Prioritization of Stockpile Maintenance with Layered Pareto Fronts

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Fall Technical Conference

5 October 2018

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Motivations

- How to make an informed, data-driven decision when decision-makers have competing interests?
- General problem description:
  - Use multiple criteria to identify the top N solutions to accomplish a goal while enabling a richer and more realistic decision
  - Given: Enumerated list of objects evaluated on multiple criteria
  - Goal: Select N objects from the list
  - How do you choose “the best” N while balancing competing objectives?

Stockpile Prioritization Problem

- 42 stockpiles across 4 groups, all could use extra funding
- Primary question of interest: Which stockpiles should received additional funding?
- The challenges:
  - Limited funds available: only **4** stockpiles can receive $$
  - How should **most critical** be measured? What data needs to be collected?
  - **Competing objectives** of stockpile managers → disagreement on how to prioritize criteria
- Cost of maintenance/surveillance similar across the different stockpiles
- 5-member decision-making team
  - The 4 stockpile group managers
  - Sponsor

Group	Number of stockpiles
A	15
B	11
C	11
D	5

Stockpile Prioritization Problem

- Budget allocation problem among stockpile programs to enhance stockpile performance
- Historic decision-making process
  - Managers of 4 stockpile groups argued with stakeholder
  - Decision often driven by presentation effectiveness and not data
- Goal: Improve the decision process to better allocate the stockpiles in most need

Structured Decision Making Using DMRCS

Stage	Steps
Define	Identify choices under consideration Identify aspects of the decision which are most important
Measure	Identify quantitative metrics to characterize aspects Gather relevant data for each metric for all choices
Reduce	Eliminate some criteria from further consideration Eliminate non-contending choices
Combine	Evaluate tradeoffs between choices Incorporate subjective weighting of criteria for all team members
Select	Identify top solutions Explore performance of top choices relative to competitors Finalize choices and how process can be defended

Objective: Define, Measure, Reduce

Subjective: Combine, Select

Anderson-Cook, C.M., Lu, L. (2015) "Much-Needed Structure: A New 5-Step Decision-Making Process Helps You Evaluate, Balance Competing Objectives" *Quality Progress* 48(10) 42-50

Define

- 42 stockpiles are under consideration
- Brainstorm which criteria should be used:
  - What would lead to a good decision?
  - Brainstorming allows consideration of many different facets of the stockpiles
- Metrics Discussed

- Various reliability metrics
- Current supply relative to projected need
- Availability of suitable alternatives
- Impact on missions

- Number of historical failure problems
- SME knowledge on problems with usage
- Quality of reliability testing procedures

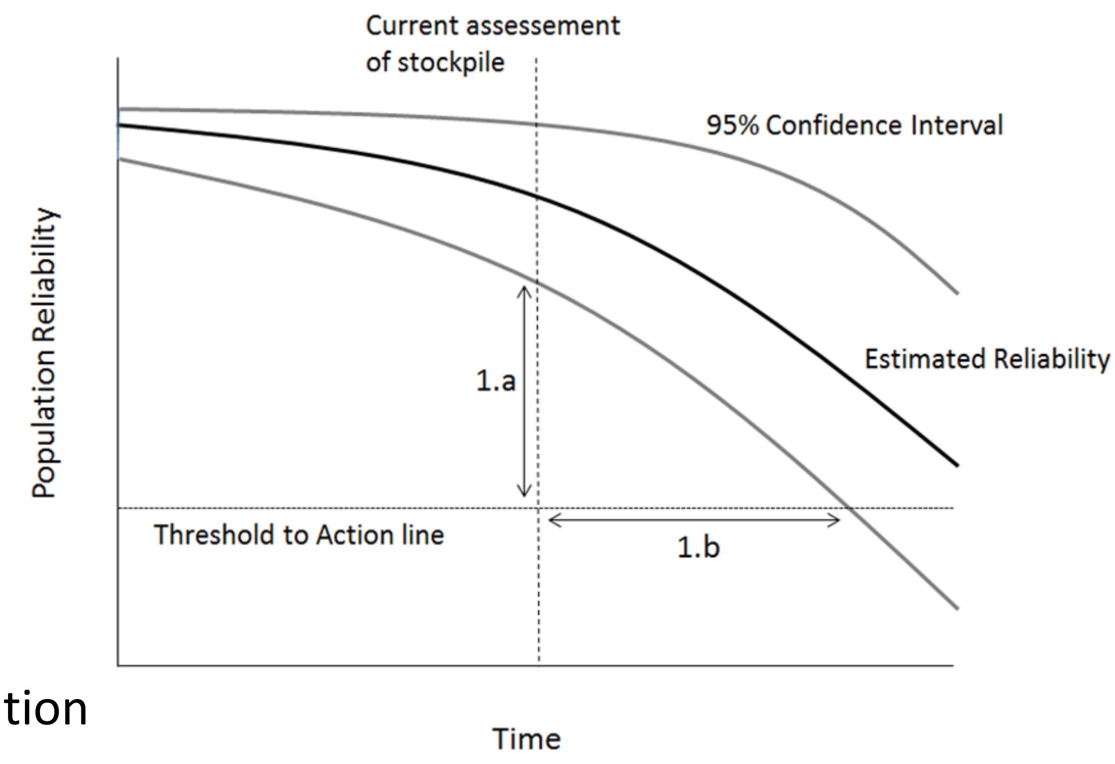
Excluded:
Too hard to collect objective data or not as essential

Measure

- Determine how each criterion will be defined and measured
- Want quantitative metrics for fair assessments
- SMEs defined what characteristics to define with each of the measures
- Reduced aspects of interest into three broad categories:
  - Overall Reliability
  - Overall Urgency
  - Consequence

