Evaluation of safety systems for multipurpose facilities – how to find an optimized solution

ITA-COSUF Workshop

“Complex Underground Multipurpose Facilities – Safety Challenges and Solutions”

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Content

- ➔ General problem and key elements
- ➔ Decision theory and its application
- ➔ Exemplarily assessment
- ➔ Conclusions

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General problem

Know your “enemy” and know your system

- Different structures will have varying threats and possible hazards
  - An extensive hazard and threat analysis is mandatory and has to be carried out for every specific facility, especially when dealing with security matters

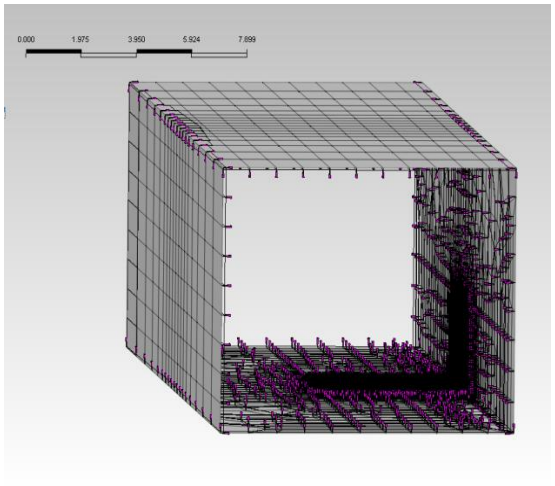
Know your “enemy” and know your system

- Every structure has its own vulnerabilities in terms of structural assessment, user assessment or its meaning for the surrounding infrastructural network
  - A holistic approach is needed, that includes every relevant criterion

How far do you want to (need to) go?

- The technical possibility to applicate a specific measure (operational, structural or organizational) does often not correlate with a general need for such a systemic upgrade and might raise conflicts with budget constraints
  - ➲ We need prioritizations of measures as well as the tools and the boundaries to do so

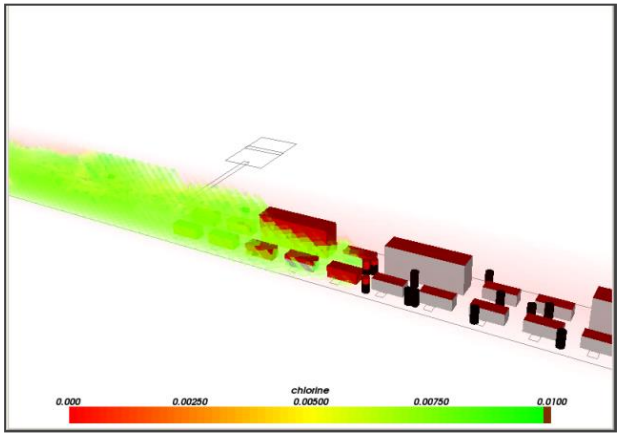
Structure



Structural assessment

- General durability and resilience under various threats
- Possible duration of repair after a damage
- Possible cost for repair
- …

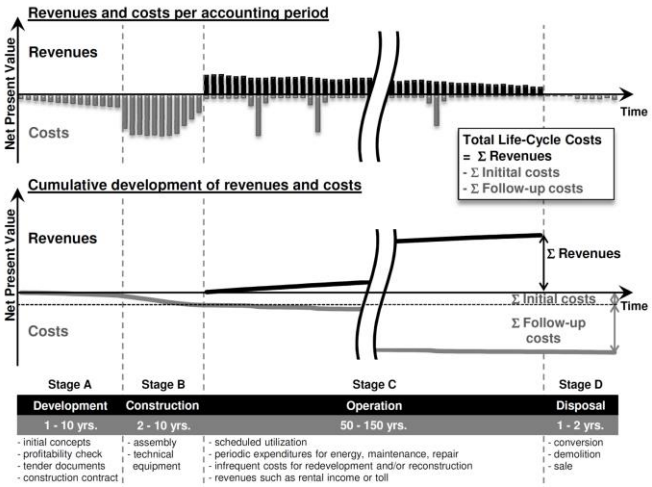
Key elements / Engineering services



Assessment of user safety

- Quantitative risk assessment with the facilities boundary conditions
- Estimation of probabilities and consequences
- Assessment of mitigation measures
- Risk accumulation and evaluation
- ….

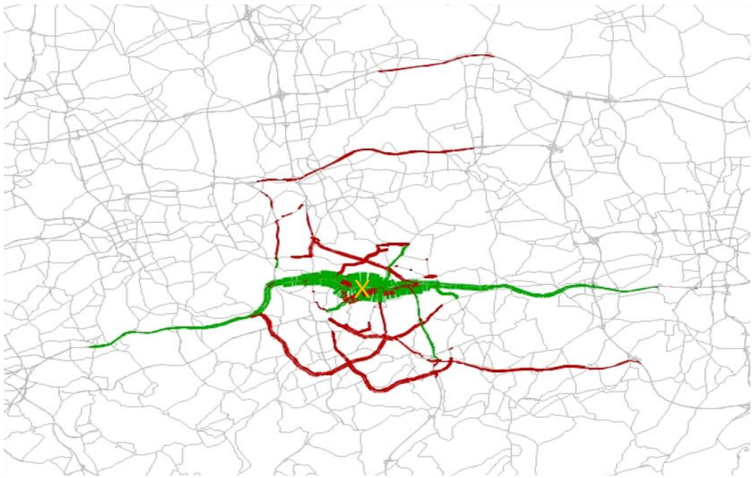
Lifecylce costs



Assessment of lifecycle costs (LCC)

- Costs for initial invest (construction, equipment, measures, etc.)
- Follow-up costs (maintenance & repair, re-invest)
- Costs for decomissioning
- …

Misc.

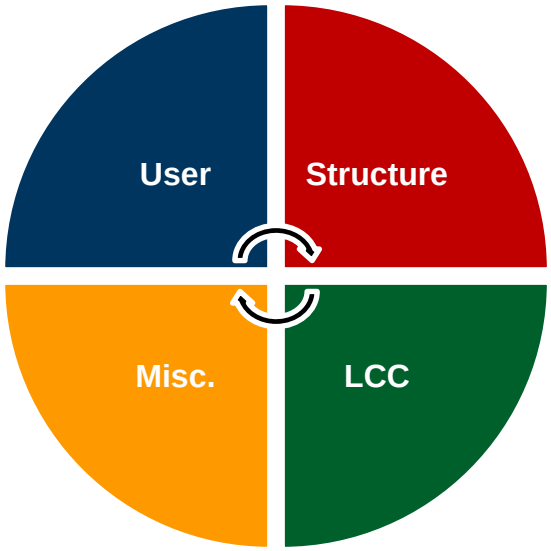


Assessment of miscellaneous criterions

- Reaction of the surrounding infrastructural network
- Symbolic meaning
- …

Holistic assessment:

- How can these specific criterions be compared with each other in regard to different layouts for safety system and operational approach?
- How can one make a traceable and transparent decision?



