Refining a probabilistic cross-impact methodology for scenario analysis

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Scenario analysis

- Scenario analysis is widely used to facilitate long-term strategic planning and to identify risks by portraying possible futures as scenarios.
- Scenarios can be defined as combinations of the realizations of different uncertainty factors.

Uncertainty factors and scenarios

**Uncertainty factors are described above and possible outcomes below them.*

Scenario 1

Geopolitics	Economic development	Regulation
Prolonged conflict between Israel and Palestine leads to blocks in world politics.	The EU economy has recovered from high inflation and interest rates.	Moderate regulatory support for green products.
Israel and Palestine agree on peace, which calms the atmosphere and increases international co-operation.	Slow economic growth, with lingering effects of high inflation and interest rates in the EU.	Strong regulatory support for green products, with subsidies and incentives.
Conflict in the Middle-East spreads to neighboring countries, which suppresses global collaboration and freezes global markets.	Moderate economic stability, with the EU maintaining steady but unremarkable growth.	Comprehensive green standards and international agreements promoting sustainable practices.

Illustration of exploring the possibilities of “green” products using scenario analysis.

Requirements

- If all scenarios are retained utilizing many uncertainty factors, there are requirements for calculating the joint probability distribution of the scenarios:
  - Computing power
  - Distinct protocol for expert assessments

Cross-impacts

- Cross-impact interpretation in Salo et al. (2021):

$$C_{ab} \coloneqq \frac{P(a \mid b)}{P(a)} \qquad \rightarrow \qquad P(a \mid b) = C_{ab} P(a),$$

where C_{ab} is the cross-impact multiplier between events a: a city experiences a major decrease in air pollution and b: the city implements a strict new environmental regulation.

Deriving cross-impact multipliers

			Printing costs		
			50-100%	10-50%	Max10%
			0,5	0,4	0,1
Global industry growth	Slow	0,3	2	0	-2
	Stable	0,5	0	2	0
	Fast	0,2	-2	0	3
Printing speed	100-200%	0,4	1	-1	-1
	200-1000%	0,5	-1	1	0
	Over 1000%	0,1	-1	0	1

→

$$C_{ij} = \sqrt{2}^{V_{ij}},$$

Where C_{ij} is the cross-impact multiplier and V_{ij} is a statement ranging from [-3, 3] (Roponen & Salo 2024)

			Printing costs		
			50-100%	10-50%	Max10%
			0,5	0,4	0,1
Global industry growth	Slow	0,3	2	1	1/2
	Stable	0,5	1	2	1
	Fast	0,2	1/2	1	3
Printing speed	100-200%	0,4	1 1/2	2/3	2/3
	200-1000%	0,5	2/3	1 1/2	1
	Over 1000%	0,1	2/3	1	1 1/2

Case study analyzing 3D-printing and its future impact on the Finnish Defense Forces in Roponen & Salo (2024).

The least squares optimization problem in Roponen & Salo (2024)

$$\min_{q(k|\mathbf{s}_{D_i})} \sum_{j \in D_i} \sum_{(k,l) \in R_{ij}} \left[\left(\sum_{\{\mathbf{s} \in S_{D_i} | s_j = l\}} q(k \mid \mathbf{s})\, q(\mathbf{s}) \right) - \widehat{C}_{kl}^{ij} \widehat{p}_k^i \widehat{p}_l^j \right]^2$$

$$\sum_{\mathbf{s} \in S_{D_i}} q(k \mid \mathbf{s})\, q(\mathbf{s}) = \widehat{p}_k^i, \ \forall k \in \{1, 2, \ldots, n_i\}$$

$$\sum_{k=1}^{n_i} q(k \mid \mathbf{s}_{D_i}) = 1, \ \forall \mathbf{s}_{D_i} \in S_{D_i}$$

$$q(k \mid \mathbf{s}_{D_i}) \geq 0, \ \forall k \in \{1, 2, \ldots, n_i\}, \ \forall \mathbf{s}_{D_i} \in S_{D_i}$$

Iterative computation of the joint probability distribution from the cross-impact multipliers

- Iterate over all uncertainty factors sequentially and calculate the joint probability distribution, using the cross-impact multipliers.
- Limiting the number of iterations:
  - Conditioning the realizations of uncertainty factors on the partial scenarios defined by preceding uncertainty factors, conditional independence and directed acyclic graphs.
  - The least squares optimization problem presented incorporates these properties.

Iterative computation of the joint probability distribution from the cross-impact multipliers

1st iteration		-
1. Nuclear power	$p(s_1^1)$	0.50
	$p(s_2^1)$	0.30
	$p(s_3^1)$	0.20

2nd iteration		1. Nuclear power		
		s_1^1	s_2^1	s_3^1
2. Renewables	$p(s_1^2 \| s^1)$	0.10	0.50	0.50
	$p(s_2^2 \| s^1)$	0.17	0.25	0.21
	$p(s_3^2 \| s^1)$	0.37	0.20	0.28
	$p(s_4^2 \| s^1)$	0.36	0.06	0.02

