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Interactive multi-scenario multi-objective robust optimization for decision-making under deep uncertainty

Babooshka Shavazipour *, *Jan Kwakkel***, *Kaisa Miettinen**

*Faculty of Information Technology, University of Jyväskylä, Jyväskylä, Finland
**Faculty of Technology, Policy and Management, Delft University of Technology, Delft, The Netherlands

Contributions

- Let the decision-maker direct the search for robust strategies
- More interactions
- Lower computation cost and time
- Increase the confidence
- More efficient for too many objectives (say more than 10)
- More robust solutions via multi-scenario MOP
- A new benchmark problem for robustness analysis

The proposed two-phase interactive framework

MORDM

1. Model Specification
objectives, constraints, uncertainties, robustness, etc.

2. Solution identification
Using a multi-objective (evolutionary) method with a reference scenario (at a time)

3. Robustness analysis
(Re-)evaluation over a wide variaty of scenarios

4. Scenario Discovery
Identify vulnerable scenrios

Kasprzyk et al. (2013)*

Phase 1: Scoping the model

1a. Decision problem definition
Decision variables, objectives, constraints, uncertain factors, robustness measures

1b. Scenario analysis
(i) Scenario generation,
(ii) Feasible regions & ideal values
(iii) Vulnerable scenarios

Phase 2: Interactive robust decision-making

2a. Preferences expression
i) Scenarios to be considered (optional)
ii) Desired objective values in selected scenarios
iii) Max num. of solutions to be compared (optional)

2b. Solution identification
Solve a multi-scenario multi-objective optimization problem

2c. Tradeoffs analysis & decision-making
Comparing solutions & tradeoffs/robustness analysis

* **MORDM**: Kasprzyk JR, Nataraj S, Reed PM & Lempert RJ (2013), 'Many objective robust decision making for complex environmental systems undergoing change', Env. Mod. & Soft. 42, 55–71.
RDM: *Lempert et al.* (2006), '*A general, analytic method for generating robust strategies and narrative scenarios*', *Management Science* 52(4), 514– 528.

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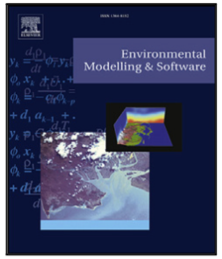

Position Paper

Check for updates

Let decision-makers direct the search for robust solutions: An interactive framework for multiobjective robust optimization under deep uncertainty

Babooshka Shavazipour [a,*], Jan H. Kwakkel [b], Kaisa Miettinen [a]

[a] *University of Jyvaskyla, Faculty of Information Technology, P.O. Box 35, (Agora), FI-40014, University of Jyvaskyla, Finland*
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ARTICLE INFO

Dataset link: https://zenodo.org/records/12709705

Keywords:
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Scenario planning
Robust decision making
Interactive methods
Multiple criteria decision-making
Future uncertainty

ABSTRACT

The robust decision-making framework (RDM) has been extended to consider multiple objective functions and scenarios. However, the practical applications of these extensions are mostly limited to academic case studies. The main reasons are: (i) substantial cognitive load in tracking all the trade-offs across scenarios and the interplay between uncertainties and trade-offs, (ii) lack of decision-makers' involvement in solution generation and confidence. To address these problems, this study proposes a novel interactive framework involving decision-makers in searching for the most preferred robust solutions utilizing interactive multiobjective optimization methods. The proposed interactive framework provides a learning phase for decision-makers to discover the problem characteristics, the feasibility of their preferences, and how uncertainty may affect the outcomes of a decision. This involvement and learning allow them to control and direct the multiobjective search during the solution generation process, boosting their confidence and assurance in implementing the identified robust solutions in practice.

Longer version

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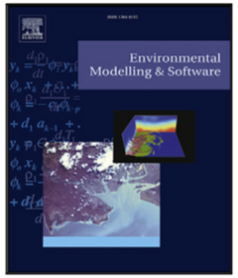

Position Paper

Let decision-makers direct the search for robust solutions: An interactive framework for multiobjective robust optimization under deep uncertainty

Babooshka Shavazipour [a,*], Jan H. Kwakkel [b], Kaisa Miettinen [a]

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Case study - water quality management*

(an extended uncertain version)

Extra treatment facilities are required to reduce the pollution of the city and the Fresh Fishery

The costs would decline Fresh Fishery's investment return and raise the city's tax rate.

Two decisions to be made are the proportional amounts of pollution to be removed from water discharge at the Fresh Fishery (x_1) and at the city (x_2).

* Narula, S. C. & Weistroffer, H. R. (1989), 'A Flexible Method for Nonlinear Multicriteria Decision-Making Problems', IEEE Transactions on Systems, Man and Cybernetics 19(4), 883–887.

Scoping the model

1a. Decision problem formulation - Water quality management (extended version)

Max Water quality at the Fresh Fishery ($f_1(\boldsymbol{x})$) $= \alpha + \left(\log\left(\left(\frac{\beta}{2} - 1.14\right)^2\right) + \beta^3\right) x_1$

Max Water quality at the city ($f_2(\boldsymbol{x})$) $= \gamma + \delta x_1 + \xi x_2 + \frac{0.01}{\eta - x_1^2} + \frac{0.3}{\eta - x_2^2}$

Max Investment return ($f_3(\boldsymbol{x})$) $= r - \frac{0.71}{1.09 - x_1^2}$

Min Rise in the city's tax rate ($f_4(\boldsymbol{x})$) $= -0.96 + \frac{0.71}{1.09 - x_1^2}$

s.t. $0.3 \leq x_1, x_2 \leq 1,$ where $\gamma = \log\left(\frac{\alpha}{2} - 1\right) + \frac{\alpha}{2} + 1.5$

Deeply uncertain variables			(Deterministic version)
Notation	Description	Range	Baseline scenario
α	Water quality index at the Fresh Fishery	[3.6, 4.24]	4.07
β	Parameter to calculate BOD reduction rate at the Fresh Fishery	[2.25, 2.29]	2.27
δ	BOD reduction rate at the city	[0.075, 0.092]	0.08
ξ	The effective rate of BOD reduction at the Fresh Fishery on the city's water quality	[0.067, 0.083]	0.075
η	Combined effective BOD reduction rate at the city	[1.2, 1.50]	1.39
r	Investment return rate	[5.1, 12.5]	8.21

Scoping the model

1a. Decision problem formulation

Robustness measure: Domain criterion* for each objective function.