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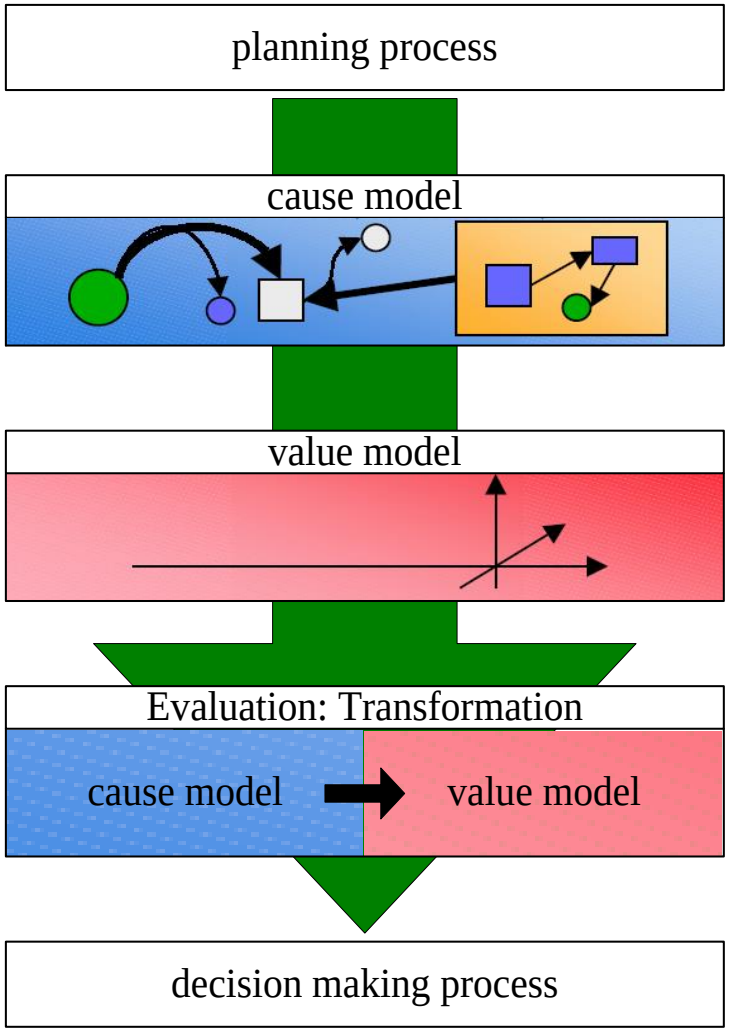
Basics of decision making

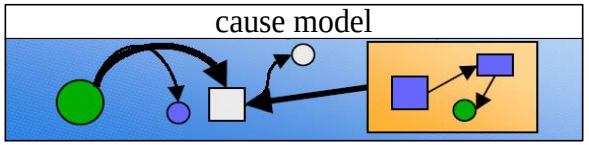
- Cause model: Gathering and analyzing of project specific data
- Value model: Assessing the scale and weight
- Consolidation of descriptive component (cause model) and normative component (value model) in the evaluation

➔ Decision making process



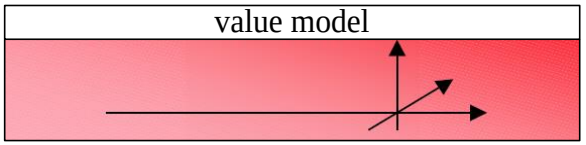
Cause model

- Impact of different operational technologies and configurations on safety & security

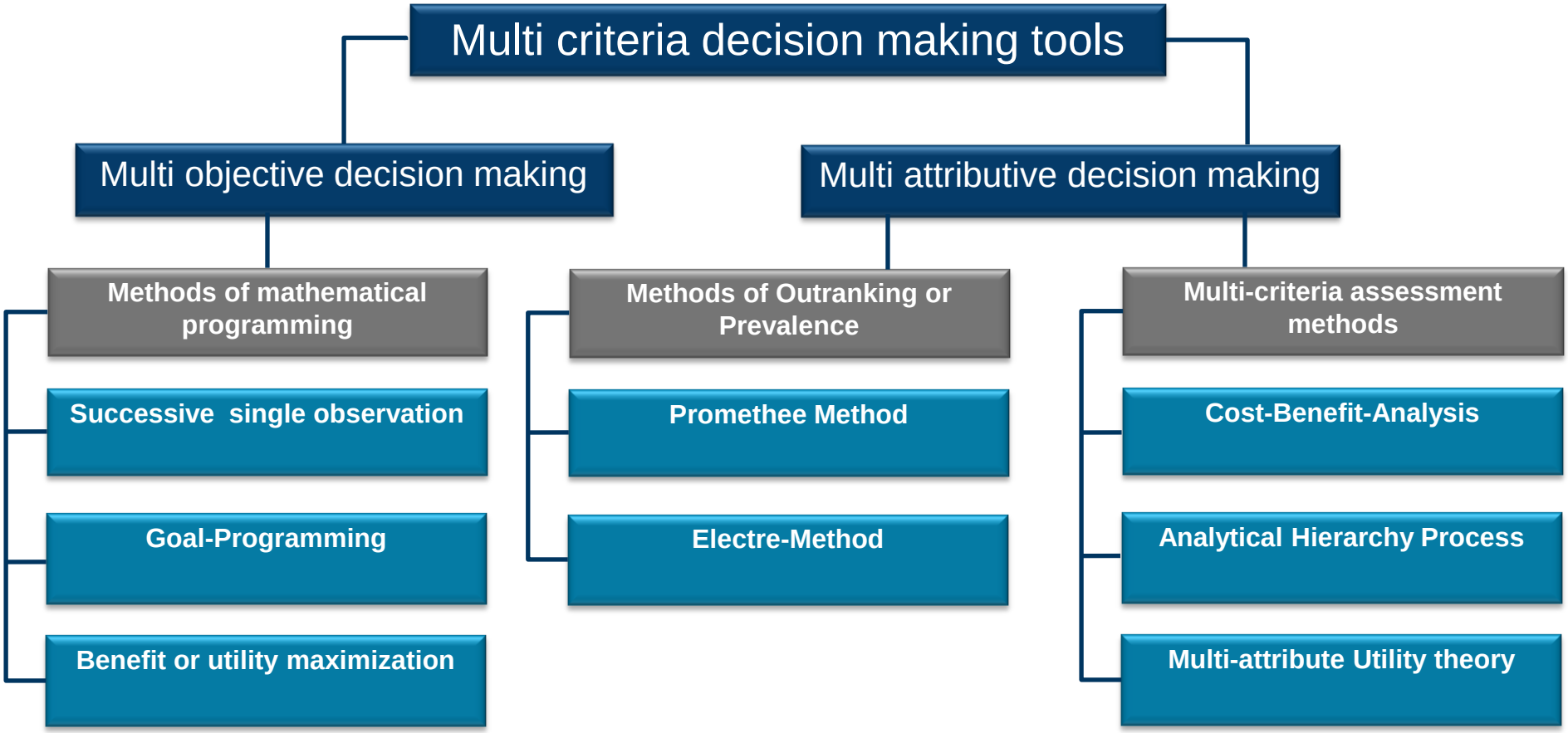


Value model

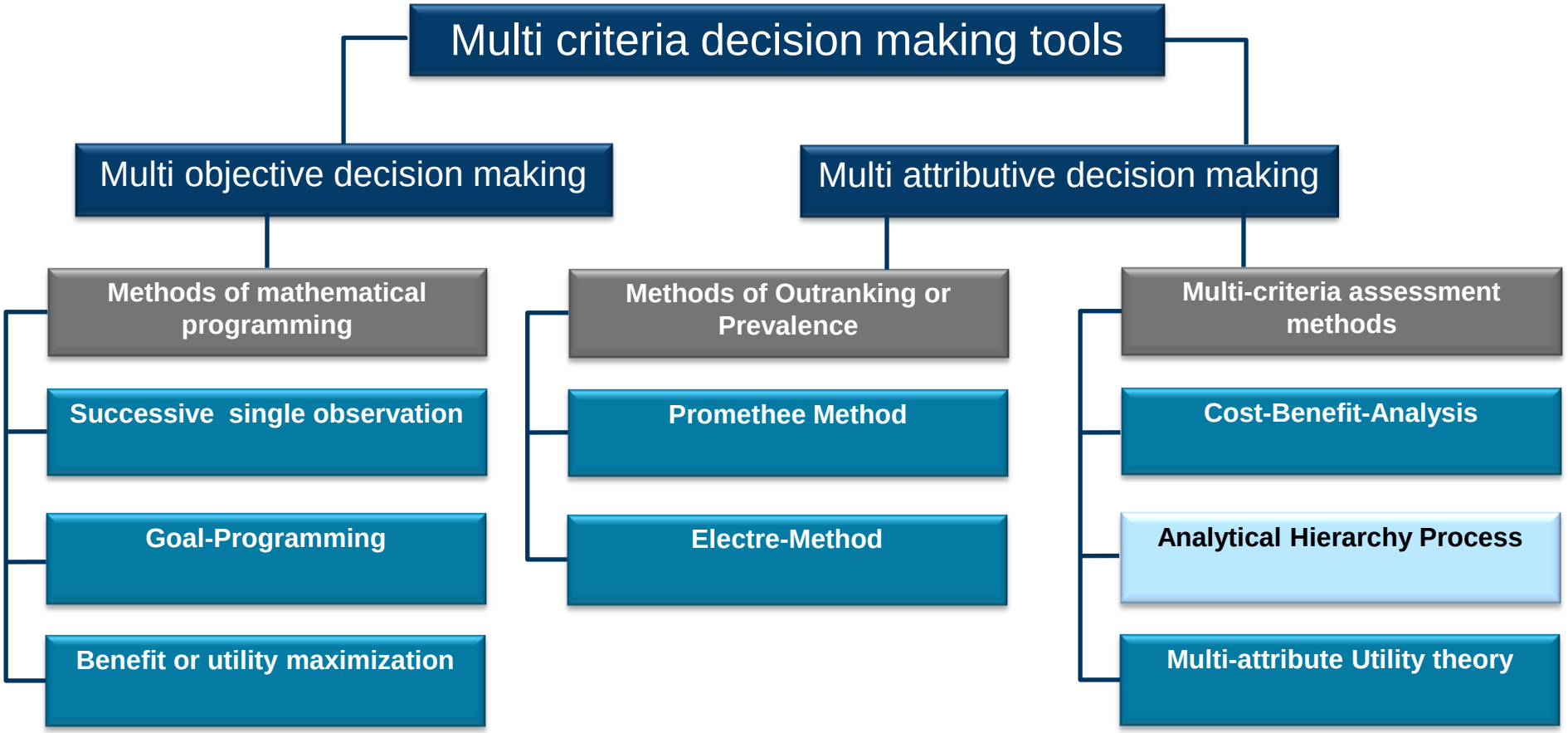
- Definition of the value model by target systems, criterions, corresponding indicators and their weighting
- Target system: Description of objectives aspired for safety & security purposes
- Classification in primary and secondary objectives or criterions
- Weighting



