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Baseline values and an application of Robust Portfolio Modeling

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Content

1. **Baseline values – the main issue**
2. Methods on assessing the baseline values and their sensitivity
3. An example of Robust Portfolio Modeling – Bridge maintenance programming at Finnish Transport Agency

Baseline values – the basics

- Recap:
  - Value function of a project, where $[x_i^0, x_i^*]$ are scaled to be between 0 and 1

$$v(x^j) = \sum_{i=0}^{n} w_i v_i(x_i^j)$$

  - Value function of a portfolio

$$V(z) = V(z_1, \dots, z_m) = \sum_{j=0}^{m} z_j v(x^j) + (1 - z_j)v^{\mathrm{B}},$$

  - where v^B is the value when the project is not selected
- So far we have seen $v^B = 0$

Baseline values – implications of $v^B = 0$

$$v(v^B) = v(x_1^0, \dots, x_n^0) = \sum_{i=0}^{n} w_i v_i(x_i^0) = 0 + 0 + \ \dots + 0$$

- The scaling of the values implicitly assumes a baseline of 0, least preferred performance levels on each attribute
- Least preferred levels justified for not selecting a project?
  - Community hospital investments example from last week (NPV, [ratings, …]): $v^B = (-150, 0, 15, \dots, 0)$
  - What if all projects have strictly *negative levels* on the attributes? Strictly *positive*?

Baseline values – simple example

- Paper by Clemen and Smith (2009) walk through a project selection example originally by Kleinmuntz (2000) with different baseline values
- $v^B = (-\$13{,}750; \text{Uncertain}, 1)$

Project	Financial contribution ($)	Risk	Fit	Days required
A	200,000	Uncertain	5	800
B	−13,750	Probable	5	250
C	125,000	Safe	4	700
D	307,500	Safe	3	650
E	−1,250	Safe	2	350
F	393,000	Uncertain	2	800
G	442,500	Uncertain	2	600
H	265,000	Probable	1	400

Project	Financial contribution	Risk	Fit	Value score	Days required	Go?
A	0.47	0.00	1.00	0.617	800	0
B	0.00	0.50	1.00	0.625	250	1
C	0.30	1.00	0.75	0.701	700	1
D	0.70	1.00	0.50	0.676	650	1
E	0.03	1.00	0.25	0.382	350	1
F	0.89	0.00	0.25	0.348	800	0
G	1.00	0.00	0.25	0.375	600	0
H	0.61	0.50	0.00	0.278	400	1
Weight	0.25	0.25	0.5			
Total value						2.66
Total days required						2,350

Baseline values – simple example

- When the baseline is changed to $v^B = v(\$0, \text{Safe}, 1) = 0.258$,
  - E and H are replaced by A
- The mutual order of project values does not change, but preference over ***portfolios of multiple projects*** can change

Project	Financial contribution ($)	Risk	Fit	Days required
A	200,000	Uncertain	5	800
B	–13,750	Probable	5	250
C	125,000	Safe	4	700
D	307,500	Safe	3	650
E	–1,250	Safe	2	350
F	393,000	Uncertain	2	800
G	442,500	Uncertain	2	600
H	265,000	Probable	1	400

Project	Financial contribution	Risk	Fit	Value score	Inc. value score	Days required	Go?
A	0.47	0.00	1.00	0.617	0.360	800	1
B	0.00	0.50	1.00	0.625	0.367	250	1
C	0.30	1.00	0.75	0.701	0.443	700	1
D	0.70	1.00	0.50	0.676	0.418	650	1
E	0.03	1.00	0.25	0.382	0.124	350	0
F	0.89	0.00	0.25	0.348	0.090	800	0
G	1.00	0.00	0.25	0.375	0.117	600	0
H	0.61	0.50	0.00	0.278	0.020	400	0
Weight	0.25	0.25	0.5				
Total value							1.59
Total days required							2,400

Baseline values – interpretation of $V(z)$

$$V(z) = \sum_{j=0}^{m} z_j v(x^j) + (1 - z_j)v^{\mathrm{B}} = \sum_{j=0}^{m} z_j\left(v(x^j) - v^B\right) + v^B$$

$$= mv^B + \sum_{j=0}^{m} z_j\left(v(x^j) - v^B\right)$$

- The value of implementing a project is its value increase over not implementing it

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Baseline values – what to do?