The decision-maker sets the following criteria for robustness and vulnerability analyses:

f_1 : Water quality at the Fresh Fishery > 4 (mg/L of dissolved oxygen [DO]),

f_2 : Water quality at the city > 4 (mg/L of DO),

f_3 : Investment return > 4 %,

f_4 : Rise in the city's tax rate < 0.1 %,

** Starr, M. K. (1963), Product Design and Decision Theory, Fundamentals of engineering design, Prentice -Hall.*

Scoping the model

1b. Scenario analysis

i) Scenario generation: we generated 10 000 random scenarios (using Latin Hypercube Sampling)
ii) Calculating the ideal (best possible) objective values: solving 30 000 +1 single-scenario single-objective optimization problems (the 4th objective has no uncertain parameter)

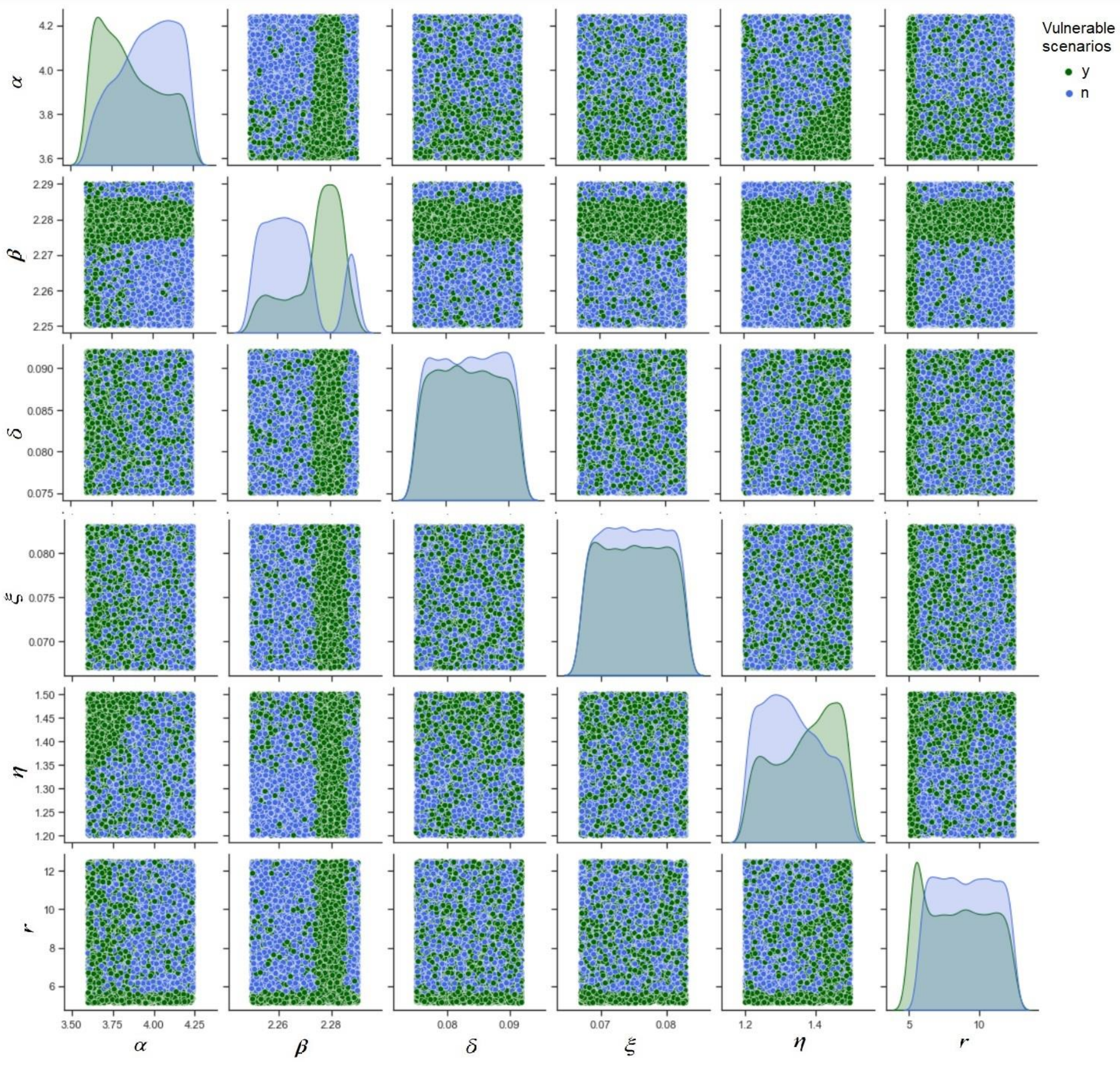
Objectives	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
Domain Criterion	> 4	> 4	> 4	< 0.1

	Objective functions			
	f_1	f_2	f_3	f_4
Best ideal values	7.224	5.440	11.790	0.00
Worst ideal values	-0.998	3.854	4.390	0.00

Scoping the model

1b. Scenario analysis

iii) Identifying the vulnerabilities (scenarios with poor performances, i.e., the objective values do not meet the domain criteria)



Interactive robust decision-making phase

Iteration 1

2a. Decision-makers' preferences

i) Scenarios to be considered (optional)
The baseline scenario (s1) + five more randomly selected scenarios--at least one vulnerable scenario that does not satisfy the domain criterion set for the first objective function (i.e., $2.273 < \beta < 2.286$).

Scenarios	Combination of deeply uncertain parameters					
	α	β	δ	ξ	η	r
s_1	4.070	2.270	0.0800	0.0750	1.39	8.21
s_2	3.868	2.262	0.0869	0.0782	1.47	10.28
s_3	3.620	2.278	0.0835	0.0750	1.23	5.84
s_4	3.372	2.254	0.0903	0.0814	1.35	11.76
s_5	3.124	2.270	0.0801	0.0686	1.29	7.32
s_6	4.116	2.286	0.0767	0.0718	1.41	8.80

Interactive robust decision-making phase

Iteration 1

2a. Decision-maker's preferences

ii) Desired objective values in selected scenarios

Objectives	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
Domain Criterion	> 4	> 4	> 4	< 0.1

Scenarios	Ideal values			
	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
s_1	5.17	4.52	7.50	0
s_2	6.02	4.19	9.57	0
s_3	3.02	4.61	5.13	0
s_4	6.14	3.87	11.05	0
s_5	4.22	3.70	6.61	0
s_6	4.44	4.52	8.09	0

Scenarios	Preferences on desired values			
	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
s_1	5	4.5	7	0.00001
s_2	5	4.5	5.5	0.00001
s_3	10	4.5	4	10
s_4	5	8	6	0.1
s_5	5	8	6	0.1
s_6	4.5	4.5	9	0.1