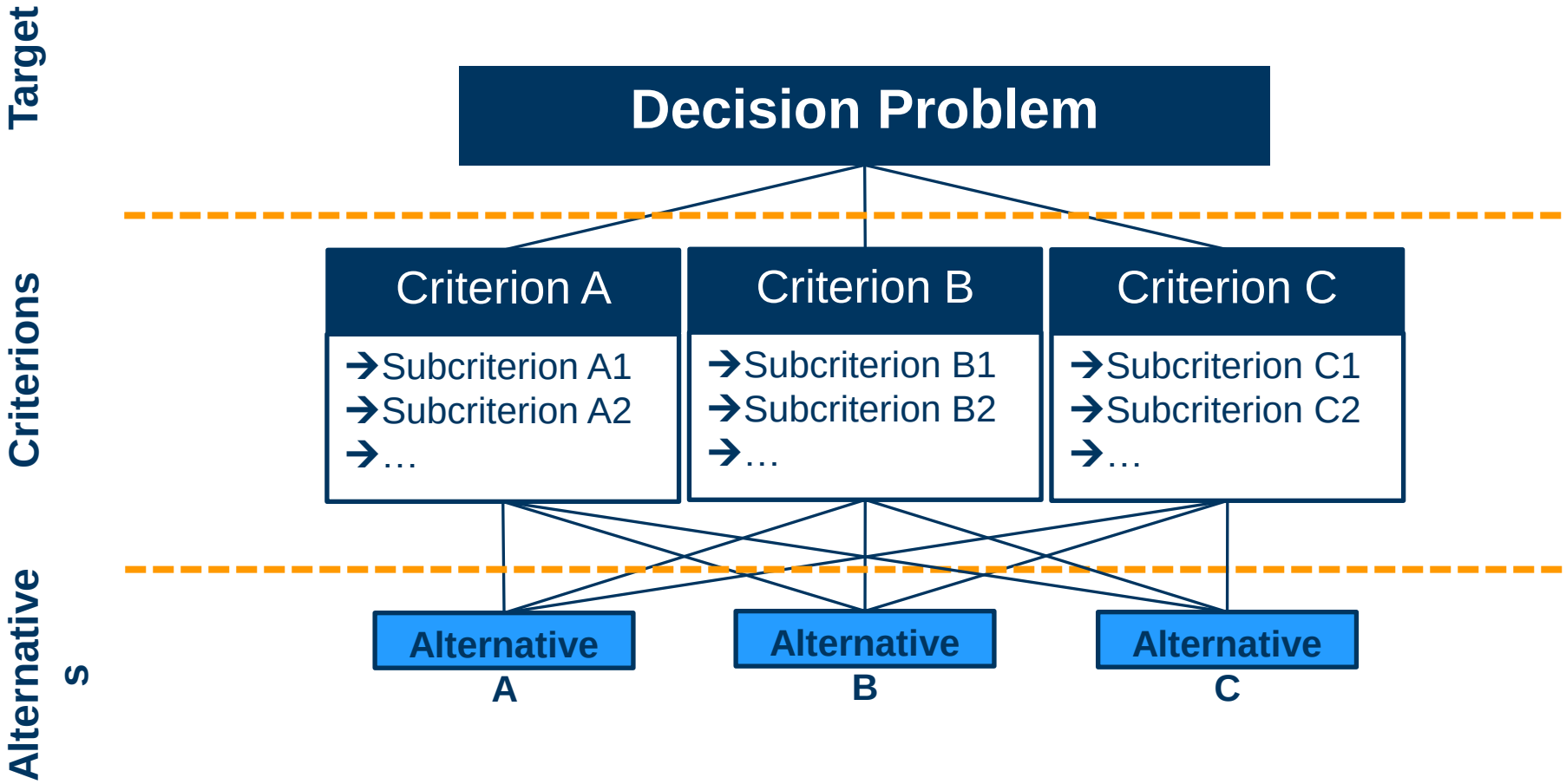
Decision theory



Decision theory



Building a hierarchical decision model for a holistic approach:



Criterion A ⟷ **Criterion C**

	Evaluation matrix			1. Square of matrix				1. weight
	A	B	C				ri	wi
A	1,000	4,000	2,000	3,000	8,667	16,000	27,667	**0,603**
B	0,250	1,000	3,000	2,000	3,000	6,500	11,500	**0,250**
C	0,500	0,333	1,000	1,083	2,667	3,000	6,750	**0,147**
SUM ci	1,750	5,333	6,000	6,083	14,333	25,500	45,917	1,000

Using qualitative or/and quantitative Data

$$w_i = \frac{\frac{1}{a_i}}{\frac{1}{a_1} + \frac{1}{a_2} + \ldots + \frac{1}{a_n}} \qquad i = 1, \ldots, n.$$

				Weight			
	Alternative A	Alternative B	Alternative C	Wa (A)	Wb (B)	Wc (SPC)	Sum
Subcriterion A1	50000 €	35000 €	25000 €	0,23	0,32	0,45	1
Subcriterion A2	10000 €	8000 €	15000 €	0,34	0,43	0,23	1
Subcriterion A3	10000 €	10000 €	12000 €	0,35	0,35	0,30	1

