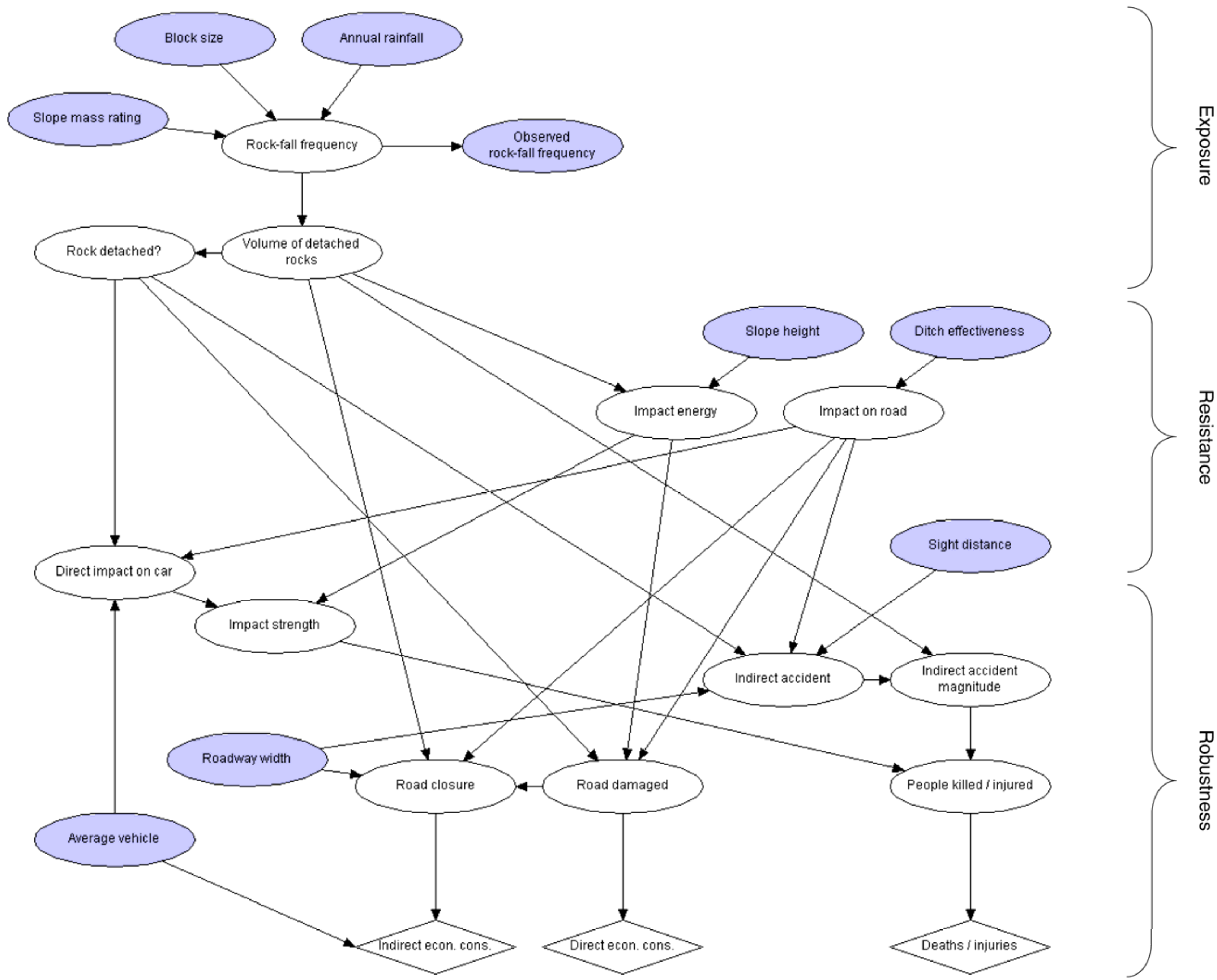
A part of the net – exposure

- The node “Volume of detached rocks” (child of rock-fall frequency)

Daily probability of rock detachement

Volume of rock	Curve 1	Curve 2	Curve 3	Curve 4	Curve 5
0	0.97	0.99	0.99	0.999	0.999839
0 - 0.3	0.017	0.0047	0.0076	6.30E-04	1.00E-04
0.3 - 1	0.01	0.004	0.002	3.00E-04	5.00E-05
1 - 3	0.002	0.001	3.00E-04	5.00E-05	1.00E-05
3 - 10	0.001	3.00E-04	1.00E-04	2.00E-05	1.00E-06