Measure

- Overall Reliability
  - Current reliability (1.a)
  - Time to threshold (1.b)
- Overall Urgency
  - Available supply
  - Availability of alternatives
- Consequence
  - How important is munition to mission?
  - Shortage assessment



Each overall criterion given a score from 0 to 10 (10 = most critical)

Measure

- Scoring method based on historical precedent
- Based on comparing **available** data for each stockpile
- Assessed via **standardized** definitions, defined by SMEs (independent from decision-making team)
- Each stockpile was assessed by several experts to obtain final score for each metric
- Objectivity in assessing scores is key → **eliminates potential bias**
- Rigorous and defensible method
  - Incorporates expert knowledge based on all aspects of stockpile design, maintenance, and surveillance
  - Labor-intensive, but **transparent** and **consistent**

Decisions are now based on quantitative & objective measures agreed upon by team

Measure: Subset of Stockpile Criteria Scores

Stockpile	Current Reliability	Time to Threshold	Overall Reliability	Available Supply	Availability of Alternate	Overall Urgency	Consequence
A1	8.5	9.5	9	7	5	6	2.5
A2	7.5	5.5	6.5	7.5	10	8.75	5.5
A3	9.5	9.5	9.5	9	8.5	8.75	9
A4	9.5	8.5	9	8.5	9	8.75	9
B1	6.5	8	7.25	8.5	6	7.25	7
B2							7
B3							8
B4							9
C1							4.5
C2							3.5
C3	9.5	6	7.75	7	9	8	9
C4	6.5	5	5.75	8	5.5	6.75	2.5
D1	7.5	7	7.25	8	5.5	6.75	2.5
D2	7	8	7.5	6.5	6	6.25	9
D3	10	8	9	8	6.5	7.25	4
D4	9	7	8	7	9	8	9
D5	6.5	6	6.25	9.5	9.5	9.5	8

Overall Reliability Min = 5.75 Max = 9.5
Overall Urgency Min = 6 Max = 9.5
Consequence Min = 2.5 Max = 9.5

Note: Due to proprietary nature of data, this data is notional (but representative of original data)

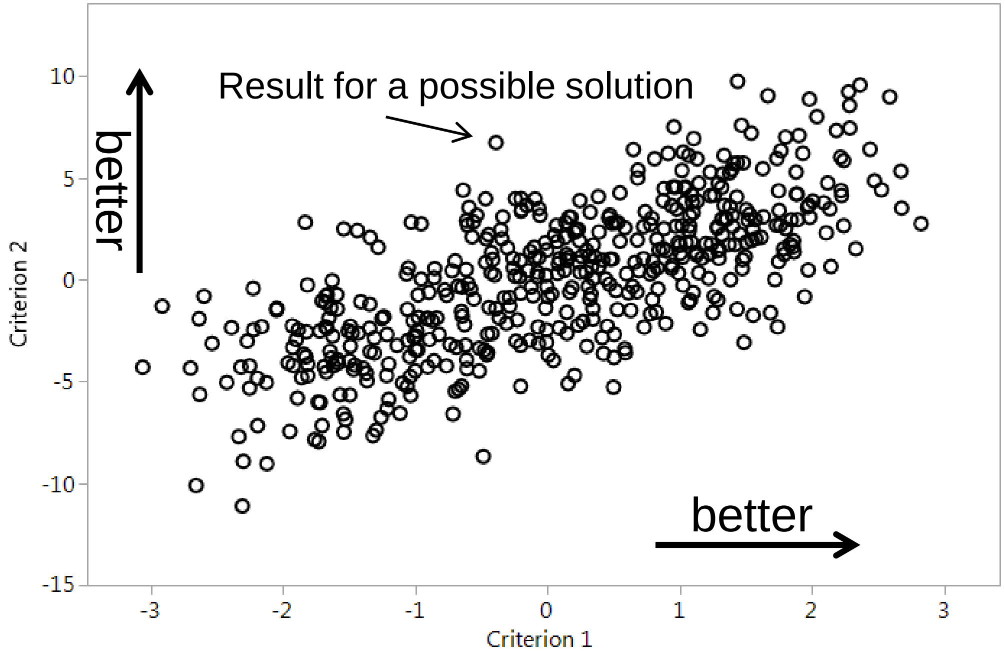
Reduce

- Reduce metrics (done previously)
- Reduce non-contending solutions from further consideration to make decision more manageable
- Can we objectively remove some stockpiles with values not critical enough before subjective choices are made?
  - Use layered Pareto Fronts
  - TopN-PFS Add-In for JMP

    (https://community.jmp.com/t5/JMP-Add-Ins/Top-N-Pareto-Front-Search-for-Structured-Decision-Making/ta-p/36527)

Pareto Front

- The set of non-inferior points in a dataset
- Goal: Eliminate dominated, inferior points from further consideration
- Balance multiple criteria simultaneously