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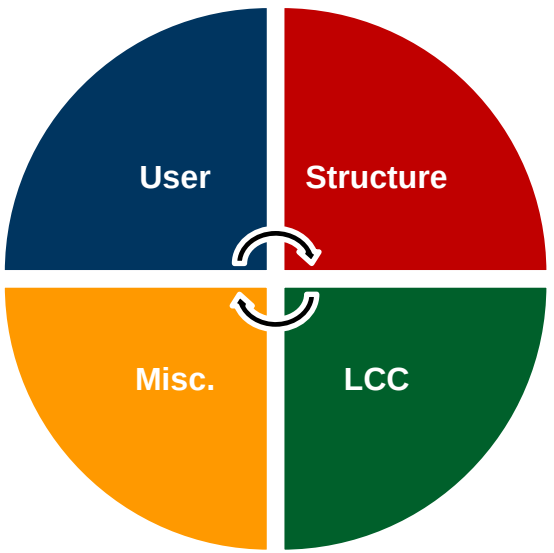
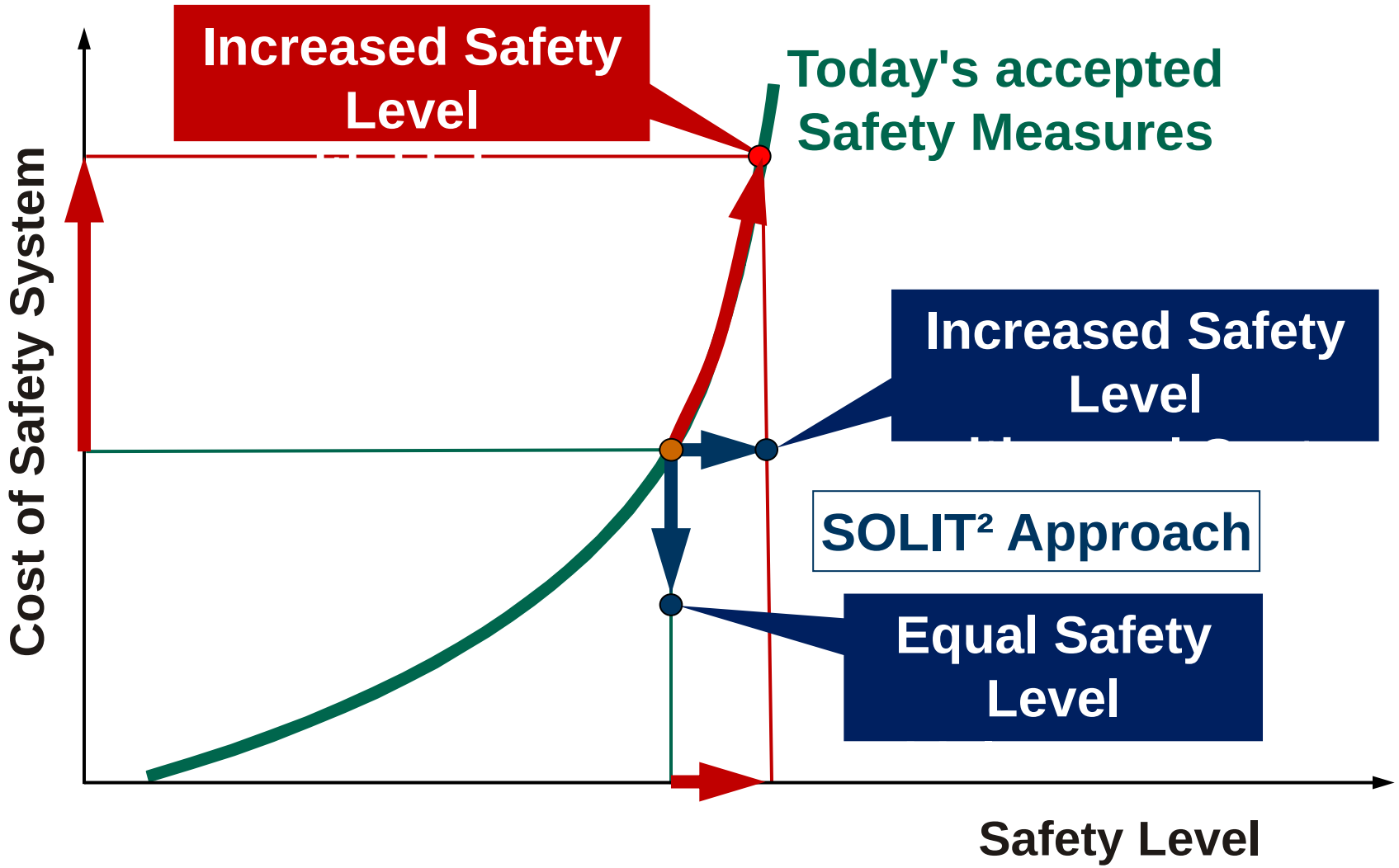
TLB

The scope of SOLIT²

- Is it possible to compensate “traditional” safety equipment by using water mist systems as a substitution?
- **Target :** lower level of risks while requiring an equal level of costs compared with “traditionally “ equipped tunnels:
- **Or:** equal level of risks while requiring a lower level of costs

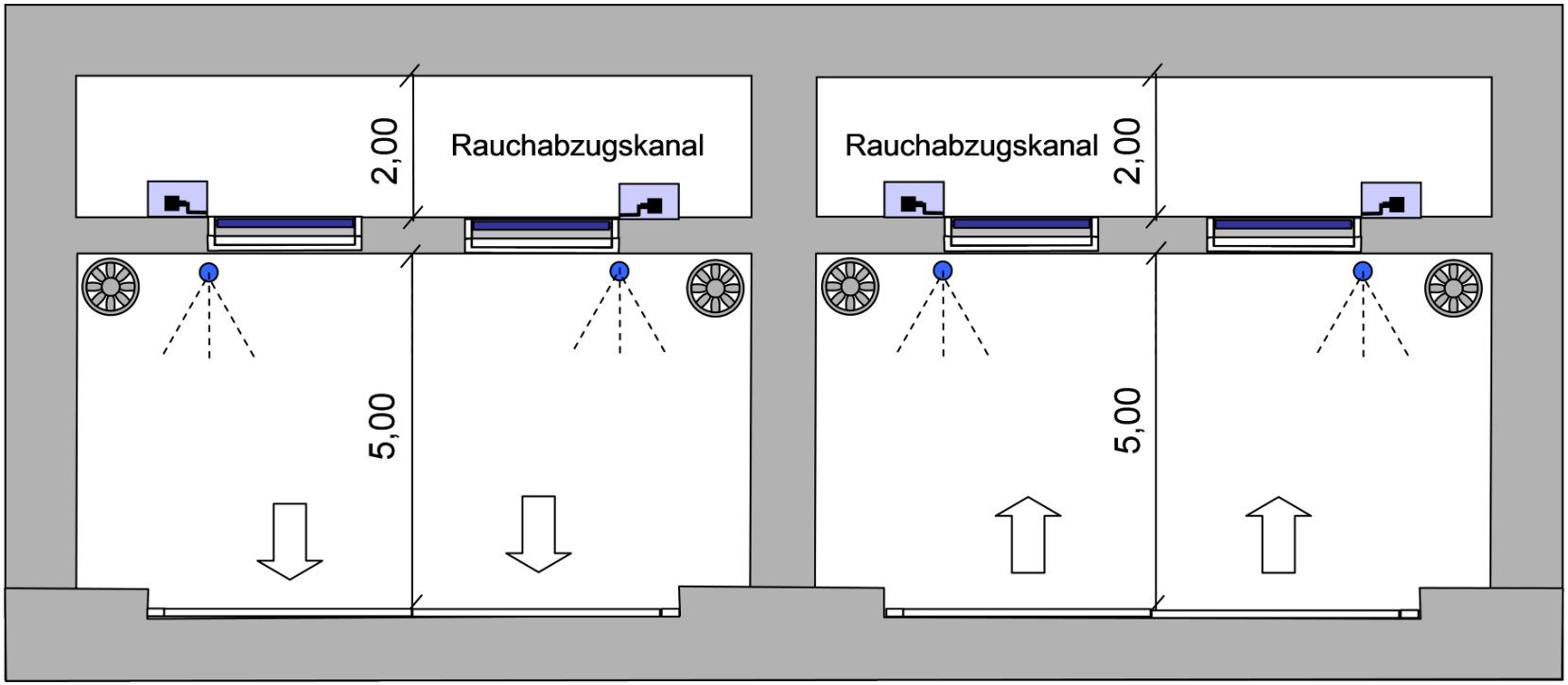


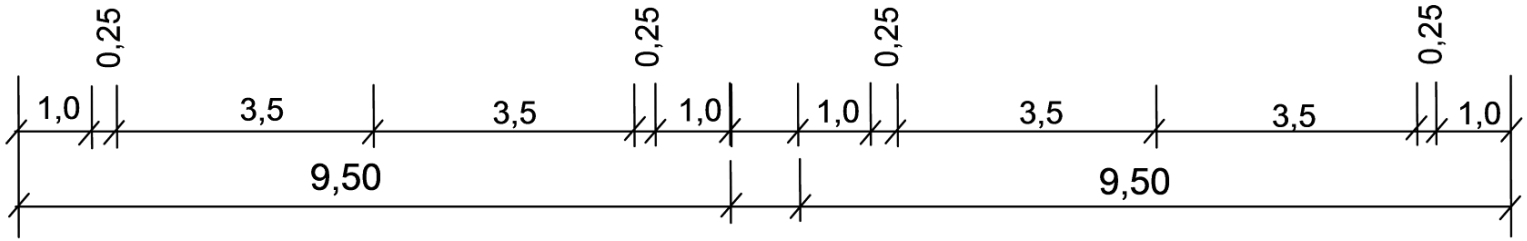

Increased Safety Level
Today's accepted Safety Measures
Increased Safety Level
SOLIT² Approach
Equal Safety Level
Cost of Safety System
Safety Level