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Sight distance
Direct impact on car
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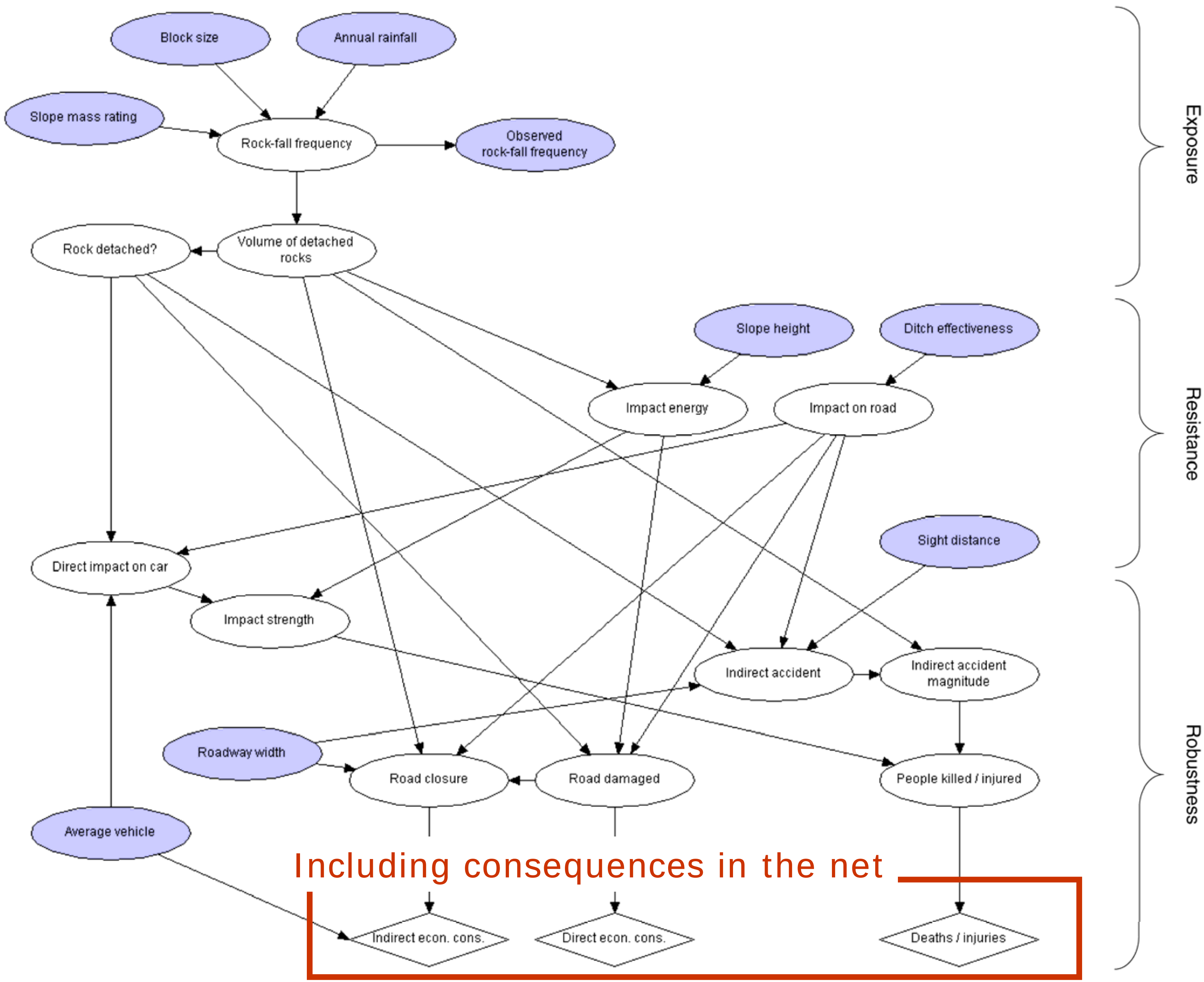
Indirect accident
Indirect accident
magnitude
Roadway width
Road closure
Road damaged
People killed / injured
Average vehicle
Indirect econ. cons.
Direct econ. cons.
Deaths / injuries
Exposure
Resistance
Robustness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Impact on road
Sight distance
Direct impact on car
Impact strength
Indirect accident
Indirect accident magnitude
Roadway width
Road closure
Road damaged
People killed / injured
Average vehicle
Including consequences in the net
Indirect econ. cons.
Direct econ. cons.
Deaths / injuries
Exposure
Resistance
Robustness