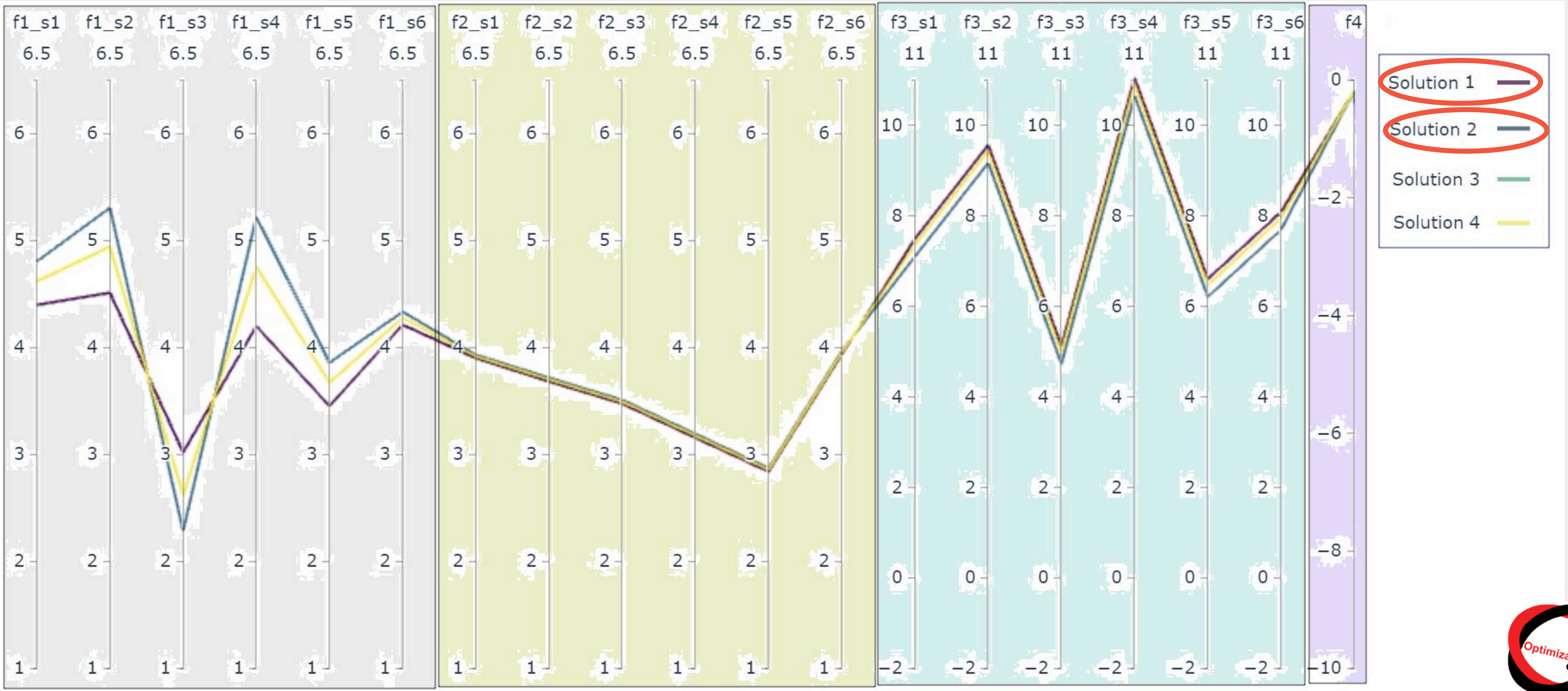
iii) Maximum number of solutions to be compared at each iteration (optional) = 4

Interactive robust decision-making phase

2b. Solution identification

Iteration 1

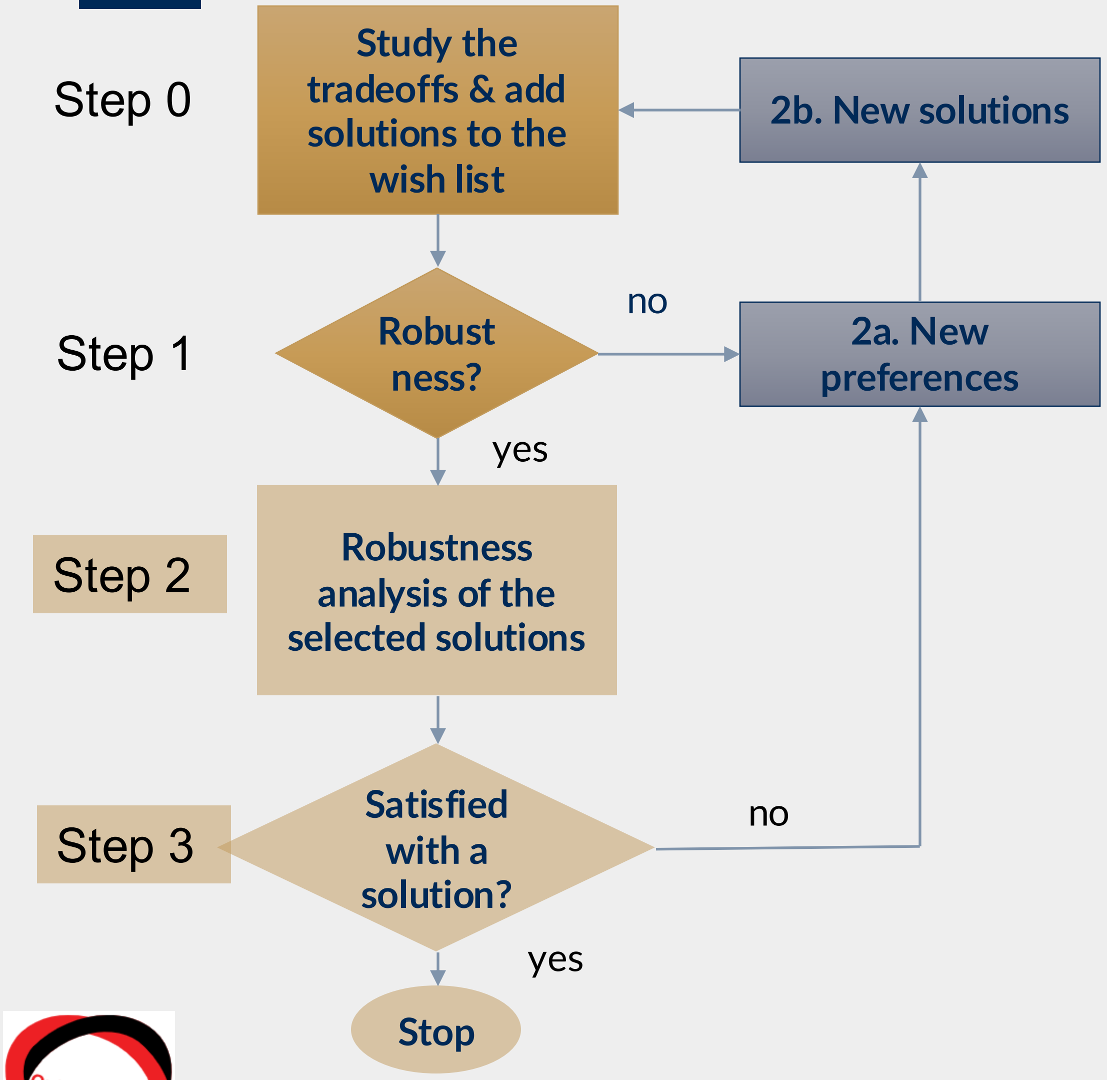
The analyst solved the corresponding optimization problem with four objectives and six scenarios and generated four solutions