3rd iteration		1. Nuclear power											
		s_1^1				s_2^1				s_3^1			
		2. Renewables											
		s_1^2	s_2^2	s_3^2	s_4^2	s_1^2	s_2^2	s_3^2	s_4^2	s_1^2	s_2^2	s_3^2	s_4^2
	$\mathbf{s}_{D_3}$	(s_1^1, s_1^2)	(s_1^1, s_2^2)	(s_1^1, s_3^2)	(s_1^1, s_4^2)	(s_2^1, s_1^2)	(s_2^1, s_2^2)	(s_2^1, s_3^2)	(s_2^1, s_4^2)	(s_3^1, s_1^2)	(s_3^1, s_2^2)	(s_3^1, s_3^2)	(s_3^1, s_4^2)
3. Storage	$p(s_1^3 \| \mathbf{s}_{D_3})$	0.81	0.62	0.29	0.07	0.88	0.49	0.36	0.20	0.88	0.70	0.57	0.02
	$p(s_2^3 \| \mathbf{s}_{D_3})$	0.19	0.38	0.71	0.51	0.12	0.51	0.64	0.29	0.10	0.30	0.25	0.02
	$p(s_3^3 \| \mathbf{s}_{D_3})$	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.51	0.02	0.00	0.18	0.96

Example of the iterations when calculating conditional probabilities in Roponen & Salo (2024).

Aim of the thesis

- Develop and refine the methodology in Roponen & Salo (2024) by interpreting the cross-impact term differently
- Comparing the results to the original method
- Possibly incorporating a real case experiment

Revised interpretation of the cross-impact term

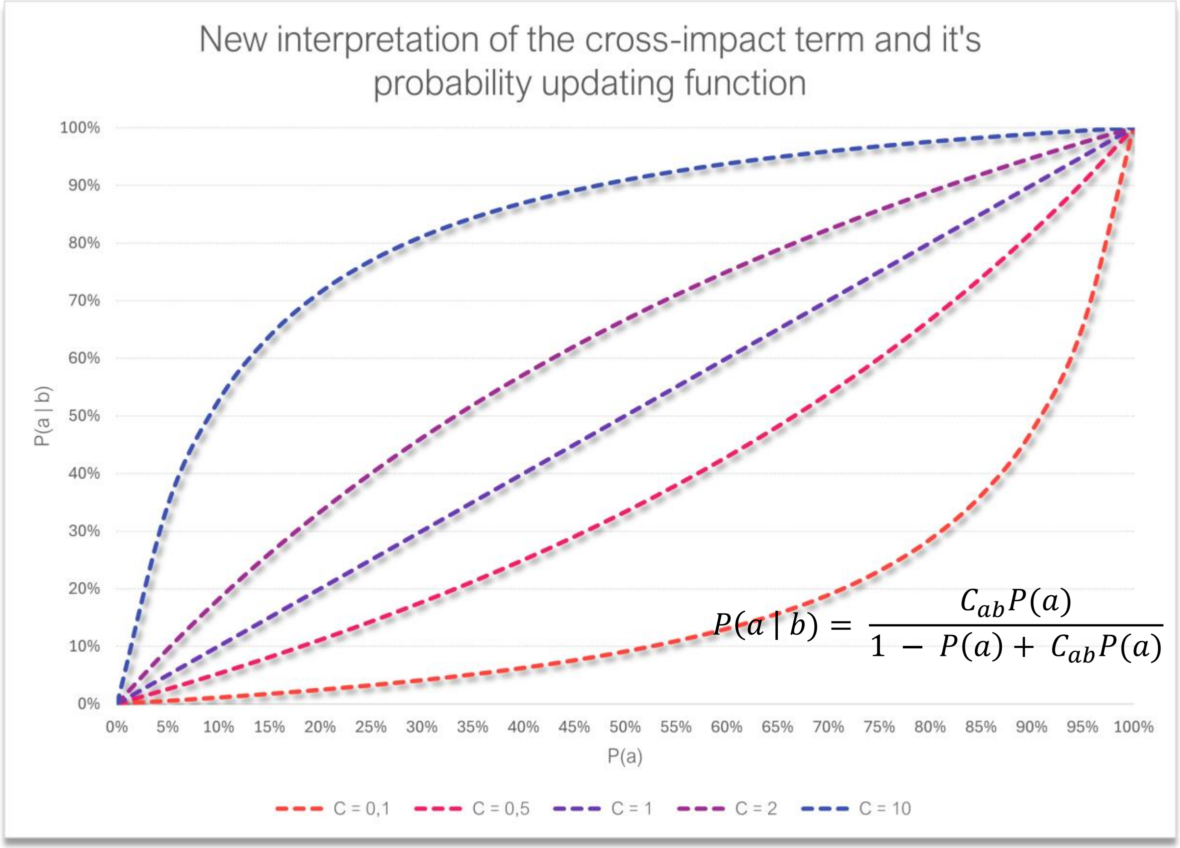
- In the revised interpretation, the cross-impact multiplier is expressed as the odds ratio between the event a, and the event a happening with the condition that b has happened:

$$\frac{P(a \mid b)}{1 - P(a \mid b)} = C_{ab} \frac{P(a)}{1 - P(a)},$$

which results in the following probability update:

$$P(a \mid b) = \frac{C_{ab} P(a)}{1 - P(a) + C_{ab} P(a)}$$

Revised interpretation of the cross-impact term



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Methods and tools

- MATLAB
- Python

Key dates

- Presentation of the topic on 17.6.2024
- Code implementation finished and tested by the end of June 2024
- Writing the thesis June-August 2024
- Results and the thesis ready by September 2024

Key references

- Salo, A., Tosoni, E., Roponen, J., & Bunn, D. W. (2021). Using cross-impact analysis for probabilistic risk assessment. Futures & Foresight Science, 4, e2103
- Roponen, J. & Salo, A. (2024). A probabilistic cross-impact methodology for explorative scenario analysis. Futures & Foresight Science, 6, e165