- What are the proposed projects? Is there a natural baseline?
  - Pre-screening, selecting projects that are at least satisfactory
- Ask the DM, a project they are indifferent between implementing and not implementing
  - Comparing alternatives -> *incomplete information (1 dimensional)* -> inequalities of the ‘real’ baseline value
- Sensitivity analysis of the baseline value in its feasible set
  - Potentially optimal portfolios and their optimality ranges
  - Projects’ value-to-cost rankings

Baseline specification – elicitation

- Methodology presented here follows the paper by Liesiö and Punkka (2014)

- Starting point is to ask if x^0 would be implemented
- Presenting a list of alternatives each dominating the previous one to limit the v^B range
  - Is there a project that the DM would implement, but wouldn't implement the next one?

Baseline specification – elicitation

Project	Financial contribution ($)	Risk	Fit	Days required
A	200,000	Uncertain	5	800
B	−13,750	Probable	5	250
C	125,000	Safe	4	700
D	307,500	Safe	3	650
E	−1,250	Safe	2	350
F	393,000	Uncertain	2	800
G	442,500	Uncertain	2	600
H	265,000	Probable	1	400

- $v(\$0, \text{Safe}, 1) > v(\$0, \text{Probable}, 1) > v(-\$13{,}750; \text{Uncertain}, 1)$
- If the DM would only implement the first project

$$\underbrace{v(\$0, \text{`probable'}, 1)}_{\approx 0.133} \leqslant v^B \leqslant \underbrace{v(\$0, \text{`safe'}, 1)}_{\approx 0.258}.$$

Baseline specification – elicitation

- If $v^B < v(x^0) = 0$, each project is worth implementing, but at a portfolio level, which ones to select?
  - Example, for a budget of 5 units
    - $v^B < 0$
    - $v(x^j) = 0$ for all $j \in \{1, 2, 3\}$
    - $c^1 = 2, c^2 = 3, c^3 = 5$
- Remember:
  - $V(z) = mv^B + \sum_{j=0}^{m} z_j\left(v\left(x^j\right) - v^B\right)$
- How to elicit negative v^B?

Baseline specification – elicitation

- Example,
  - $m = 5$
  - $x^0 = (\$1000, \text{Uncertain}, 3), x^* = (\$6000, \text{Safe}, 5)$

- 1: DM prefers a portfolio $(x^0, x^0) \succ (x^*)$
- 2: DM prefers a portfolio $(x^*, x^*) \succ (x^0, x^0, x^0)$

$$V(z) = mv^B + \sum_{j=0}^{m} z_j\left(v\left(x^j\right) - v^B\right)$$

- (whiteboard)

Baseline specification – elicitation

- Works generally
  - P1: k times projects with attribute levels x^0
  - P2: $k - 1$ times projects with attribute levels x^*
- Find k' that the DM prefers
  - P1 when $k = k'$
  - P2 when $k = k' + 1$
  - -> $v^B \in [-k', k' + 1]$
- Previous example, $k' = 2$
- Comparison of any two portfolios with *unequal* number of projects can be used to elicit constraints on v^B

Baseline specification – where to?