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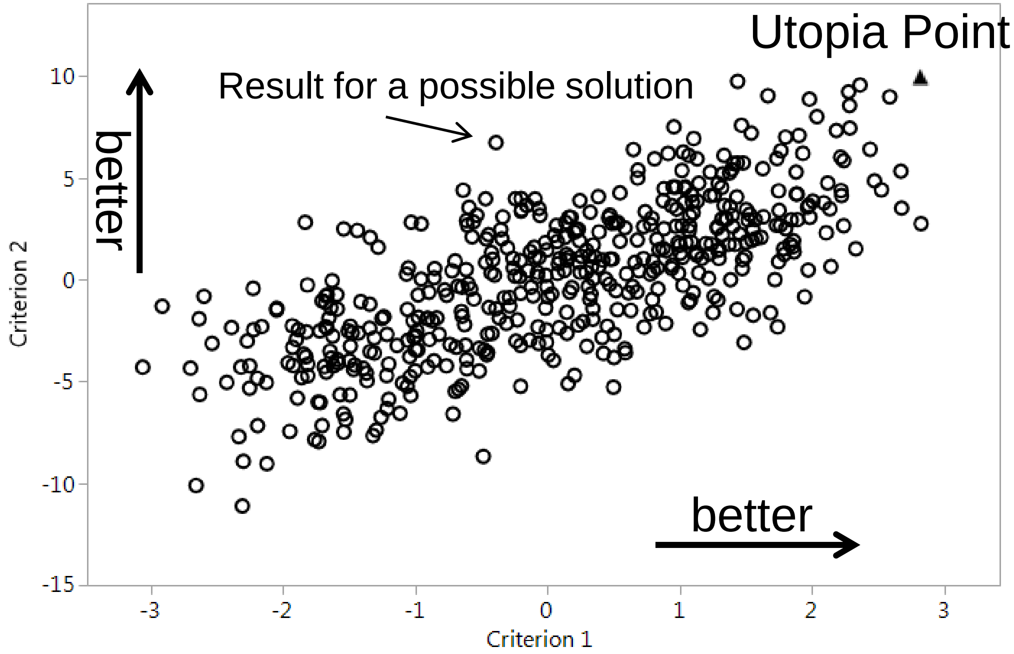

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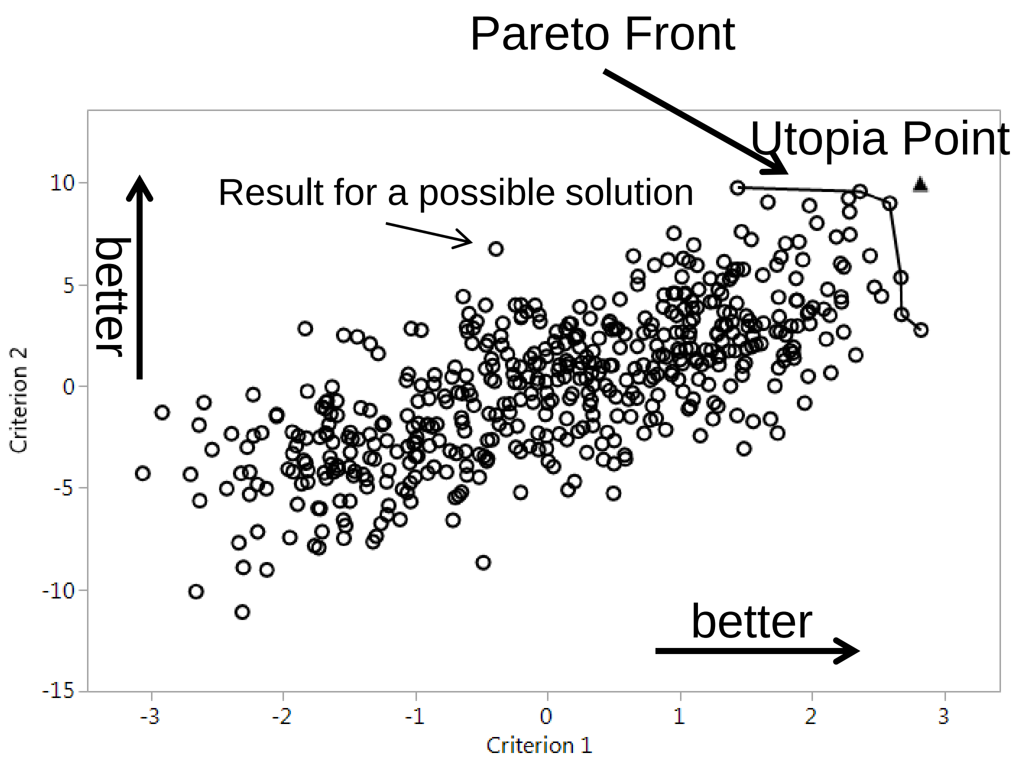
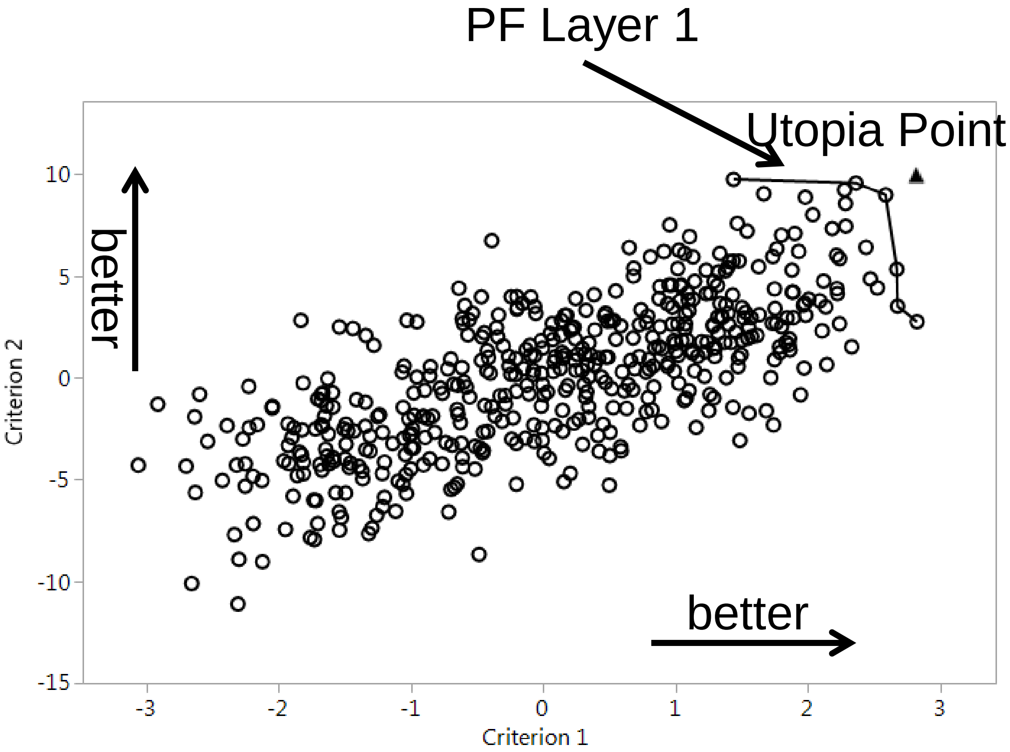