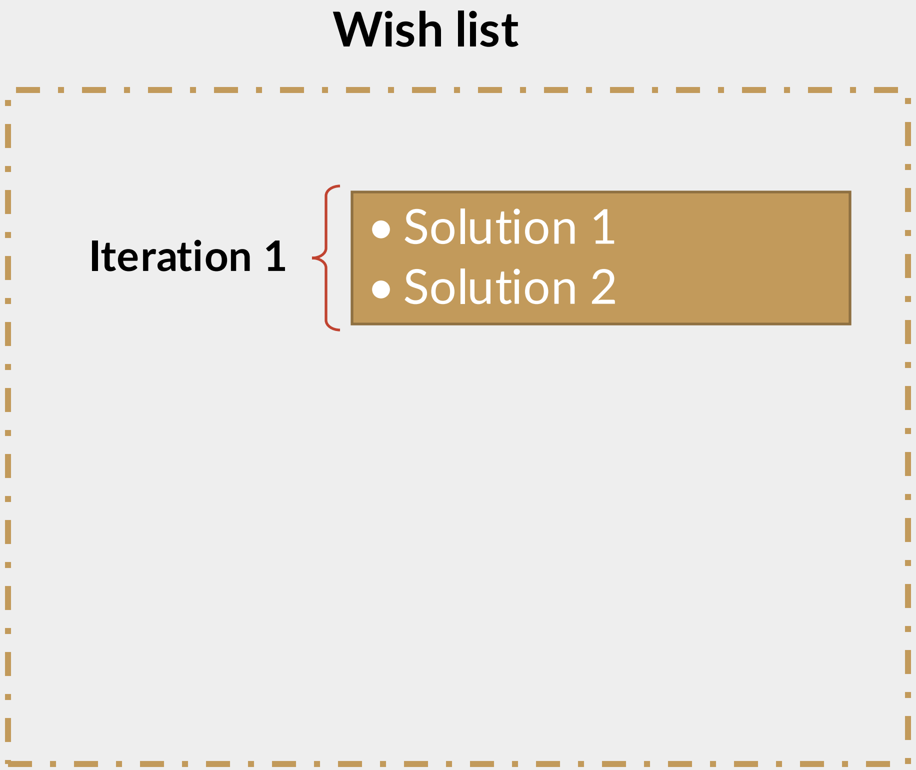


Interactive robust decision-making phase

2c. Trade-off analysis and decision-making

Iteration 1





Interactive robust decision-making phase

Iteration 2

2a. Decision-maker's preferences

i) The same 6 scenarios

ii) Desired objective values in selected scenarios

Objectives	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
Domain Criterion	> 4	> 4	> 4	< 0.1

Scenarios	Preferences (previous iteration)			
	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
s_1	5	4.5	7	0.00001
s_2	5	4.5	5.5	0.00001
s_3	10	4.5	4	10
s_4	5	8	6	0.1
s_5	5	8	6	0.1
s_6	4.5	4.5	9	0.1

Scenarios	Preferences on desired values			
	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
s_1	4	15	4	0.00001
s_2	4	15	4	0.00001
s_3	10	15	4	0.00001
s_4	4	15	4	0.00001
s_5	4	15	4	0.00001
s_6	4	15	4	0.00001

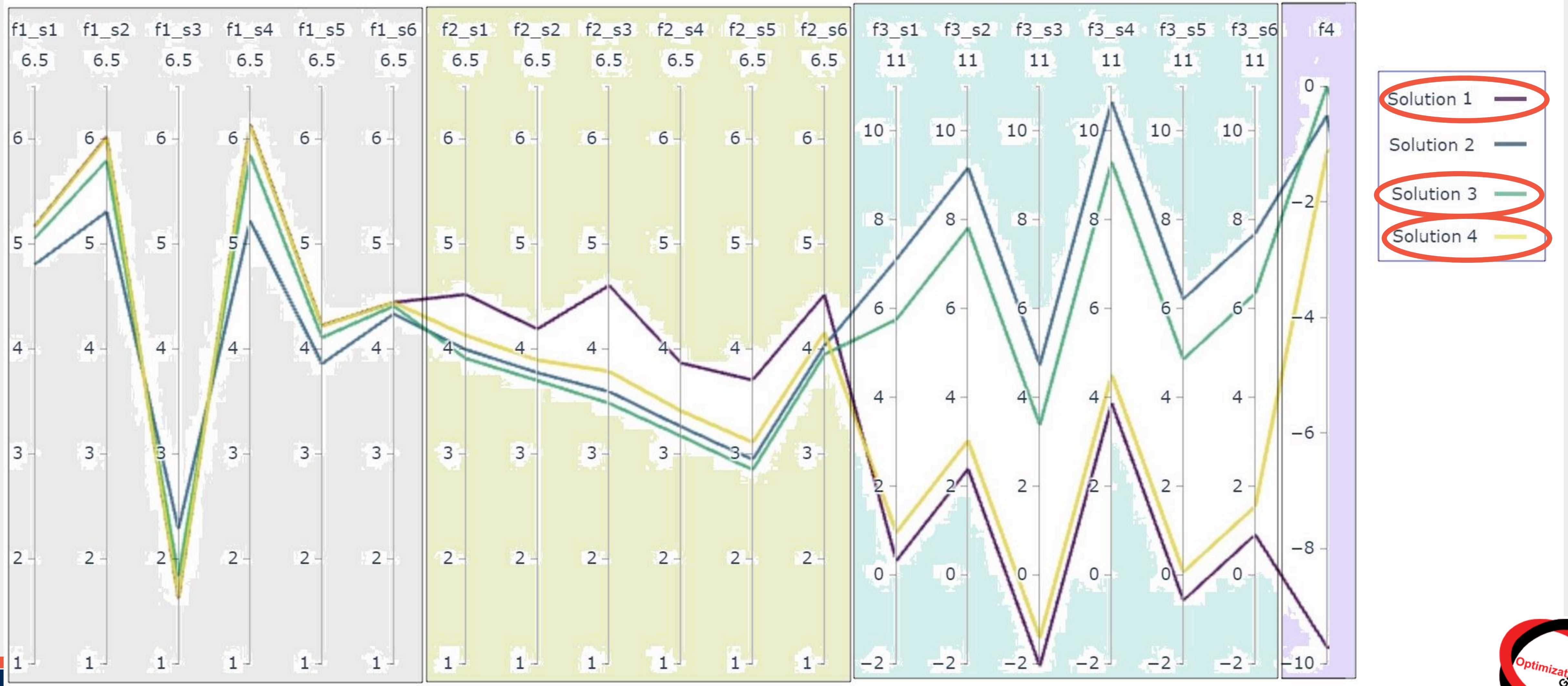
iii) Maximum number of solutions to be compared at each iteration (optional) = 4