- So far, elicitation
- Incomplete information in 1D
  - How to investigate the change of optimal portfolio as the $v^B \in (-\infty, 1]$ changes?
  - $V(z, v^B)$

  - Incomplete weight information from last week

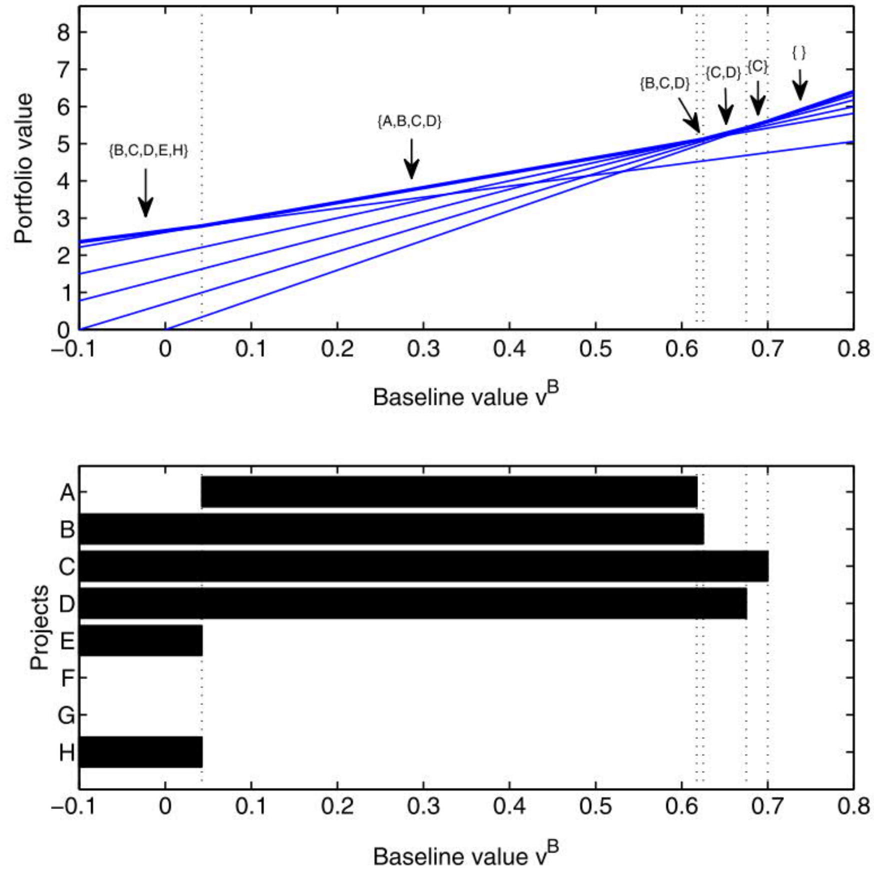
Potentially optimal portfolios

- A portfolio is *potentially optimal,* if for some feasible baseline value v^B its value is *at least as good as* the value of any of the other portfolios
- A portfolio can either be optimal for a single v^B or an interval $v^B \in [\underline{d}, \overline{d}]$
  - *Optimality range*

$$[\underline{d}, \overline{d}] = \{v^B \in (-\infty, 1] | z \in \text{argmax}_{z' \in Z_F} V(z', v^B))$$