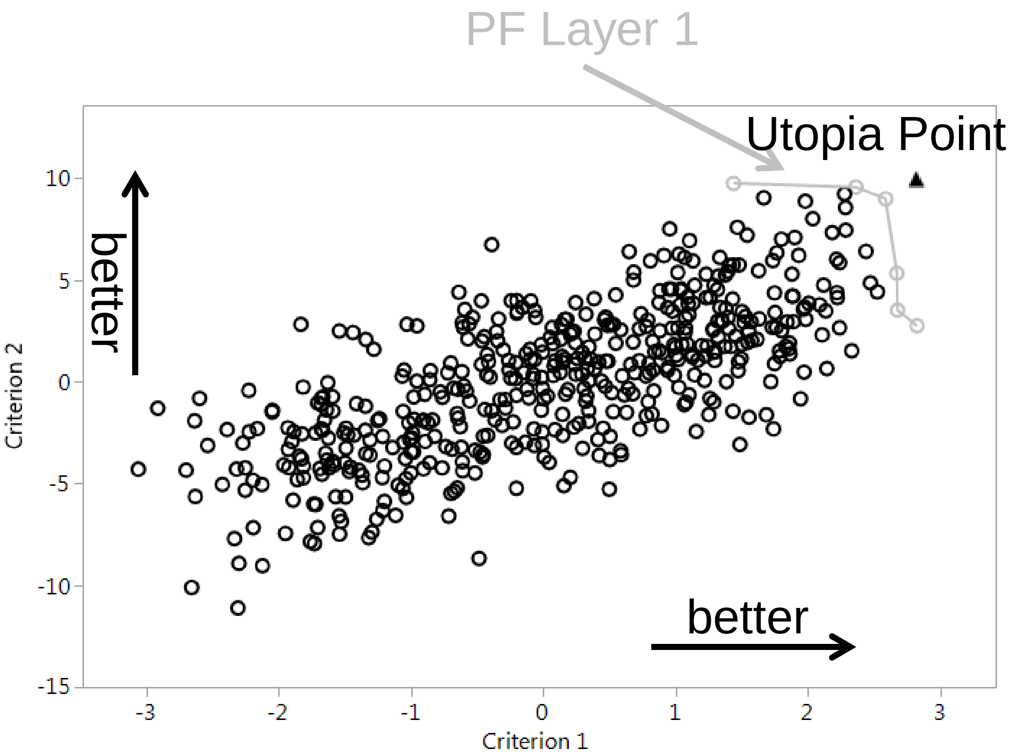
Layered Pareto Front

- Find points on the Pareto Front



Layered Pareto Front

- Find points on the Pareto Front
- Remove these from obtainable criterion region



Layered Pareto Front

- Find points on the Pareto Front
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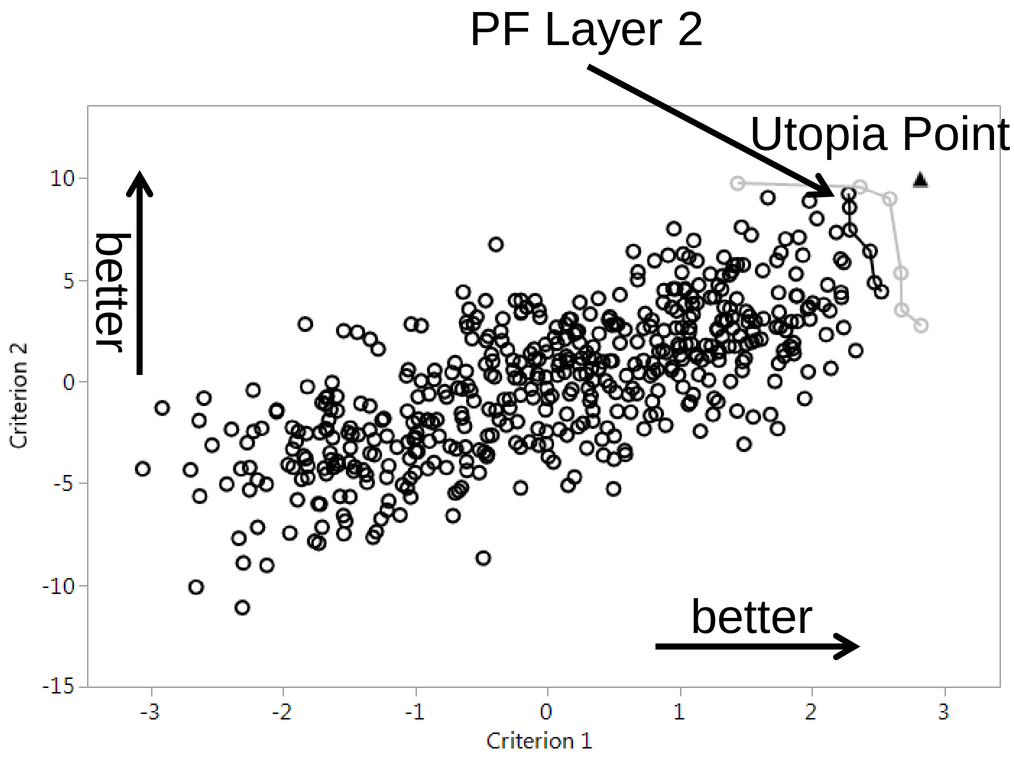
- Find a new Pareto Front based on the remaining points