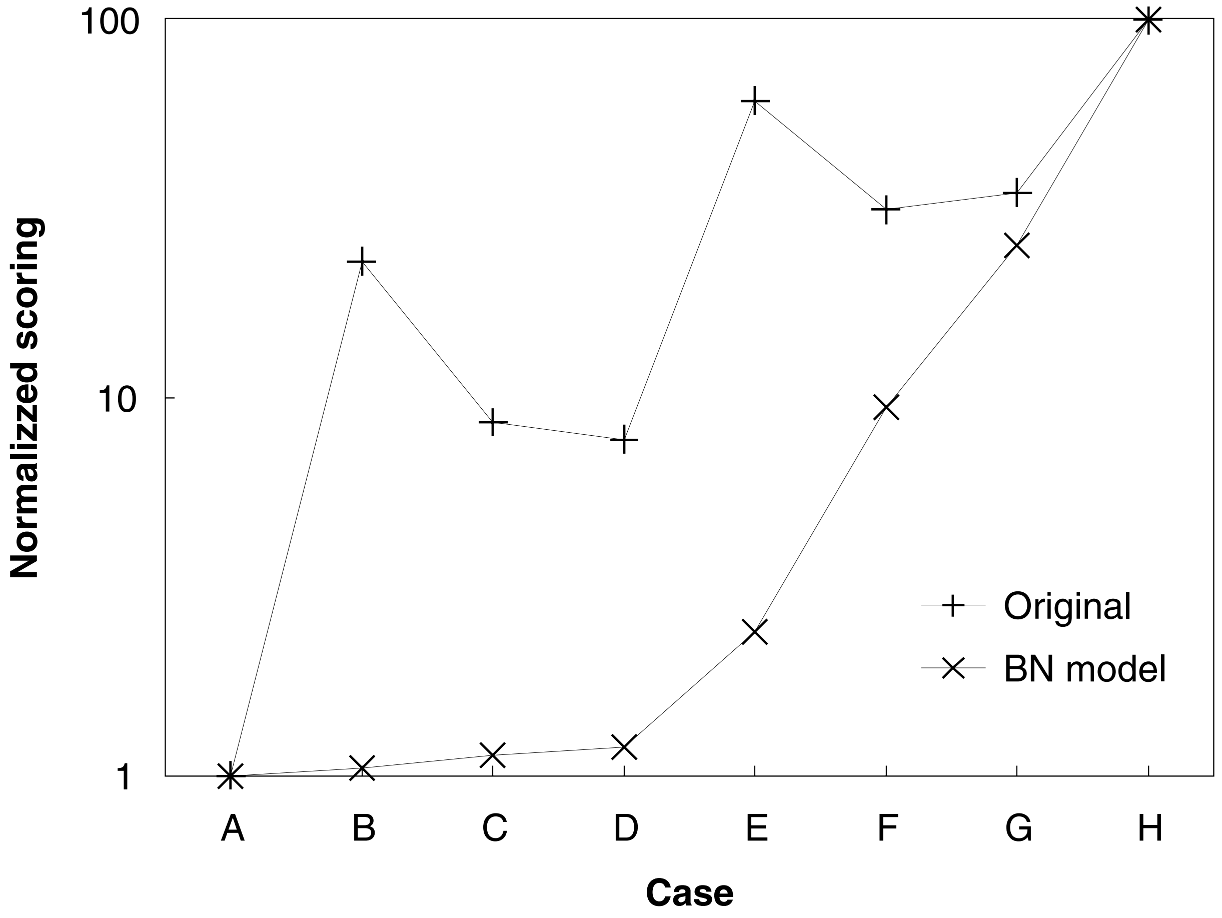
Comparing the ratings

Table 1. Investigated cases.