Potentially optimal portfolios

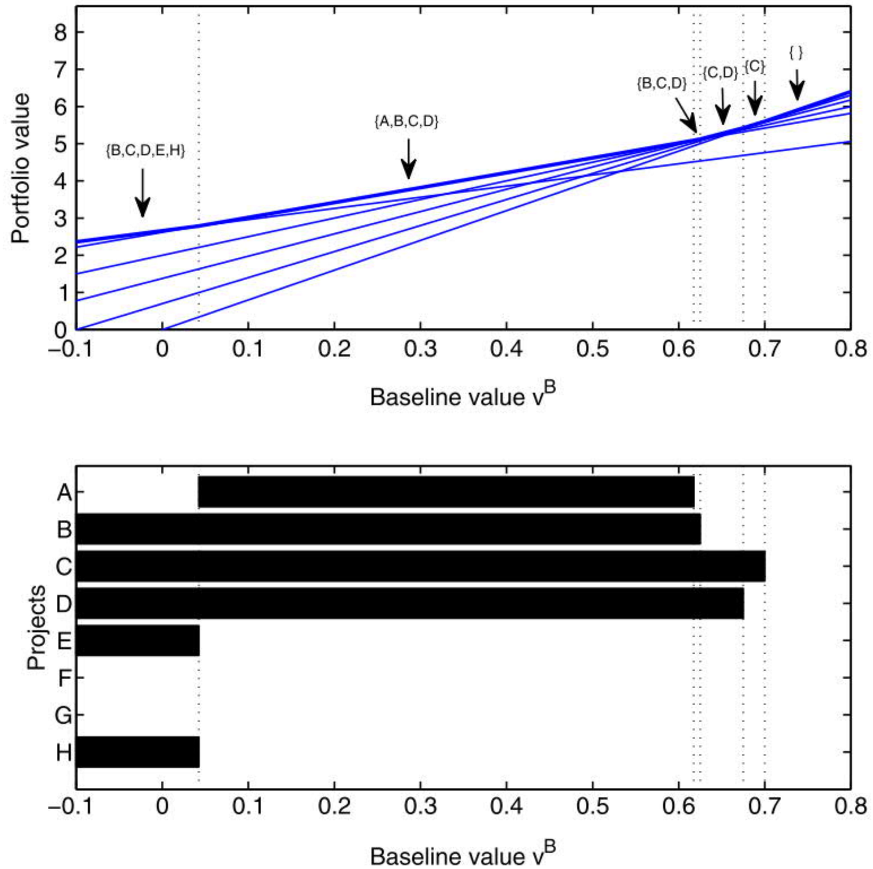
Project	Financial contribution ($)	Risk	Fit	Days required
A	200,000	Uncertain	5	800
B	–13,750	Probable	5	250
C	125,000	Safe	4	700
D	307,500	Safe	3	650
E	–1,250	Safe	2	350
F	393,000	Uncertain	2	800
G	442,500	Uncertain	2	600
H	265,000	Probable	1	400



- Liesiö and Punkka (2014) present an algorithm to find all the potentially optimal portfolios and optimality ranges

Potentially optimal portfolios

- The *size* of the potentially optimal portfolio determines its relative location of its optimality range



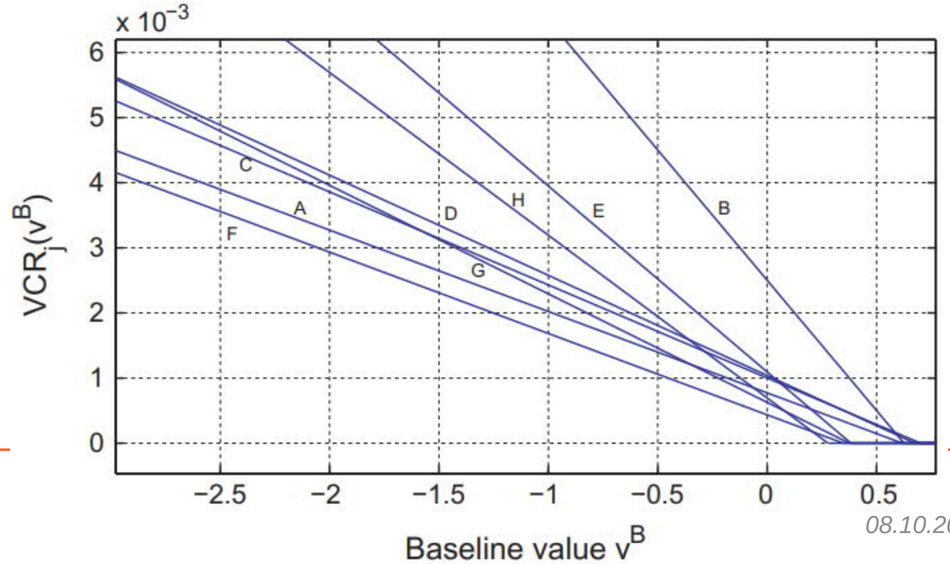
Projects’ value-to-cost ratios

- $VCR_j = \frac{v(x^j)}{c_j}$
  - Implicit assumption of $v^B = 0$
  - Intuition: efficiency of used resources
- $VCR_j(v^B) = \max\left(\frac{v(x^j)-v^B}{c_j}, 0\right)$
  - Intuition: efficiency of *gained* value
  - Works as a project prioritization rule for budgets that are not fixed