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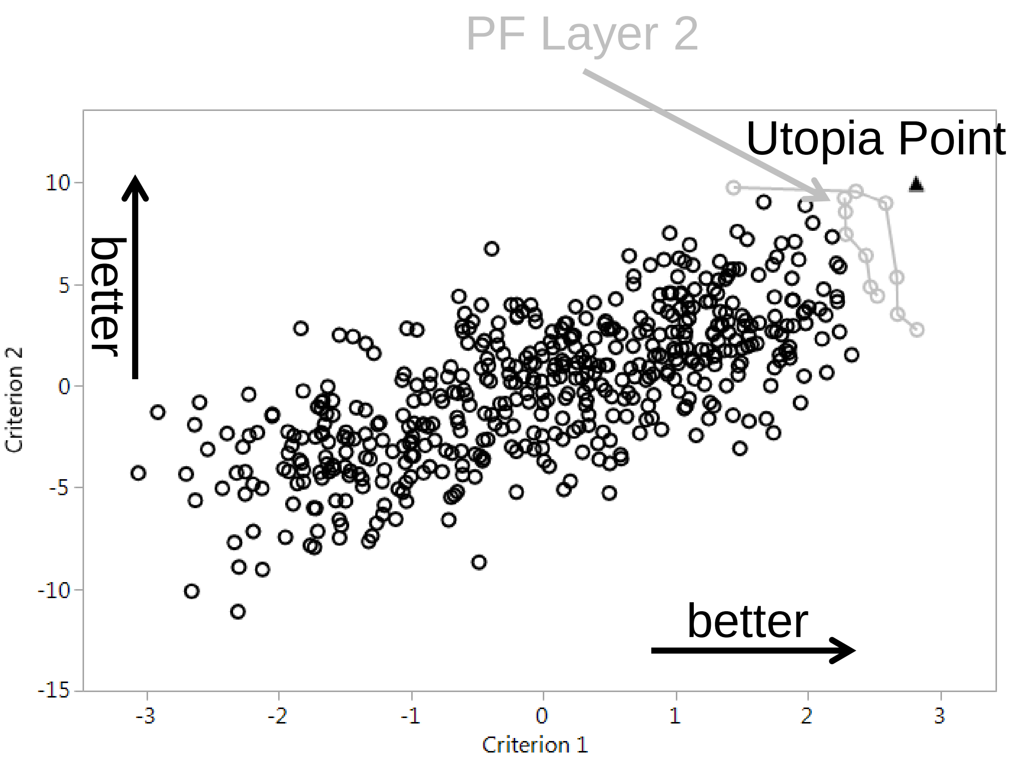

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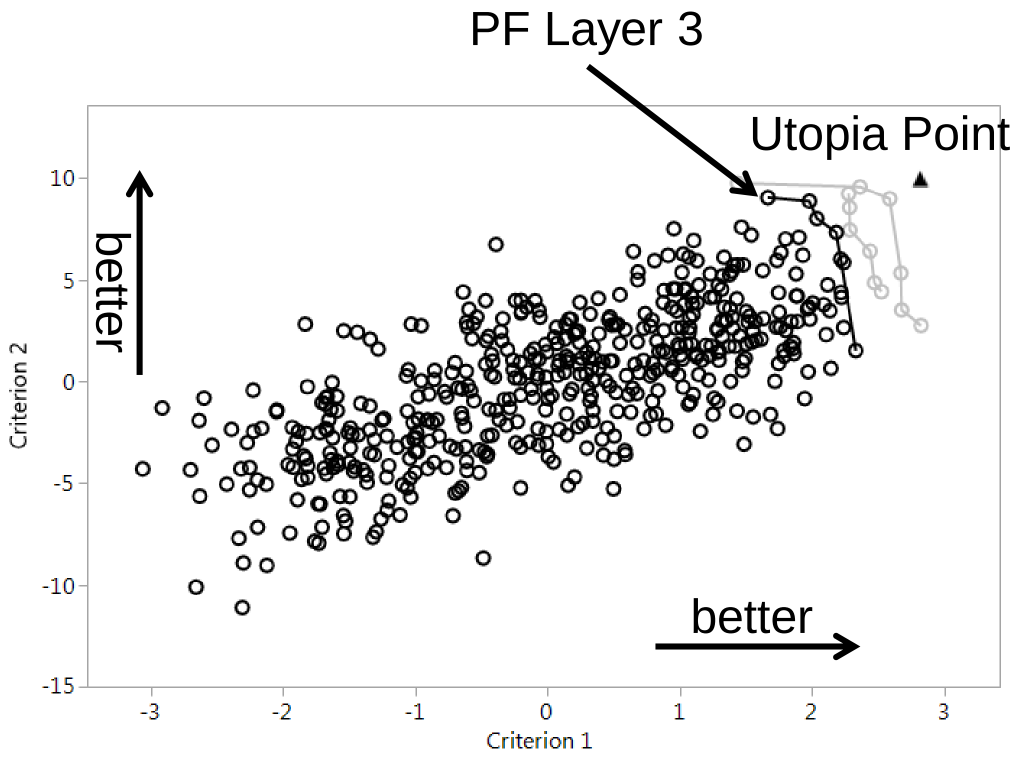
- Continue until have m layered Pareto Fronts