Master tunnel design

- Square cross section:
  “RQ 31t” according to RAA (Richtlinien für die Anlagen von Autobahnen, Guidelines for the design of highways)
- False ceiling, exhaust gas tunnel
- Traffic volume (DTV): 20,000 vehicles/day per tube
- Fully equipped according to German RABT

Master Tunnel Design (Length: 3000 m)

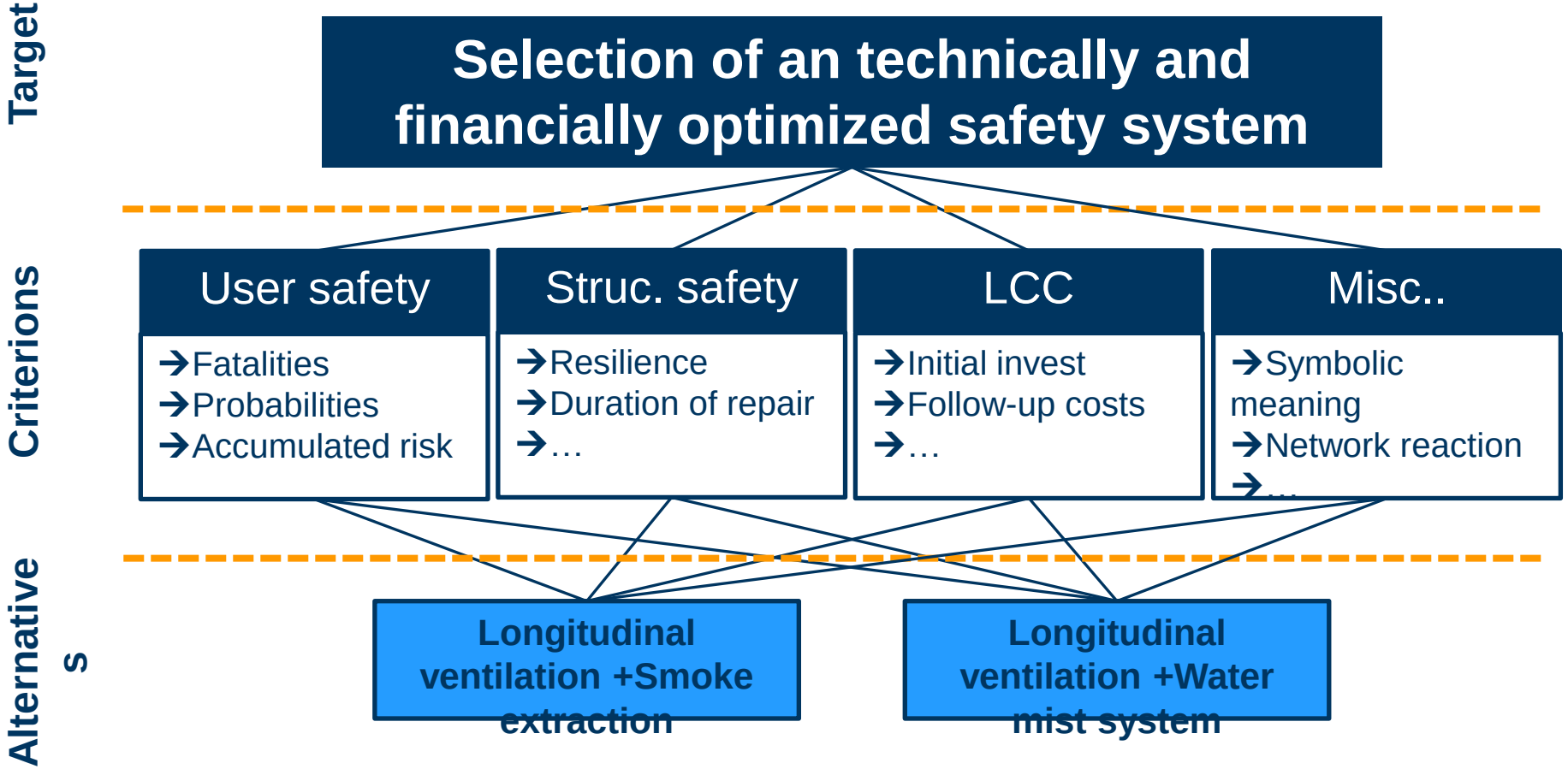




Compensated tunnel design

- Identical cross section
- **No** false ceiling
- Smoke extraction compensated by water mist system
- Identical traffic volume (DTV): 20,000 vehicles/day per tube
- Fully equipped according to German RABT

Adopting the hierarchical decision model:



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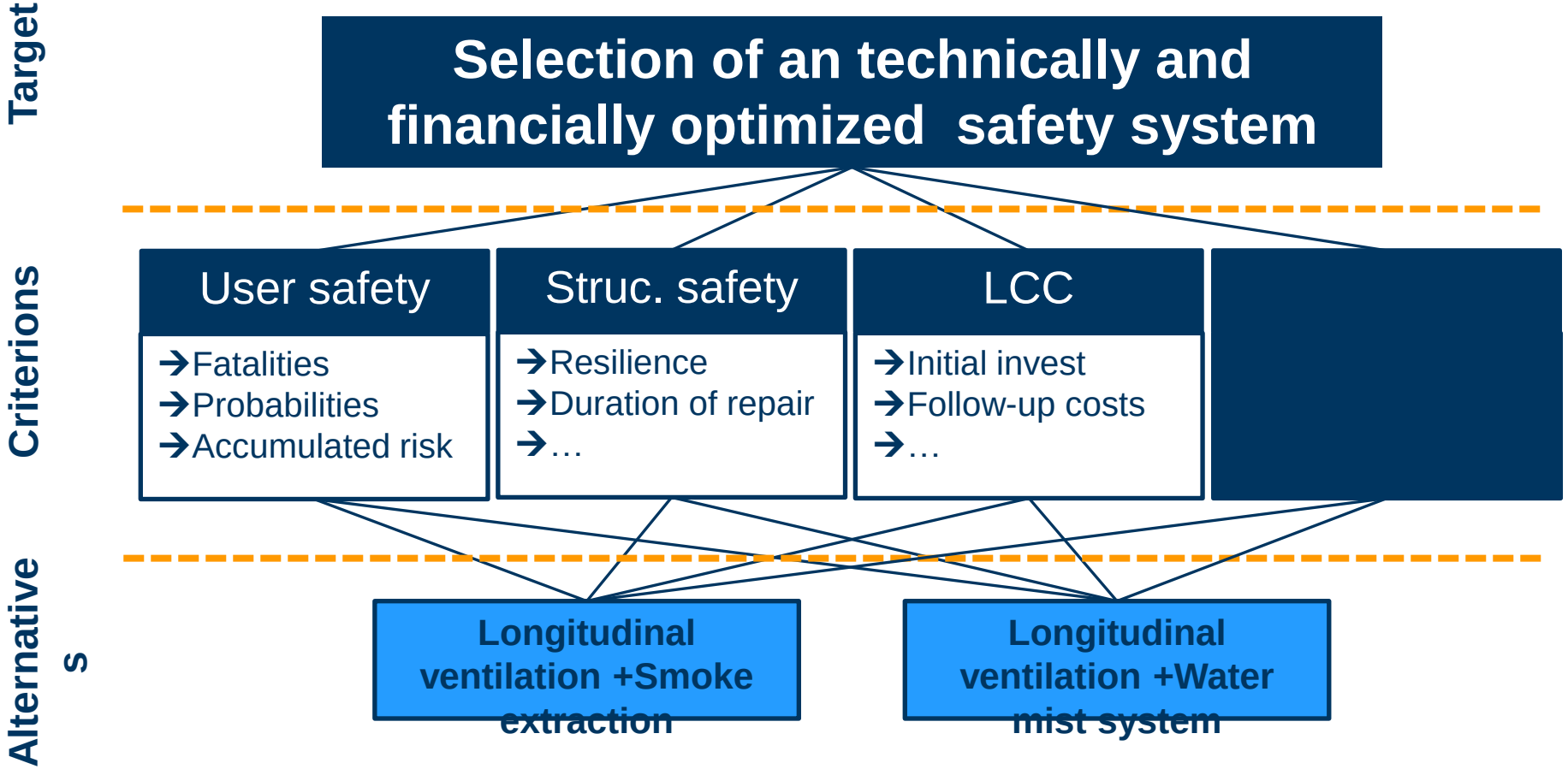
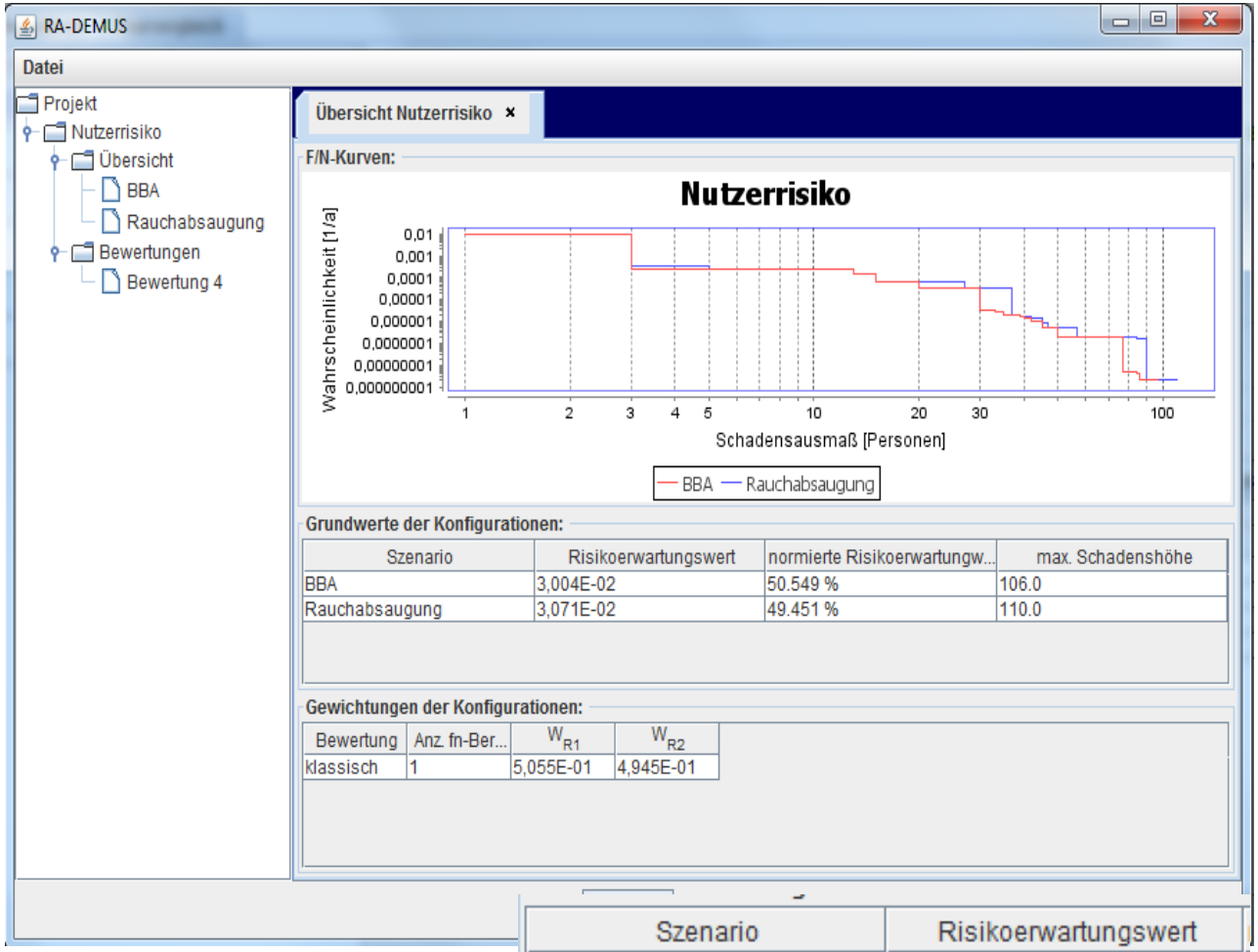


Exemplarily assessment

Assessment for a 100 MW pool fire

User safety

- ➔Fatalities
- ➔Probabilities
- ➔Accumulated risk



Szenario	Risikoerwartungswert
BBA	3,004E-02
Rauchabsaugung	3,071E-02

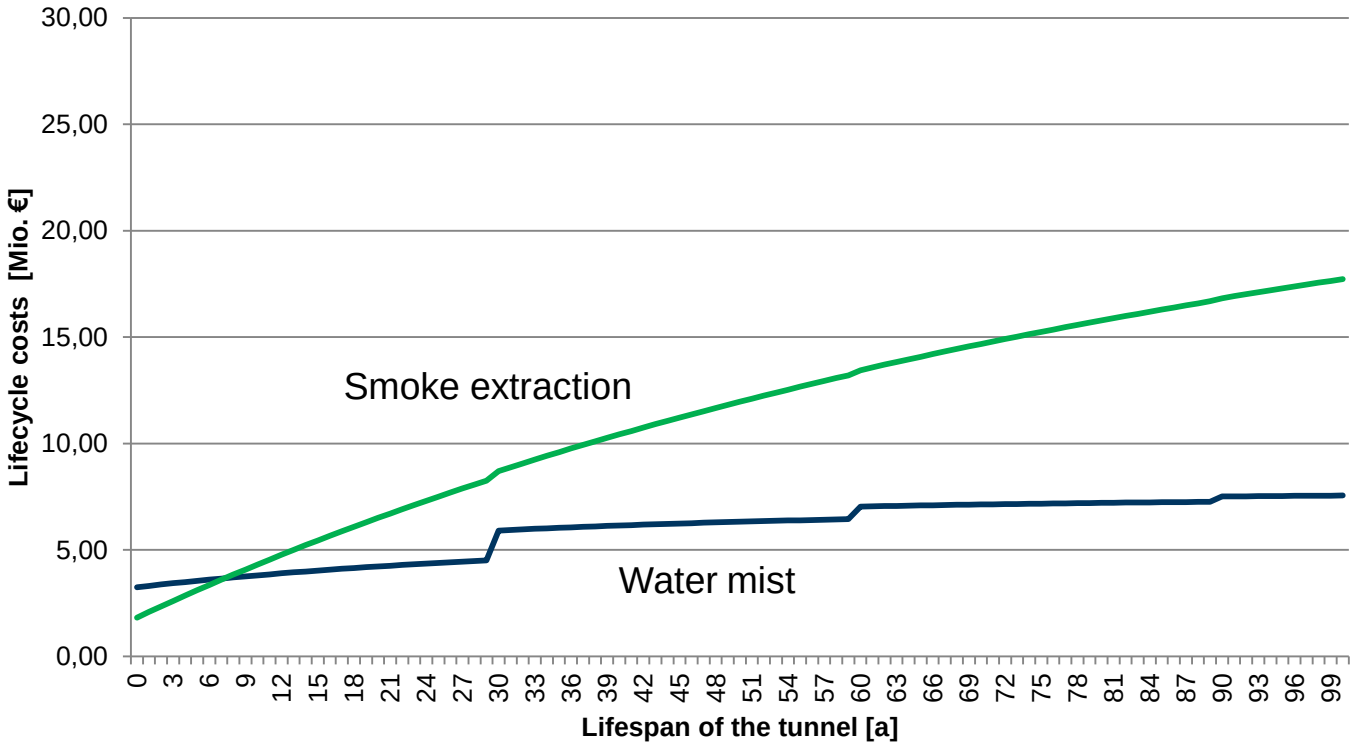
Exemplarily assessment

Assessment for a 100 MW pool fire

Alternative	NPV (t=100 a)	Initial costs	Follow-up costs
Smoke extraction	17.726.133,19 €	1.824.000,00 €	15.902.133,19 €
Water mist	7.554.501,84 €	3.250.000,00 €	4.304.501,84 €