Projects' value-to-cost ratios

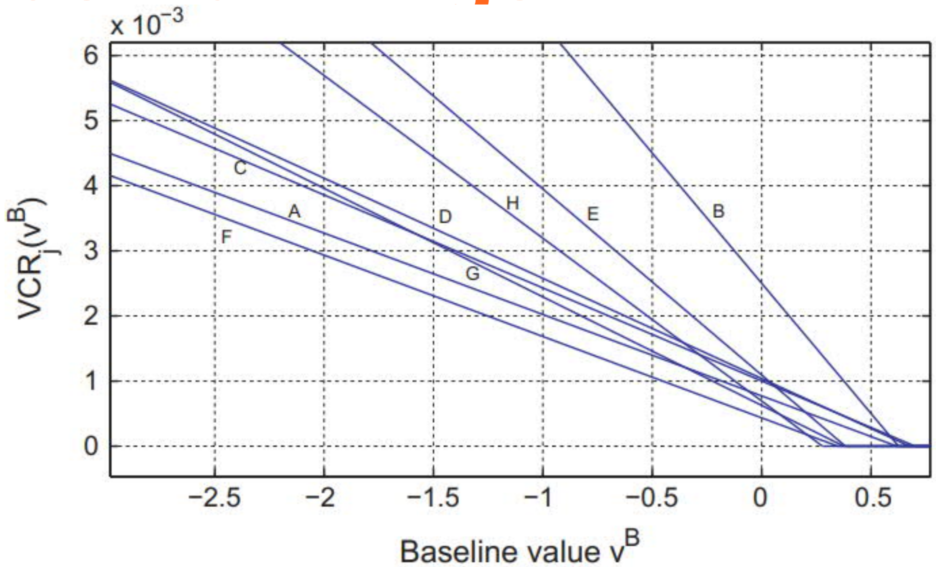
- VCR is consistent with dominance
  - At least as good for all, strictly better for some
  - B has the third largest value after C and D is the least expensive
- Ranking of the projects?

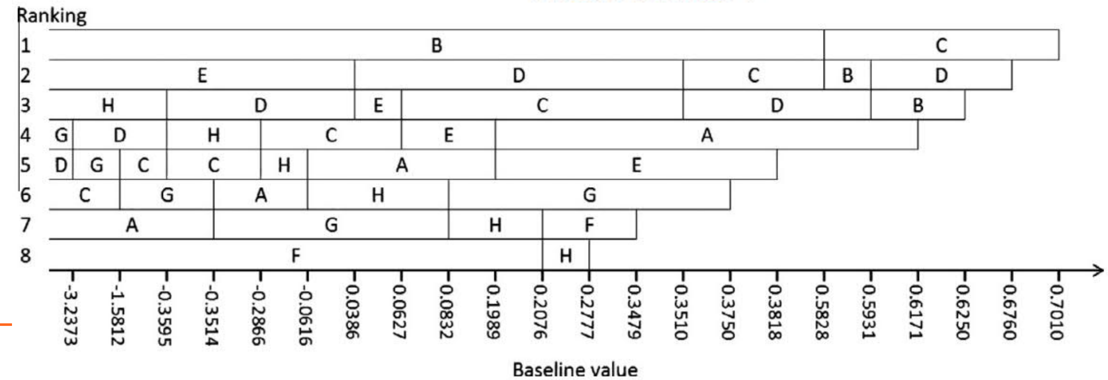
Project	Financial contribution ($)	Risk	Fit	Days required	Value score
A	200,000	Uncertain	5	800	0.617
B	–13,750	Probable	5	250	0.625
C	125,000	Safe	4	700	0.701
D	307,500	Safe	3	650	0.676
E	–1,250	Safe	2	350	0.382
F	393,000	Uncertain	2	800	0.348
G	442,500	Uncertain	2	600	0.375
H	265,000	Probable	1	400	0.278