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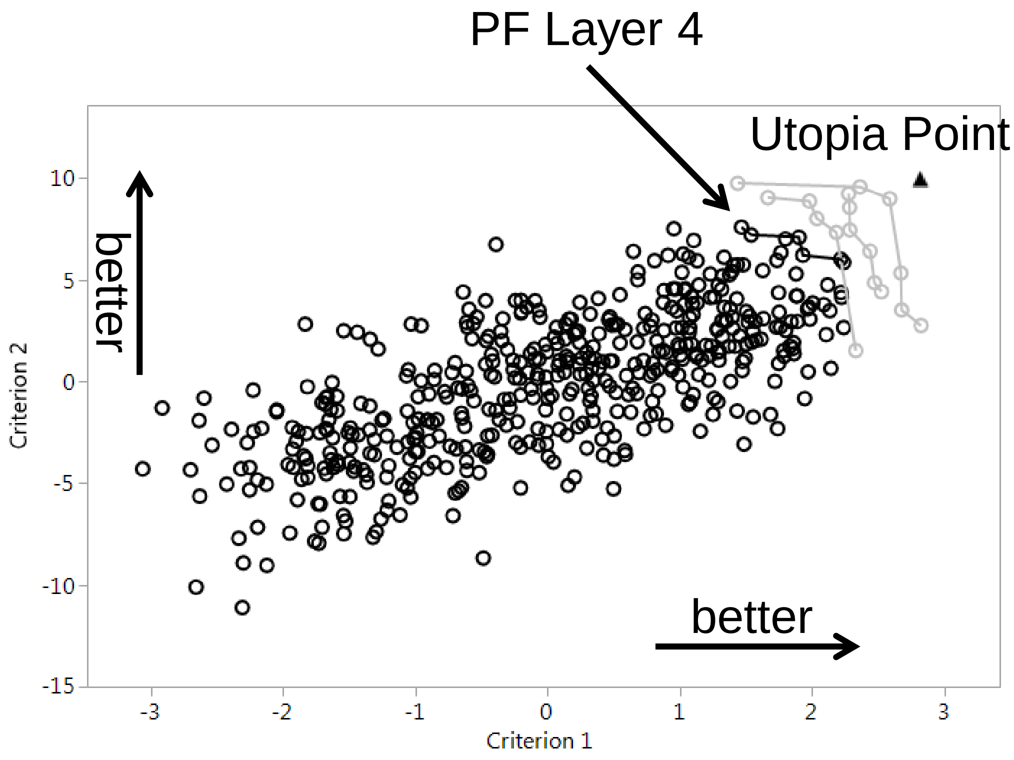

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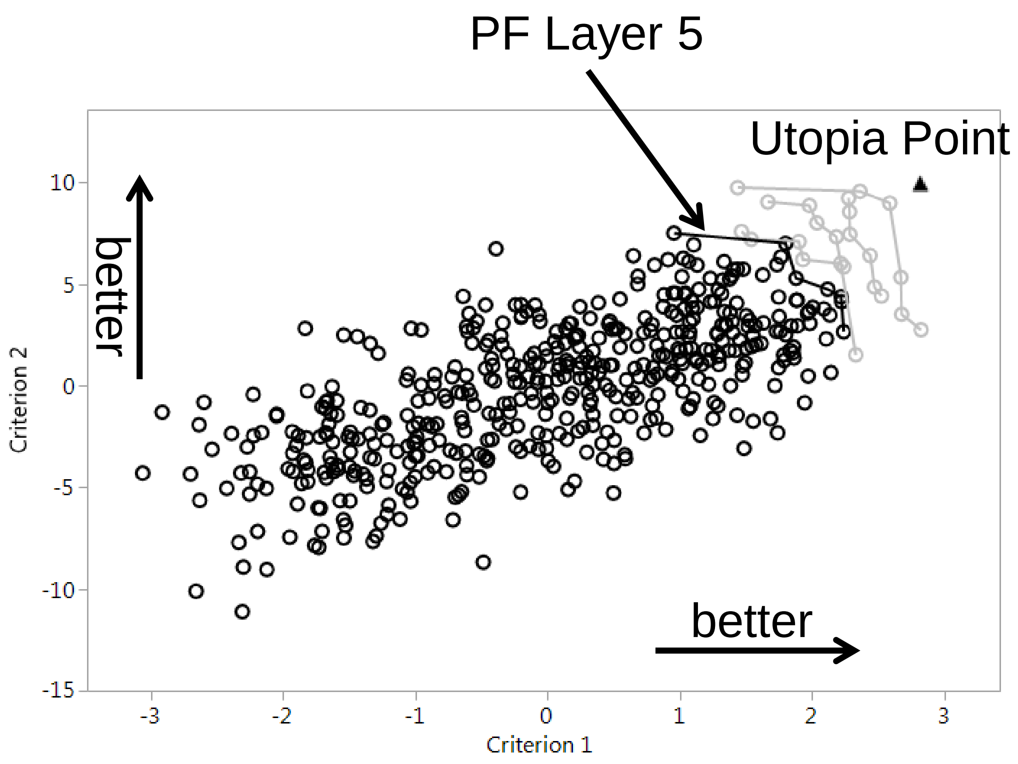