LCC

- ➔Initial invest
- ➔Follow-up costs
- ➔…



Exemplarily assessment

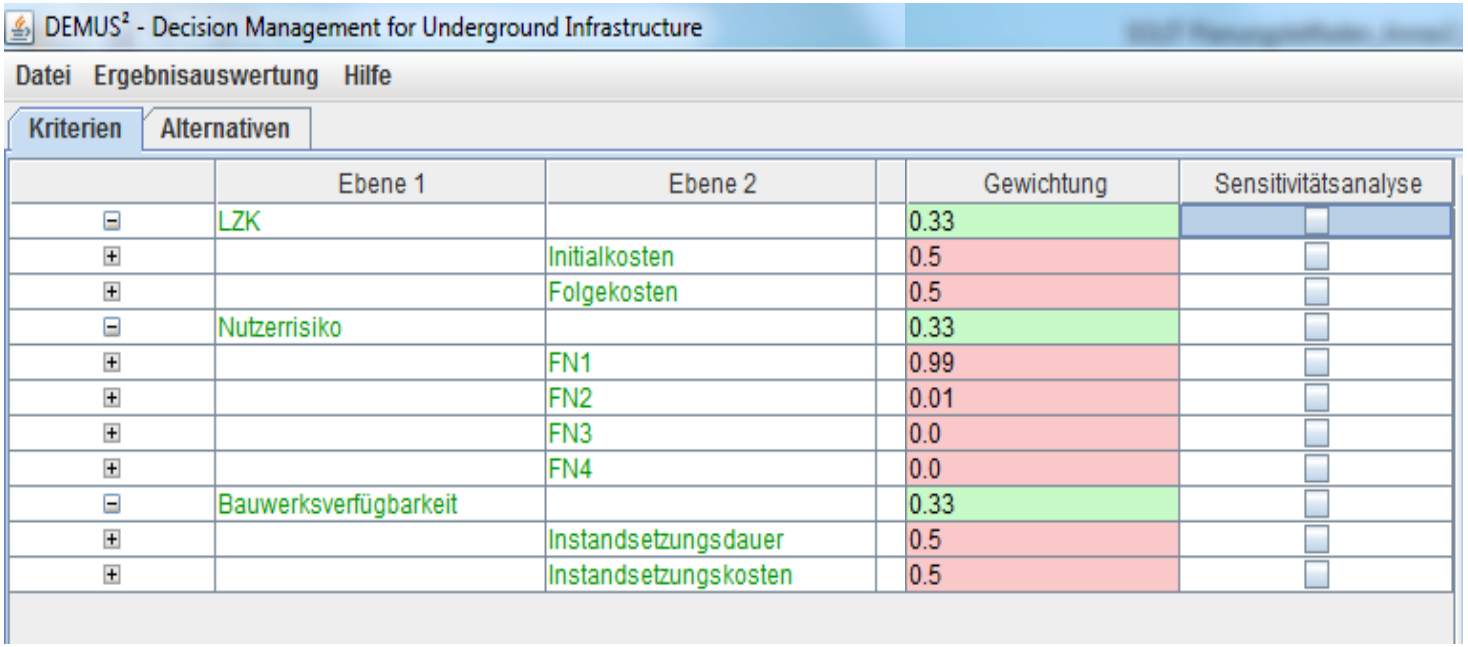
Assessment for a 100 MW pool fire

Struc. safety

→Resilience
→Duration of repair
→…

- Was not part of the assessment in SOLIT²
- Test results showed that max T within the test tunnel, especially at the crown and the inverts, was significantly reduced when using the water mist system
- With that in mind it‘s rather safe to say that the structural damage due to the fire would be reduced accordingly in a structural assessment
- Staying on the safe side an equal amount of damage was applied for both