Interactive robust decision-making phase

2b. Solution identification

Iteration 2

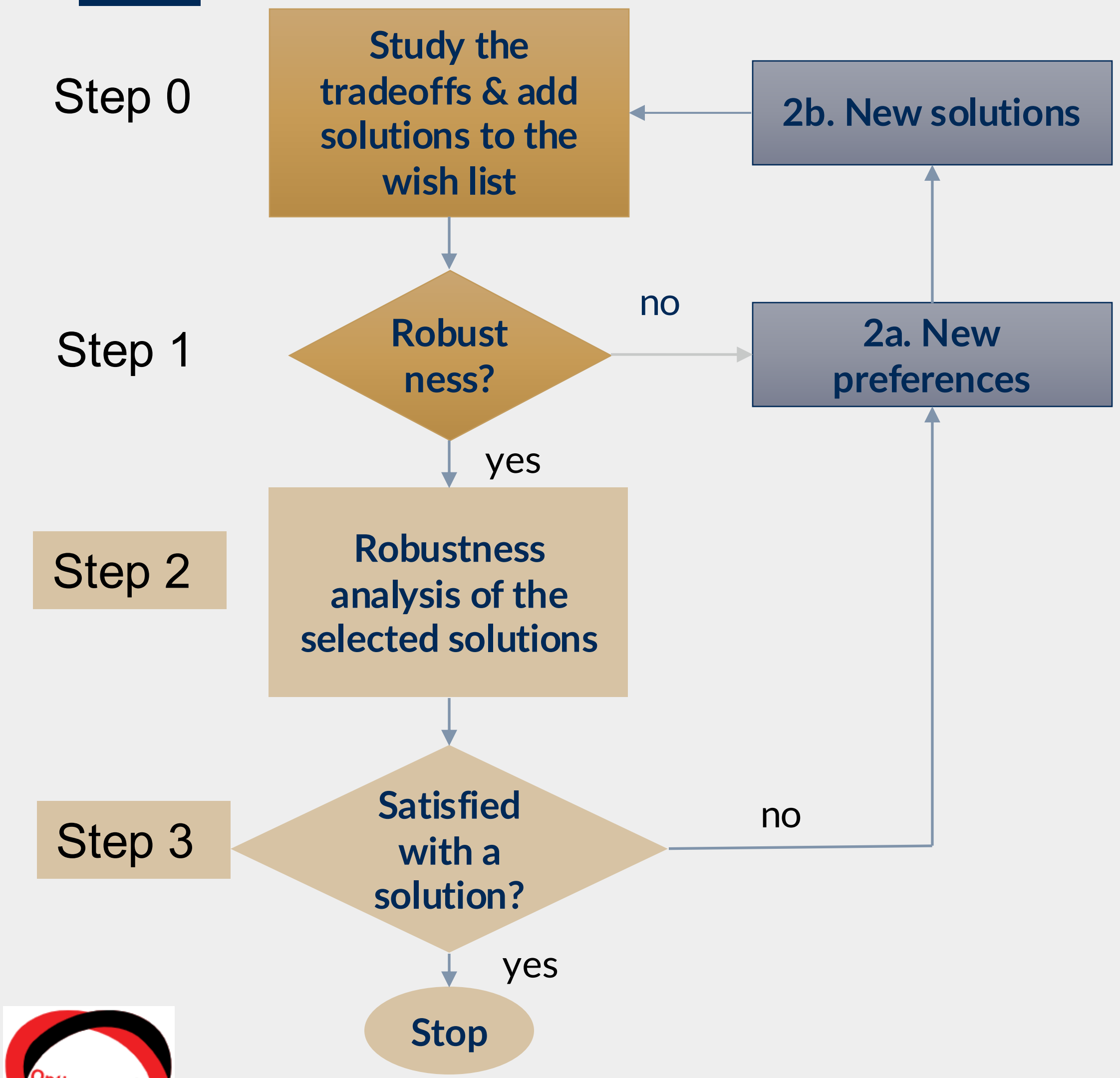
The analyst solved the corresponding sixth-scenario fourth-objective optimization problem and generated four solutions

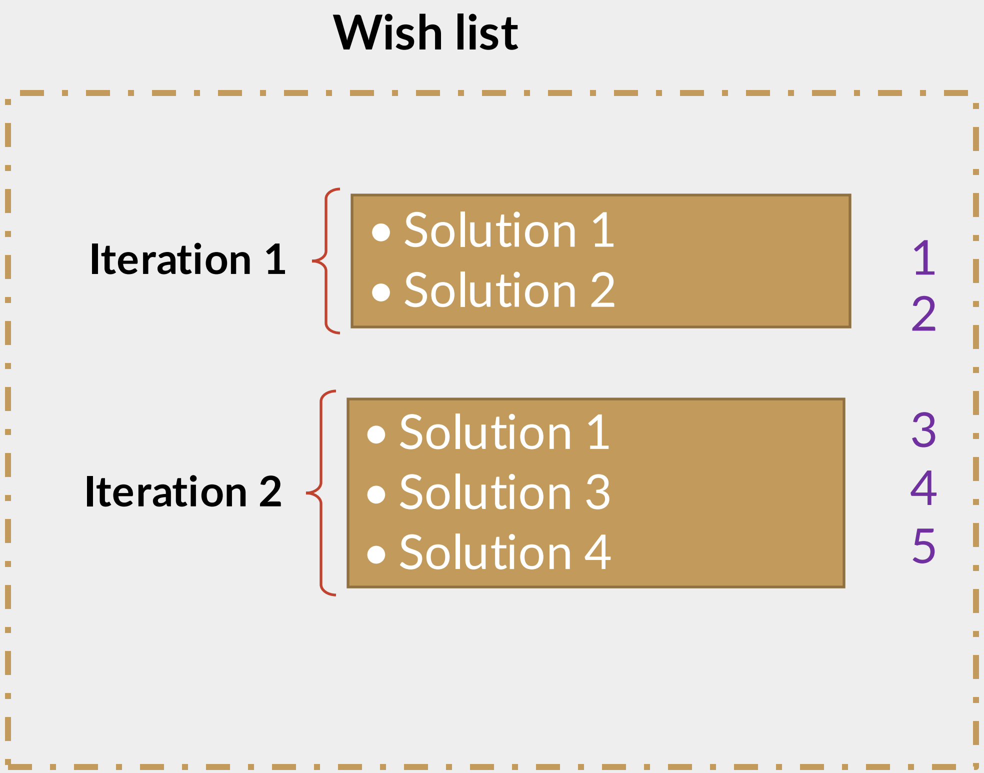


Interactive robust decision-making phase

2c. Trade-off analysis and decision-making

Iteration 2





Interactive robust decision-making phase

Iteration 3

2a. Decision-maker's preferences

i) The same 6 scenarios

ii) Desired objective values in selected scenarios

Objectives	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
Domain Criterion	> 4	> 4	> 4	< 0.1

Scenarios	Ideal values			
	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
s_1	5.17	4.52	7.50	0
s_2	6.02	4.19	9.57	0
s_3	3.02	4.61	5.13	0
s_4	6.14	3.87	11.05	0
s_5	4.22	3.70	6.61	0
s_6	4.44	4.52	8.09	0

Scenarios	Preferences on desired values			
	f_1 (max)	f_2 (max)	f_3 (max)	f_4 (min)
s_1	5	5.4	7	5
s_2	5.5	6.4	9	5
s_3	3.1	6.4	4.5	5
s_4	5.5	6	10	5
s_5	4	6	5	5
s_6	4.4	6.4	7	5