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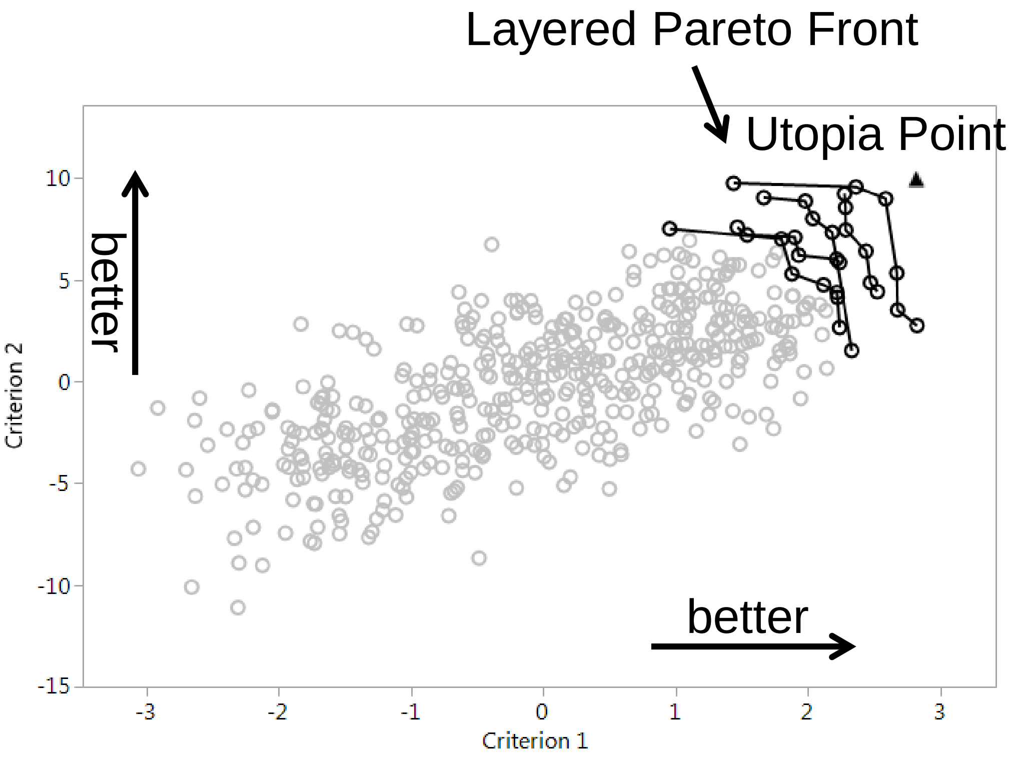
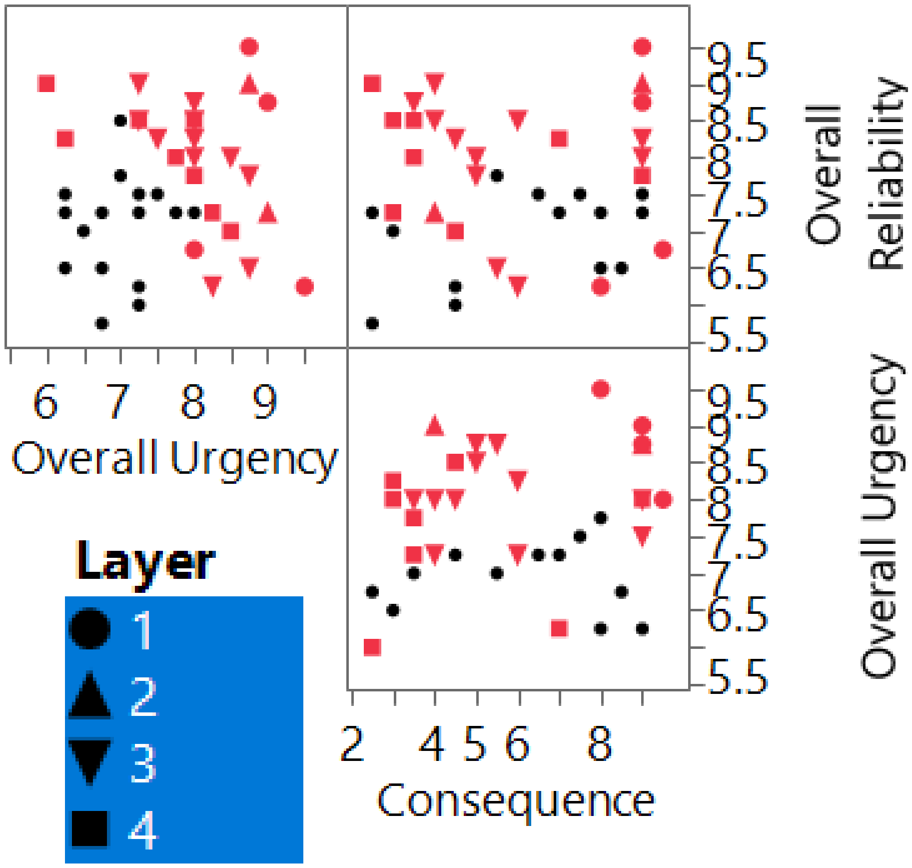


Reduce: Stockpile

- 26/42 stockpiles in 4 PF layers
- Objectively eliminate 16 (approx. 1/3) stockpiles from further consideration
- Why PF layers?
  - Consider stockpile A4: (OR,OU,C) = (9,8.75,9)
  - A4 not in first PF layer; dominated by A3 (OR,OU,C) = (9.5,8.75,9)
  - But still fairly critical



Combine

- Evaluate tradeoffs among contenders using desirability functions
- Make diverse criteria (potentially measured on different scales) comparable

$$Add\ DF_j = \sum_{i=1}^{k} w_i d_{ij}$$
$$Multi\ DF_j = \prod_{i=1}^{k} d_{ij}^{w_i}$$
$$\sum w_i = 1; w_i \geq 0$$

- d_{ij} are desirability scores; map original values to [0,1] scale
- Weights are subjective & may change top N rankings
    - –Must reflect decision-makers' priorities (which likely differ)

Derringer, G., & Suich, R. (1980). "Simultaneous optimization of several response variables." *Journal of Quality Technology, 12*, 214-219.