Projects’ value-to-cost rankings

- Liesiö and Punkka (2014) present an algorithm to compute the VCR rankings





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Recap: Sensitivity analysis

- Potential optimality and VCR provide insight on the changing optimal portfolios over different baseline values
- Help in elicitation
  - No need for search patterns
  - For instance, whether a project(s) corresponding to a ‘critical’ v^B is worth implementing

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Application of Robust Portfolio Modeling – bridge repair selection (FTA)

- Road bridges:
  - Different profiles, different states in the life cycle
  - Repair prioritization required
  - Objectives: minimize maintenance costs, maximize safety
  - What bridges should be selected for repair, given a (yearly) budget?
- Planning horizon of three years
  - Bridge inspections not necessarily up-to-date
  - Flexibility in decision timings, not now-or-never
- *Repeated application*

RPM application – Attributes

The criteria used in the RPM model.

i	Criterion name	Motivation (value base)	Measurements (data)	Scale
1	Sum of damages	Key measure of overall condition, reporting	Standardized numerical index entitled 'VPS'	Continuous
2	Traffic significance	Significance of bridge, number of users	Road category Traffic volume	Discrete Discretized
3	Width deficiency	Bottleneck for traffic flow, safety risk	Difference between road and bridge width	Discretized
4	Carrying deficiency	Bottleneck for heavy trucks, safety risk	Carrying capacity category	Discrete
5	Exposure to salt	Faster deterioration and sensitivity to damages	Construction material Salt sources	Discrete Discrete
6	Visual appearance	Customer satisfaction (marginal role in VPS)	Site category Tidiness classification	Discrete Discrete

RPM application – Model

$$V(p, w, v) = \sum_{j=1}^{m} z_j(p) \sum_{i=1}^{n} w_i v_i^j$$

- Incomplete information of the attribute weights
  - Sum of damages ≥ traffic, functional deficiencies ≥ exposure to salt, visual appearance ≥ 0,02
- v^B = 0 !
  - Check with the DM, does x^0 require maintenance?
- Core Index, share of non-dominated portfolios containing a project

RPM application – Costs and constraints

- Planning horizon of three years
- Different districts
- Constraints:
  - Budget (total)
  - Maximum number of bridges (district)
  - Minimum damage point sum reduction (total)
- Unit maintenance cost measure €/m^2 by the deck area depending on type, material and condition
  - Correlations: size -> traffic -> damage -> cost