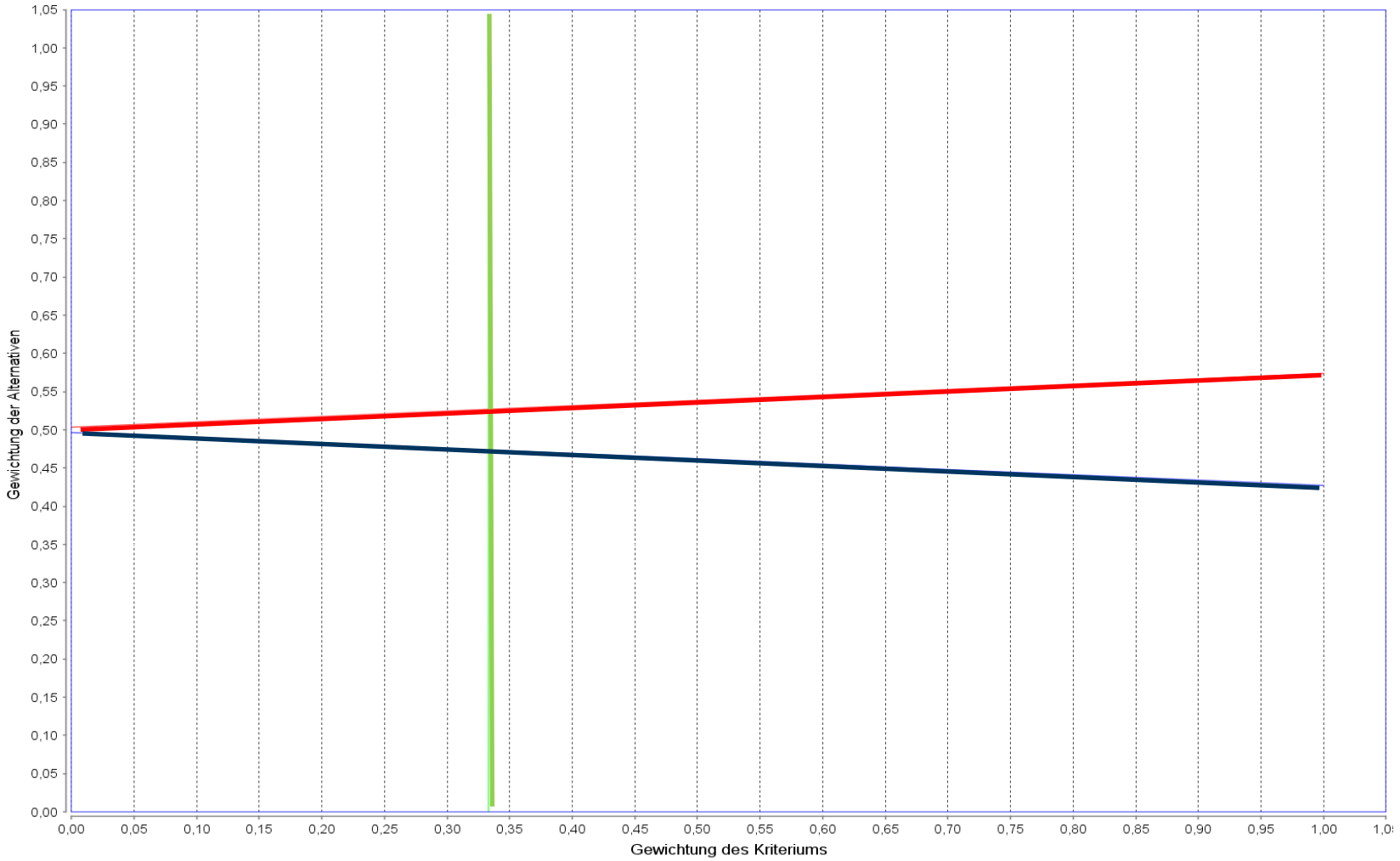
Prioritizations and overall result



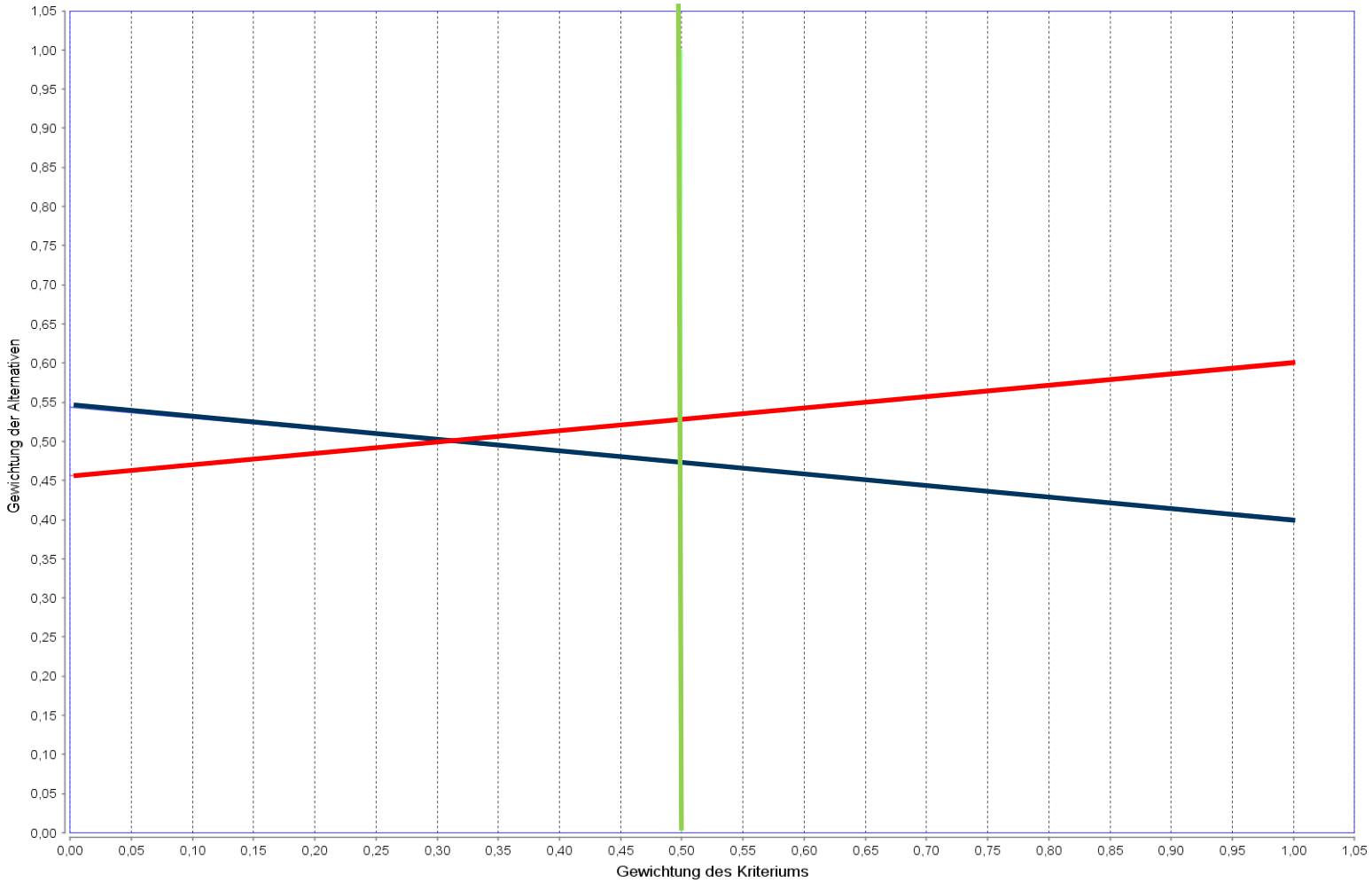
	Ebene 1	Ebene 2	Gewichtung	Sensitivitätsanalyse
⊟	LZK		0.33	
⊞		Initialkosten	0.5	
⊞		Folgekosten	0.5	
⊟	Nutzerrisiko		0.33	
⊞		FN1	0.99	
⊞		FN2	0.01	
⊞		FN3	0.0	
⊞		FN4	0.0	
⊟	Bauwerksverfügbarkeit		0.33	
⊞		Instandsetzungsdauer	0.5	
⊞		Instandsetzungskosten	0.5	

Alternatives	Weighting
Water mist	52,7%
Smoke extraction	47,3 %

Sensitivityanalysis for the main criterion “LCC”



Sensitivityanalysis for the sub criterion “Follow-up costs”



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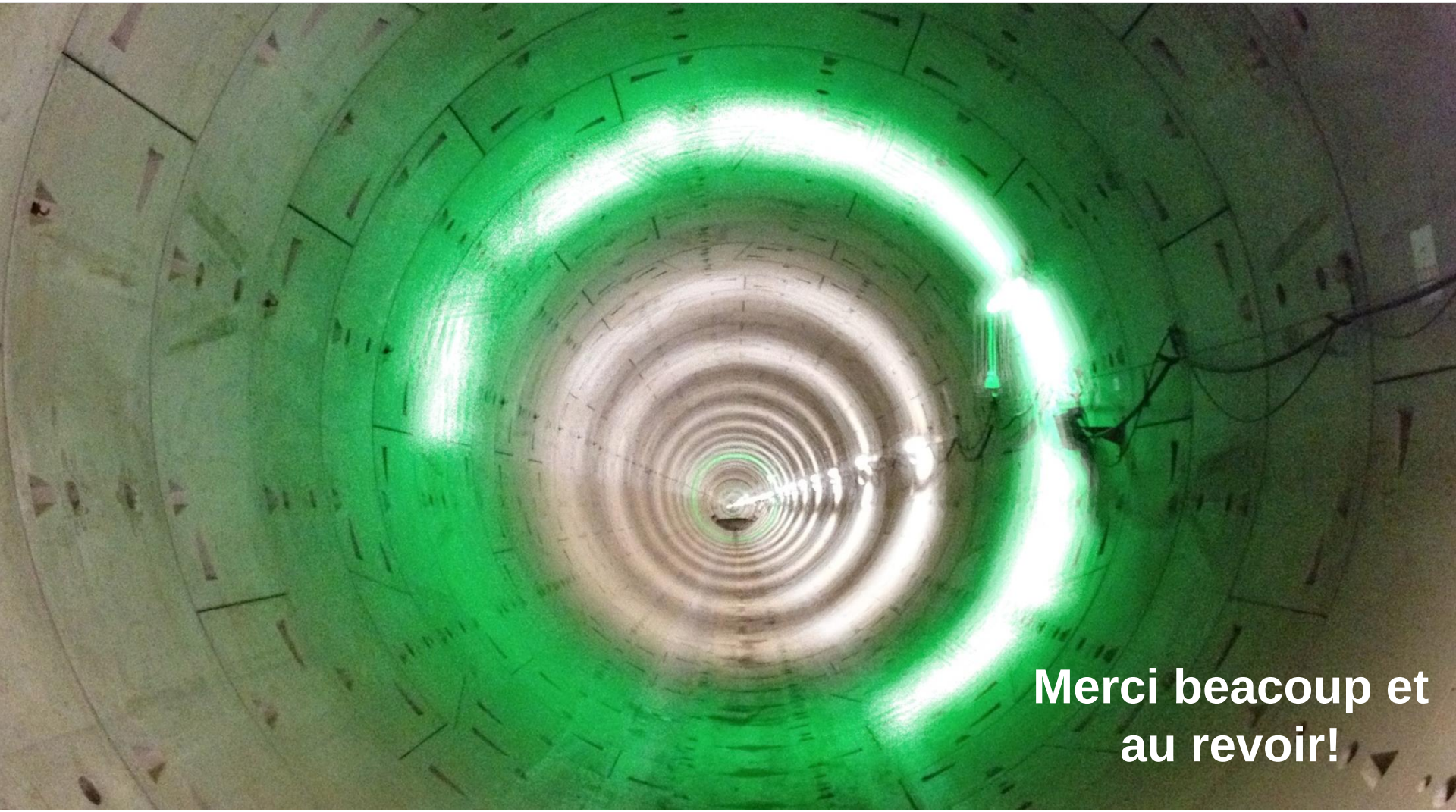
Conlusions

- For assessing the need for and the efficiency of specific measures, a safe design or of a systemic upgrade a holistic approach is needed
- Holistic approaches ask for different expert knowledge from varying fields of expertise to make the mandatory assessment possible
- Approaches like the AHP provide help for making transparent and traceable decisions



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