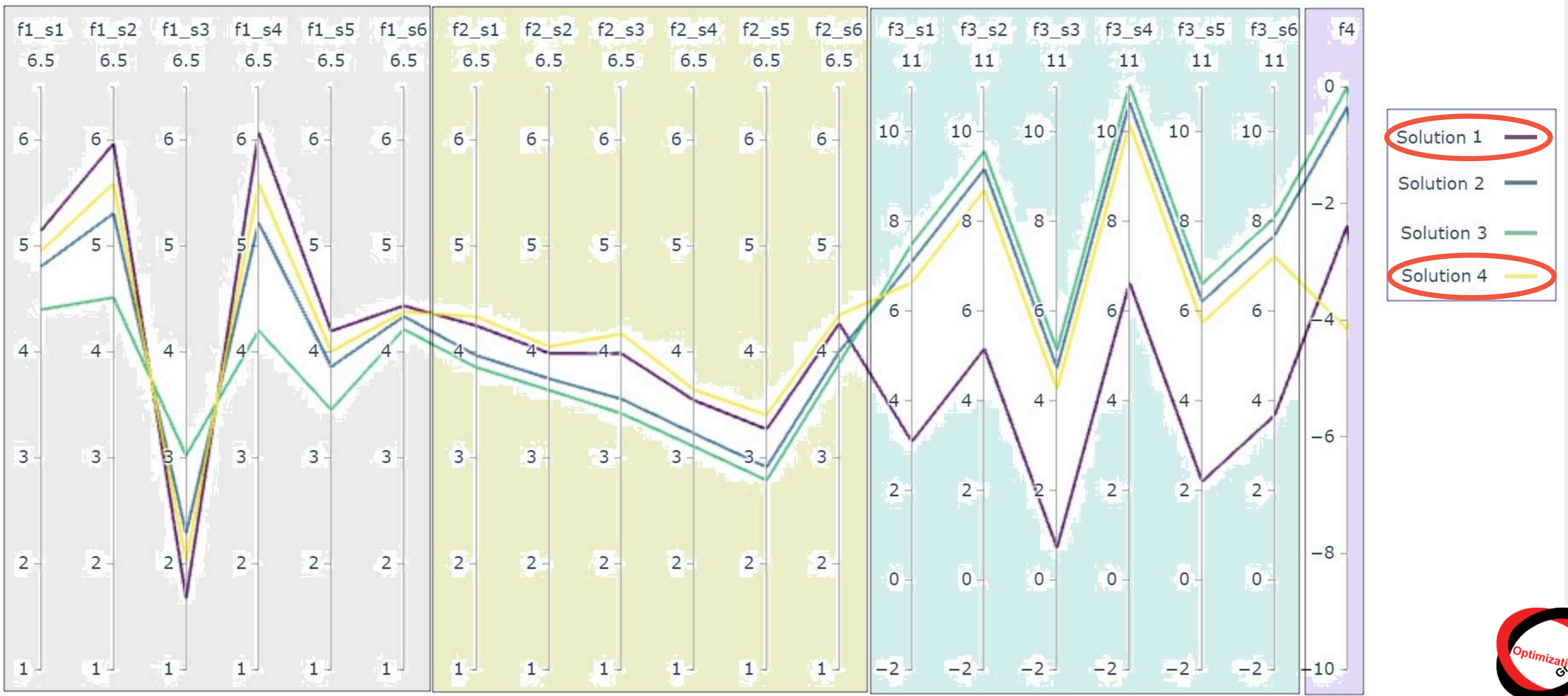
iii) Maximum number of solutions to be compared at each iteration (optional) = 4

Interactive robust decision-making phase

2b. Solution identification

Iteration 3

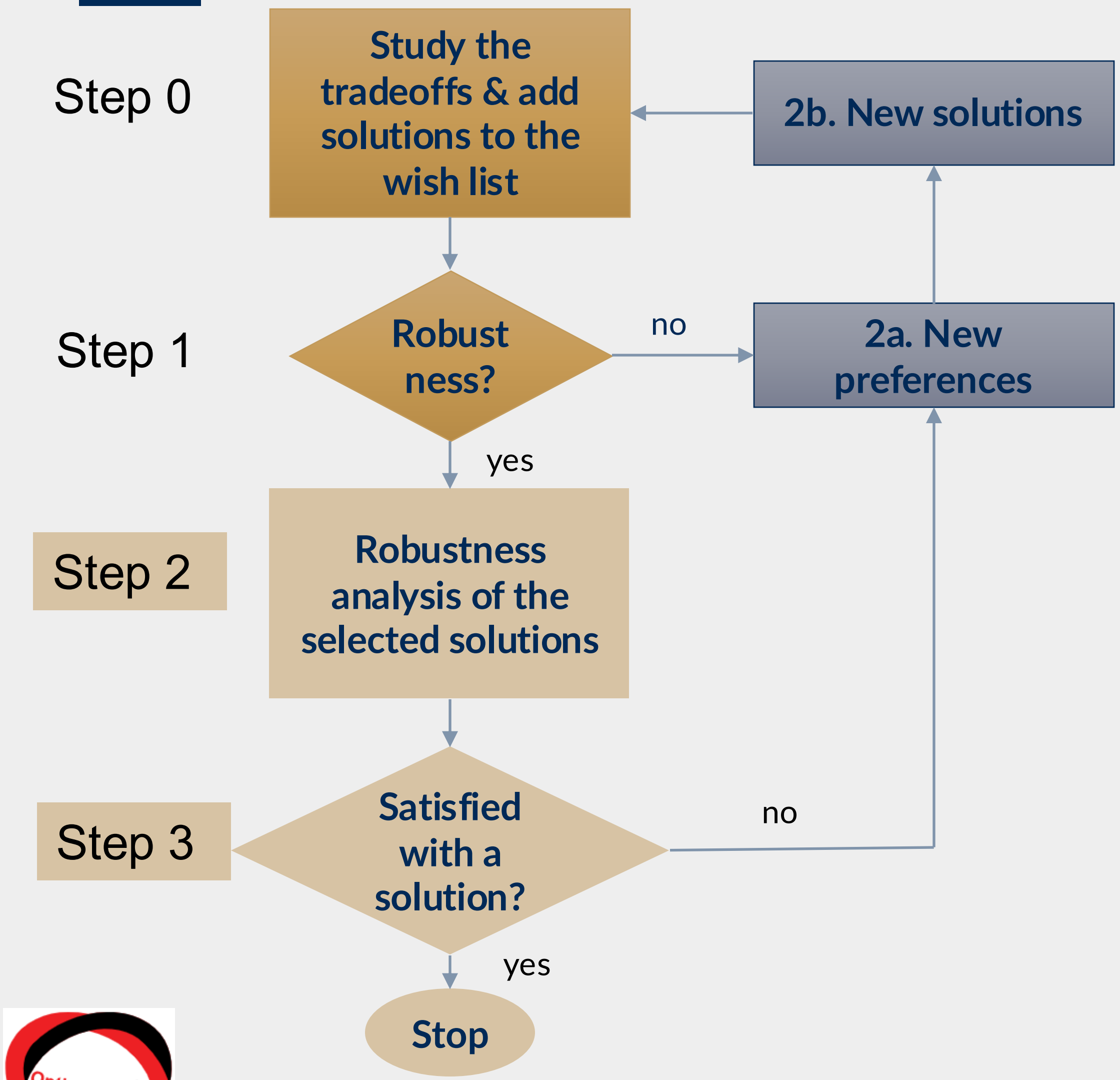
The analyst solved the corresponding sixth-scenario fourth-objective optimization problem and generated four solutions