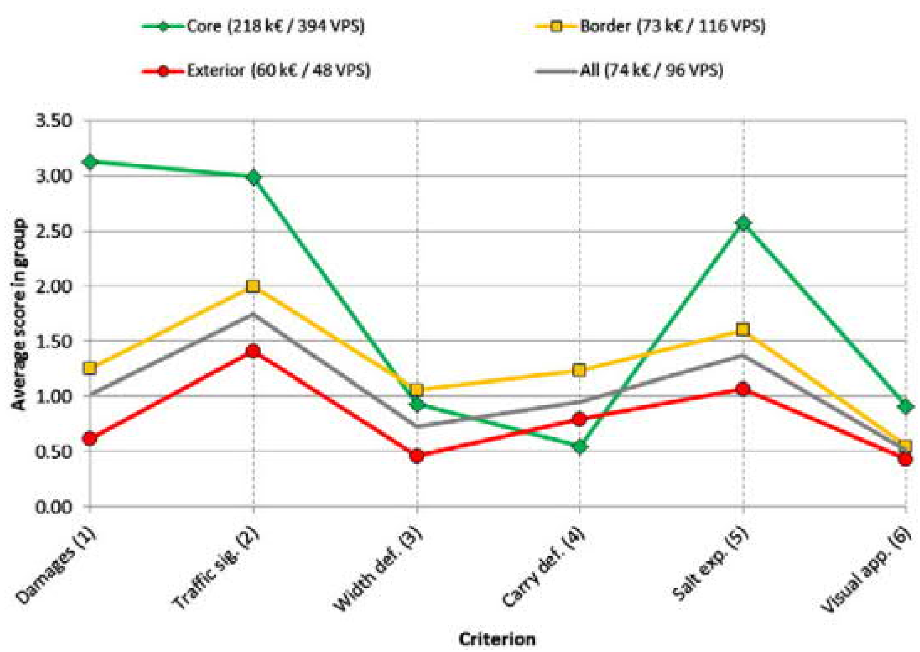
RPM application – Results

- Different relative size budgets, different Core Index ratios

Case	Constraints and number of bridge candidates				Core Index results		
District	Budget	Max number	Min VPS	Candidates	Core	Border	Exterior
A	15.0	120	18,000	606	34	232	340
B	4.5	33	4000	183	8	78	97
C	6.0	39	7500	319	7	99	213
D	9.0	90	12,000	385	22	178	185
E	10.0	75	10,000	222	30	106	86

RPM application – Results

- Core bridges have high wear profiles
- Borderline bridges more difficult to evaluate without such a model
- Cost and size budgets:
  - Fewer large bridges, but portfolios of only smaller bridges infeasible



RPM application – Results

Identification		Core	Criteria scores						Parameters		Condition, age, traffic, size, material etc					
ID	Name	Index	C 1	C 2	C 3	C 4	C 5	C 6	Cost	VPS	Facts	Facts	Facts	Facts	Facts	Facts
71	Lupajan silta	1.00	3.80	3.0	1	0	3.00	0.67	158000	428	...	...	...	...	...	...
163	Rödhällsund	1.00	2.89	2.5	2	1	3.00	1.33	75000	325	...	...	...	...	...	...
178	Vähäjoen silt	1.00	2.86	4.0	1	0	3.00	0.00	279000	321	...	...	...	...	...	...
180	Raisionjoen s	1.00	2.36	4.0	1	0	3.00	1.33	172000	177	...	...	...	...	...	...
622	Lapinjoen silt	1.00	4.00	3.5	1	0	3.00	1.33	242000	787	...	...	...	...	...	...
643	Lapin silta	1.00	3.02	2.0	4	3	0.00	0.00	80000	340	...	...	...	...	...	...
666	Kappelinsalm	1.00	3.64	2.5	1	1	3.00	1.33	142000	410	...	...	...	...	...	...
700	Loimijoen silt	1.00	4.00	3.5	1	0	3.00	2.00	588000	724	...	...	...	...	...	...
707	Rausenojan	1.00	2.26	3.5	0	0	3.00	0.67	56000	283	...	...	...	...	...	...
762	Friitalan silta	1.00	3.62	3.0	4	3	2.25	2.00	180000	271	...	...	...	...	...	...
821	Harjunpään j	1.00	3.46	3.5	1	0	3.00	1.33	210000	390	...	...	...	...	...	...
2390	Skanssinmä	1.00	3.26	4.0	0	1	4.00	0.00	104000	244	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
651	Raakkuun sil	0.99	4.00	1.0	1	3	0.00	0.67	23000	512	...	...	...	...	...	...
931	Matalaojan si	0.99	1.88	3.5	1	0	3.00	1.33	221000	212	...	...	...	...	...	...
754	Tulkkilan silta	0.98	4.00	0.0	4	3	0.00	1.33	301000	2485	...	...	...	...	...	...
1807	Korven ristey	0.90	1.28	4.0	0	0	4.00	0.67	105000	96	...	...	...	...	...	...
1389	Kilpijoen silta	0.84	2.73	0.0	2	4	0.00	1.33	11000	307	...	...	...	...	...	...
489	Paavolan silt	0.75	1.66	1.0	3	3	0.00	1.33	32000	187	...	...	...	...	...	...
64	Haaron silta	0.62	1.82	0.0	4	3	0.00	0.67	17000	136	...	...	...	...	...	...
31	Piikkiönjoen s	0.44	0.26	3.0	4	0	3.00	1.33	67000	19	...	...	...	...	...	...
1591	Lähteenojan	0.44	2.26	0.0	2	2	0.00	0.67	21000	254	...	...	...	...	...	...
528	Savikosken s	0.37	2.55	0.0	2	0	0.00	1.33	88000	287	...	...	...	...	...	...
1497	Mökköisten s	0.27	1.43	0.0	4	2	0.00	0.67	62000	161	...	...	...	...	...	...
487	Kurkelan silta	0.11	1.56	2.0	0	0	3.00	1.33	161000	117	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
54	Muurlanjoen	0.00	1.43	2.0	0	1	0.00	0.67	52000	107	...	...	...	...	...	...