Cases:	A	B	C	D	E	F	G	J
Slope height	1	4	2	1	2	3	3	4
Ditch effect.	1	4	2	2	1	3	4	4
Vehicles	1	1	2	1	4	3	3	4
Sight distance	1	1	2	3	3	3	3	4
Roadway width	1	1	2	2	2	3	2	4
SMR	1	1	2	2	4	3	2	4
Block size	1	1	2	1	4	3	1	4
Rain & Freezing	1	1	2	1	4	3	1	4
Observed freq.	1	1	2	2	4	3	4	4

Comparing the ratings

- Results for some example cases:



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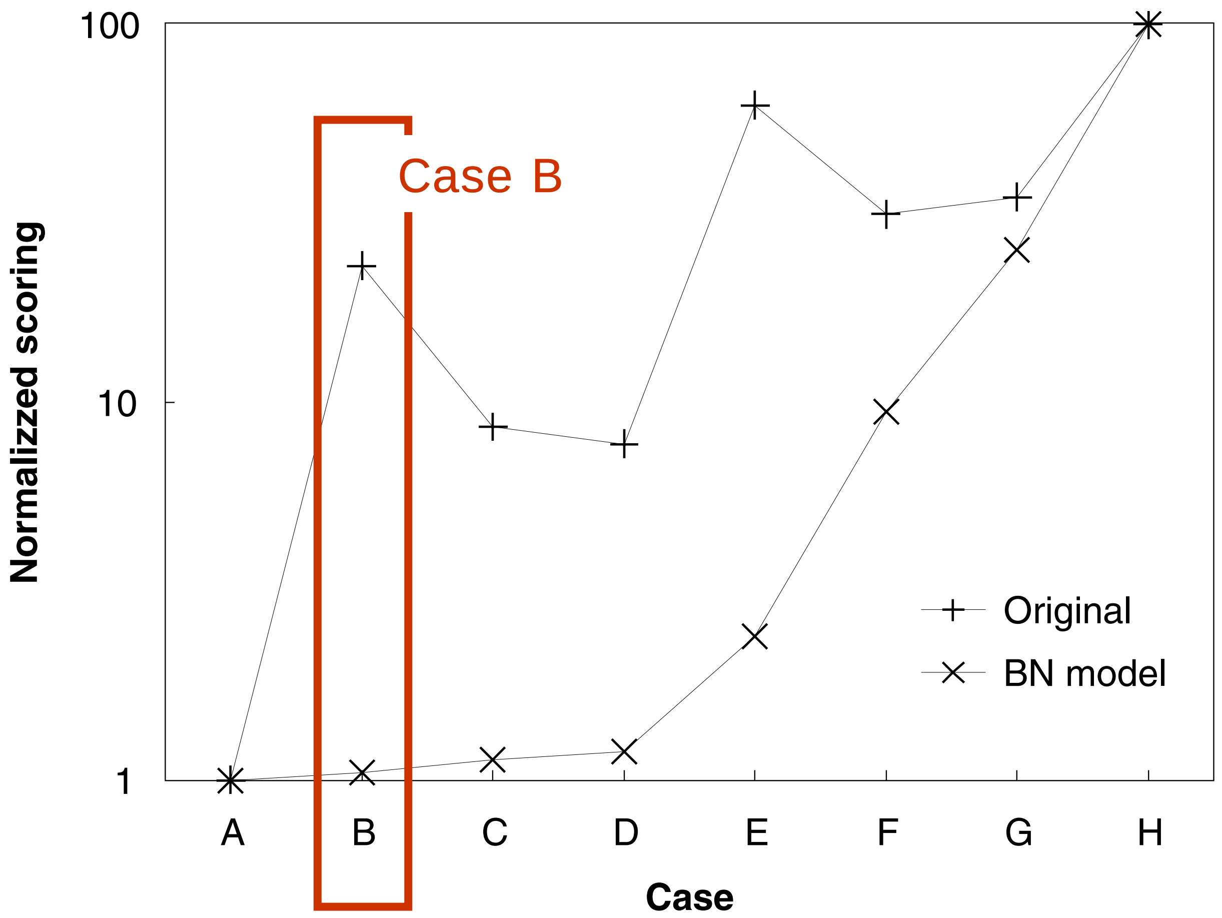

Comparing the ratings

Table 1. Investigated cases.

	Cases:	A	B	C	D	E	F	G	J
Vulnerab.	Slope height	1	4	2	1	2	3	3	4
Vulnerab.	Ditch effect.	1	4	2	2	1	3	4	4
	Vehicles	1	1	2	1	4	3	3	4
	Sight distance	1	1	2	3	3	3	3	4
	Roadway width	1	1	2	2	2	3	2	4
	SMR	1	1	2	2	4	3	2	4
	Block size	1	1	2	1	4	3	1	4
	Rain & Freezing	1	1	2	1	4	3	1	4
	Observed freq.	1	1	2	2	4	3	4	4