Interactive robust decision-making phase

2c. Trade-off analysis and decision-making

Iteration 3



Wish list

Iteration 1
- Solution 1 — 1
- Solution 2 — 2

Iteration 2
- Solution 1 — 3
- Solution 3 — 4
- Solution 4 — 5

Iteration 3
- Solution 1 — 6
- Solution 4 — 7

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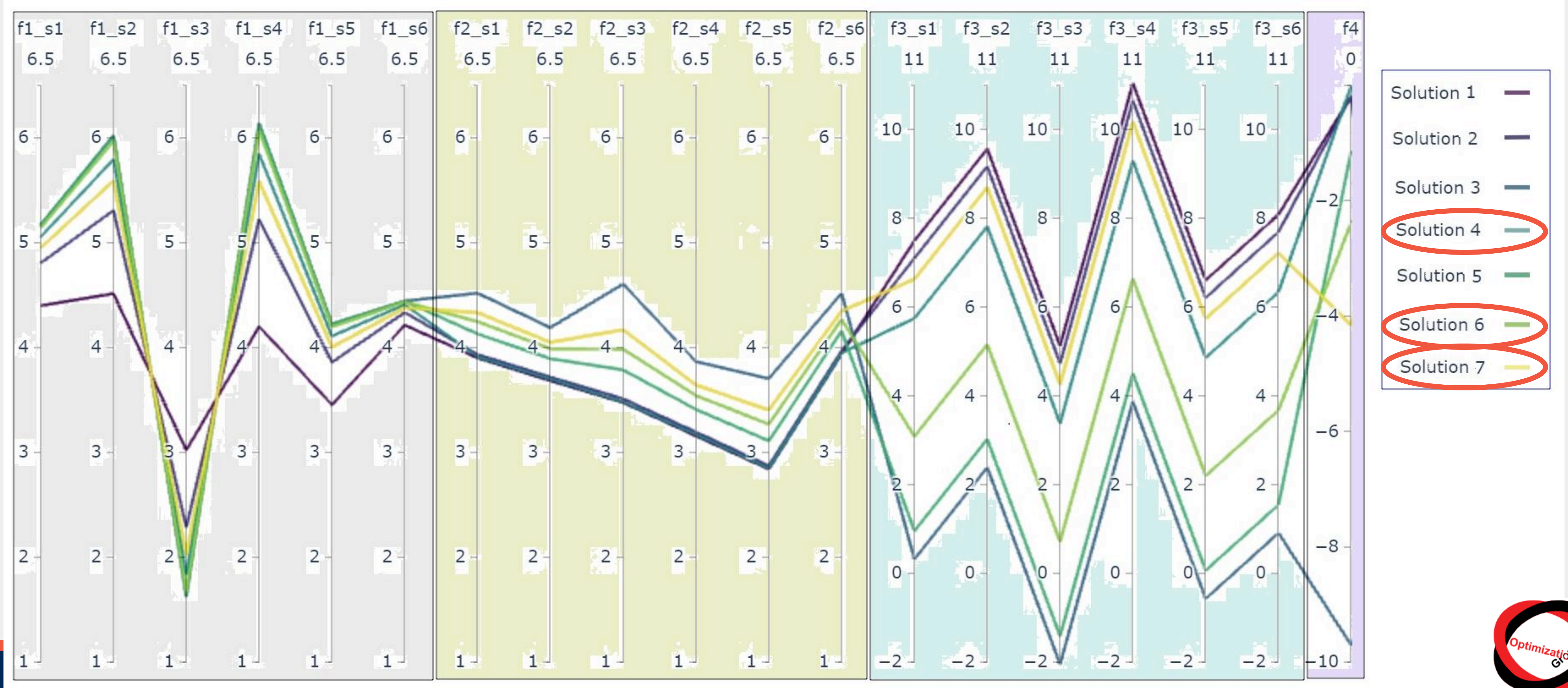
Interactive robust decision-making phase

2c. Trade-off analysis and decision-making

Iteration 3

Comparing seven candidate solutions selected in three iterations



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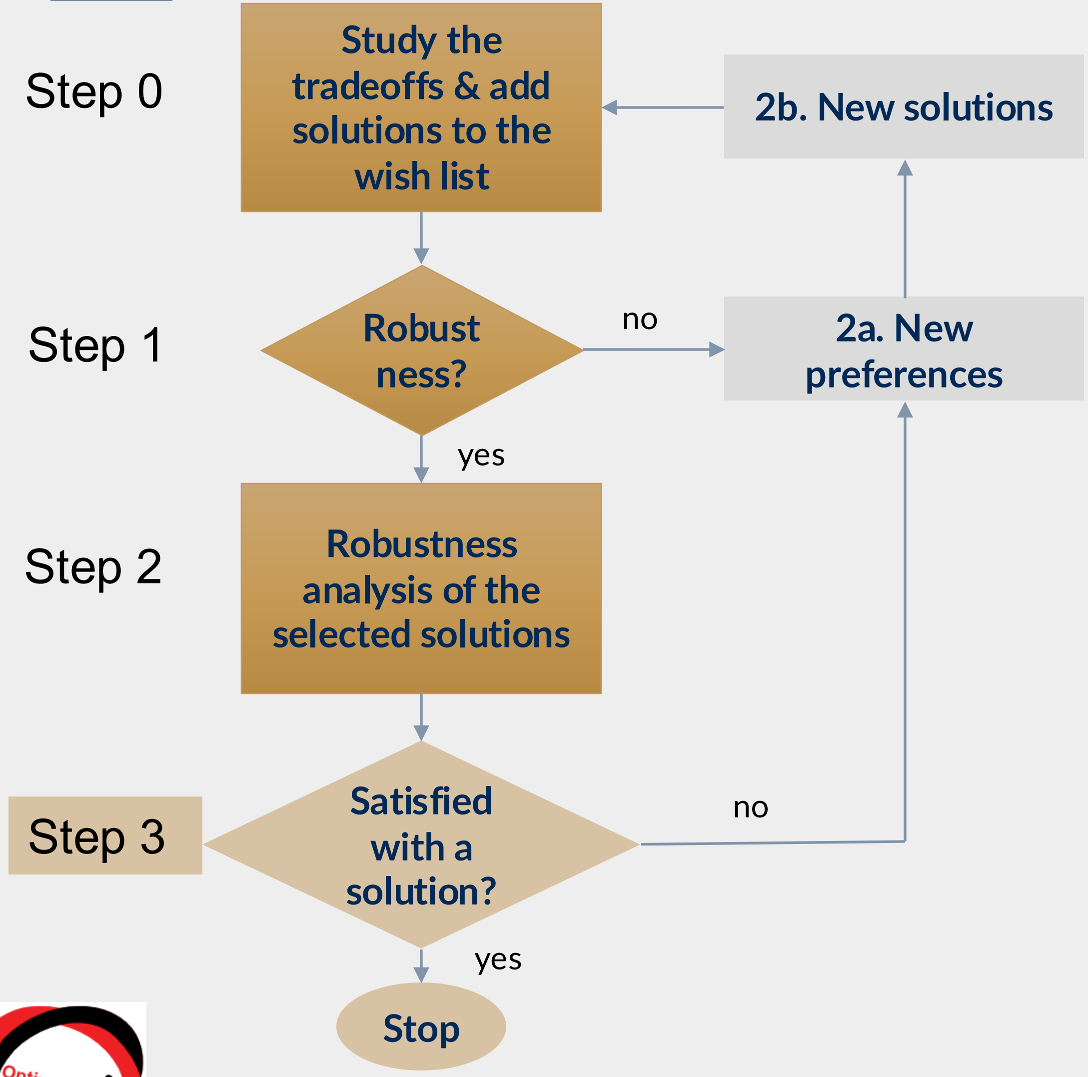
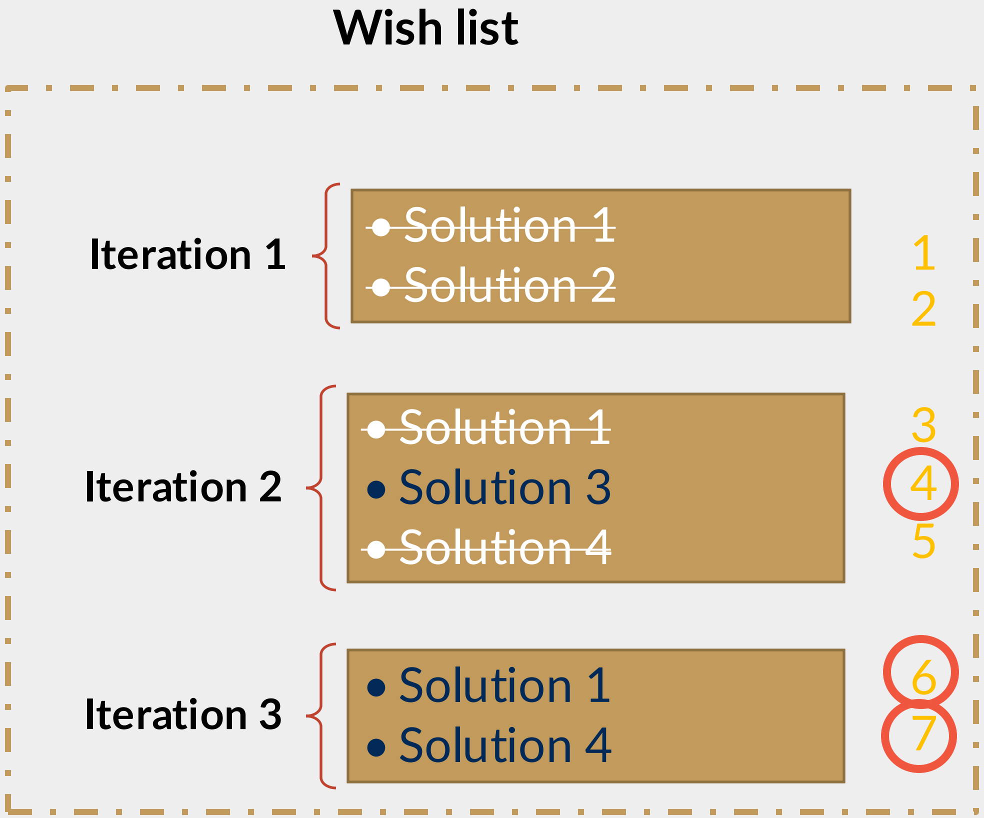
Iteration 3