Summary

- Baseline values should be considered in portfolio modelling applications
- Potential optimality and value-to-cost rankings provide insight on the result sensitivity
- Core Indexes of the non-dominated alternatives can be used to provide decision recommendations under incomplete information

References

- Mild, P., Liesiö, J., Salo, A., 2015: Selecting Infrastructure Maintenance Projects with Robust Portfolio Modeling, Decision Support Systems 77, s. 21-30.
- Kleinmuntz, D. N. 2000. CBA Associates. Department of Business Administration, University of Illinois at Urbana-Champaign, Champaign, IL.
- Clemen, R. T., Smith, J. E., 2009: On the Choice of Baselines in Multiattribute Portfolio Analysis: A Cautionary Note, Decision Analysis 6/4, s. 256-262.
- Liesiö, J., Punkka, A., 2014: Baseline Value Specification and Sensitivity Analysis in Multiattribute Project Portfolio Selection, European Journal of Operational Research 273/3, s. 946-956.

Homework – Potential optimal alternatives, an iterative approach

- Consider the project selection example of the presentation with slight changes to the attribute values
- The value functions are linear for each of the attributes (compare to slide 5 if uncertain)
- Budget for days: 2500

Project	Financial contribution ($)	Risk	Fit	Days required
A	200,000	Probable	2	850
B	−13,750	Uncertain	3	450
C	125,000	Safe	4	700
D	307,500	Safe	3	650
E	−1,250	Safe	2	350
F	393,000	Uncertain	2	800
G	442,500	Uncertain	2	600
H	265,000	Probable	1	400

- Note that the attribute Fit it is now 1-4, which affects the scaling

$$\text{max.} \sum_{j \in \{A,B,\ldots H\}} z_j\left(v^j - v^B\right) + v^B$$

$$\text{s. t.} \sum_{j \in \{A,B,\ldots H\}} c_j z_j \leq 2500$$

$$z \in \{0, 1\}$$

Homework – Potential optimal alternatives, an iterative approach

- What happens now when $v^B \in [-1, 1]$? Small example like this can be iterated by testing out “all” of the baseline values (e.g. *for vB = -1:0.01:1: …*)
- Task 1: Solve the problem, using e.g. Matlab/Julia(/Excel)
- Task 2: comment briefly on the changes, e.g., how is v^B range affected and what projects are now preferred (compare slide 17)

Project	Financial contribution ($)	Risk	Fit	Days required
A	200,000	Probable	2	850
B	−13,750	Uncertain	3	450
C	125,000	Safe	4	700
D	307,500	Safe	3	650
E	−1,250	Safe	2	350
F	393,000	Uncertain	2	800
G	442,500	Uncertain	2	600
H	265,000	Probable	1	400

- The goal is to underline the relation between scaling and v^B, and to practice optimization
- Submit the results to *tommi.anttila@aalto.fi* due 15.10. 9:00
  - Use headline “MS-E2191 hw7”
- If you end up completely stuck, ask me on Telegram @tommila or by mail