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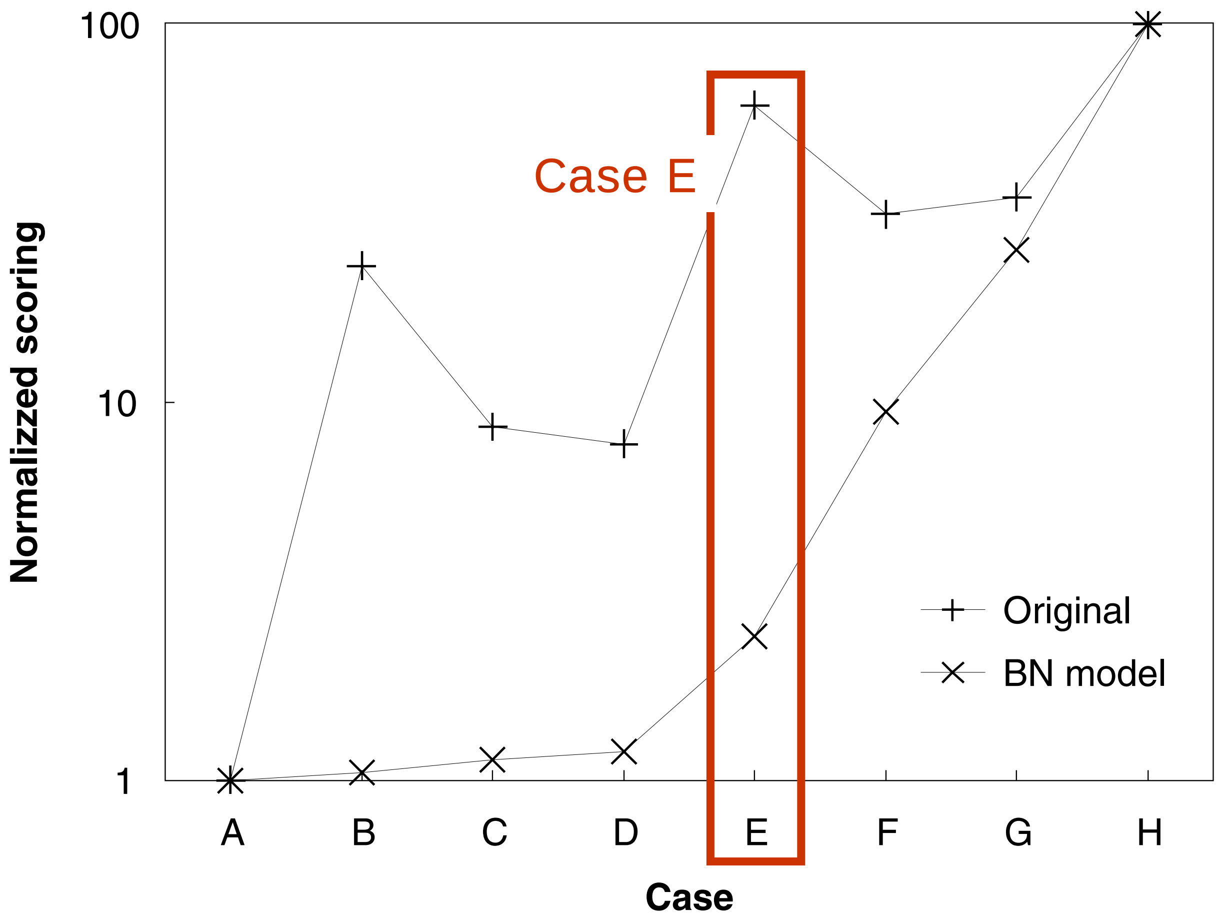

Comparing the ratings

Table 1. Investigated cases.

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Vulnerab.	Ditch effect.	1	4	2	2	1	3	4	4
	Vehicles	1	1	2	1	4	3	3	4
	Sight distance	1	1	2	3	3	3	3	4
	Roadway width	1	1	2	2	2	3	2	4
	SMR	1	1	2	2	4	3	2	4
	Block size	1	1	2	1	4	3	1	4
	Rain & Freezing	1	1	2	1	4	3	1	4
	Observed freq.	1	1	2	2	4	3	4	4

Discussion & conclusions

- The BN provides a simple but consistent model for risk assessment
- The BN can consistently include contradicting information
- The BN can cope with the unavailability of indicators
- Different levels of detailing can be incorporated into a common model – e.g. an improved geological model could be included in the example
- The net can be extended to include mitigation actions for optimisation purposes
- The net can be easily extended to model an entire road link

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- Thank you for your attention!

- Questions?