Interactive robust decision-making phase

2c. Trade-off analysis and decision-making

Iteration 3

To robustness analysis, for each objective function, the analyst re-evaluated each solution over the 10 000 randomly generated scenarios and counted the number of scenarios meeting the domain criterion in each solution.

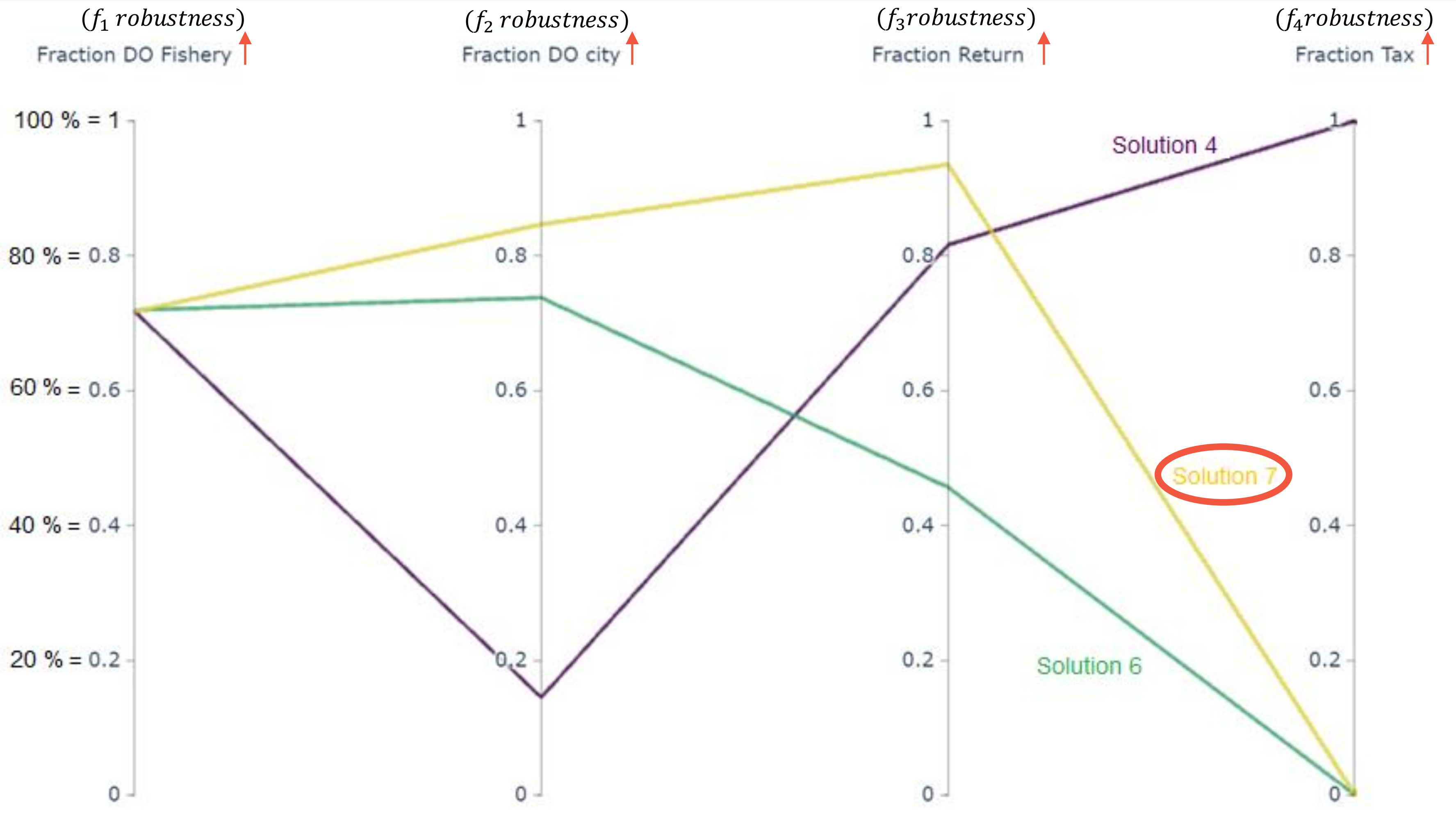


Fig. The robustness trade-offs of the selected solutions (number of scenarios satisfying the domain criterion for each objective).

Conclusions

- We propose an interactive framework involving decision-makers during the solution process to gain insight into the problem and can influence the solution process when they provide their preferences.

- However, there is a need for experimental studies in different real-life problems to see how it would be successful.

- Single decision-maker vs Group of decision-makers

Contributions

- First interactive multiobjective optimization method
- To involve the decision-maker within the search and focus only on the region of interest
- Lower computation cost and the cognitive load
- Both exploration and exploitation are possible
- Increase the confidence
- Open many new directions
    - Scenario generation and selection
    - Preference information
    - Adaptive robust solutions
- A new benchmark problem for robustness analysis

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Multi-scenario multi-objective robust optimization under deep uncertainty: A posteriori approach

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Visualizations for decision support in scenario-based multiobjective optimization

Babooshka Shavazipour[a,*], Manuel López-Ibáñez[b], Kaisa Miettinen[a]

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Canadian Journal of Forest Research
Article

Interactive decision support and trade-off analysis for sustainable forest landscape planning under deep uncertainty

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