Combine

- Several choices team must make:
  - How to scale original criteria values?
  - Which desirability function?
  - What values of weights for each criterion?
- TopN-PFS Add-In provides several options to meet decision-makers' needs
- **Scaling:**
  1. Use the natural range of each metric; map 10 (most critical) to $d_{ij} = 1$ and 0 (least critical) to 0
  2. Use the range of the observed data; e.g., for Overall Reliability, 5.75 → 0, and 9.5 → 1
  3. Use the range of data on the top N PFs layers; e.g., for Overall Reliability, 6.25 → 0, and 9.5→ 1

Scaling choice does not affect solutions on PFs

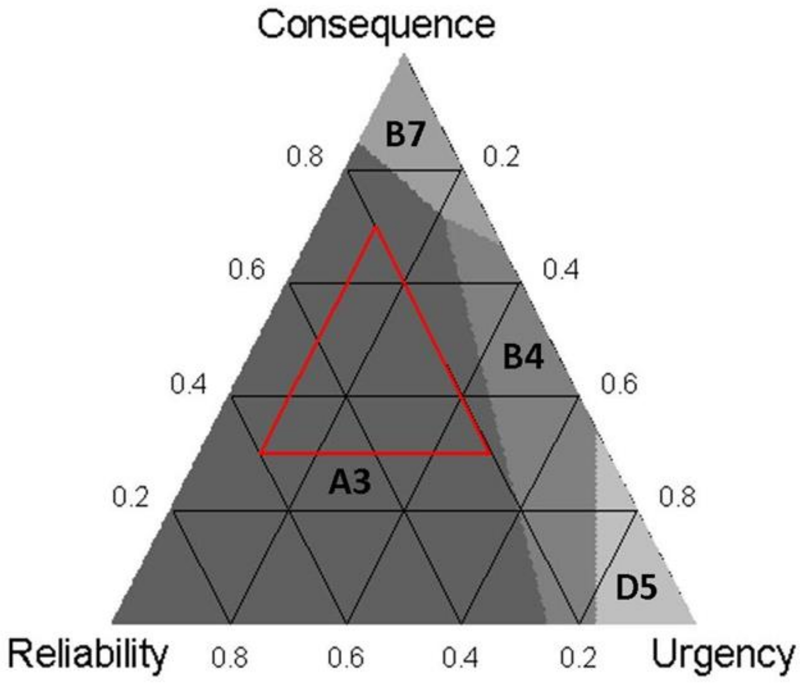
Combine

- Several choices team must make:
  - How to scale original criteria values?
  - Which desirability function?
  - What values of weights for each criterion?
- TopN-PFS Add-In provides several options to meet decision-makers' needs
- **Desirability Function:**
  - Multiplicative DF more severely penalizes low criterion values than the additive DF
  - Additive DF is more forgiving for poor performance of one criterion

Did not want to eliminate potentially critical stockpile
Evaluated impact of DF choice

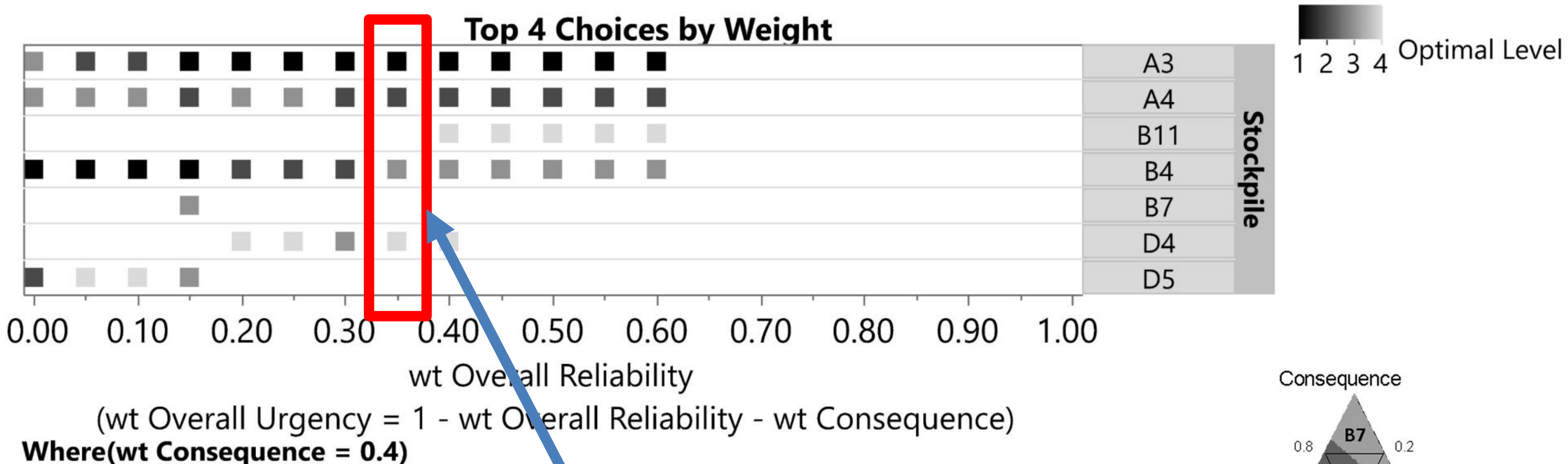
Combine

- Several choices team must make:
  - How to scale original criteria values?
  - Which desirability function?
  - What values of weights for each criterion?
- TopN-PFS Add-In provides several options to meet decision-makers' needs
- **Weights**
  - First consider which are most critical choices across all weights
  - 4 stockpiles identified as most critical across all weights
  - Both stockpiles with top individual scores and those with balanced high scores are identified as critical

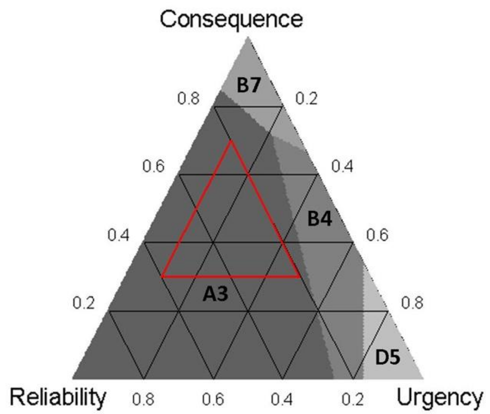


Select – Deeper Dive Across All Weights

Goal: Identify top **4** critical stockpiles



For (OR, OU, C) = (0.35, 0.25, 0.4), most critical stockpiles are: A3, A4, B4, D4



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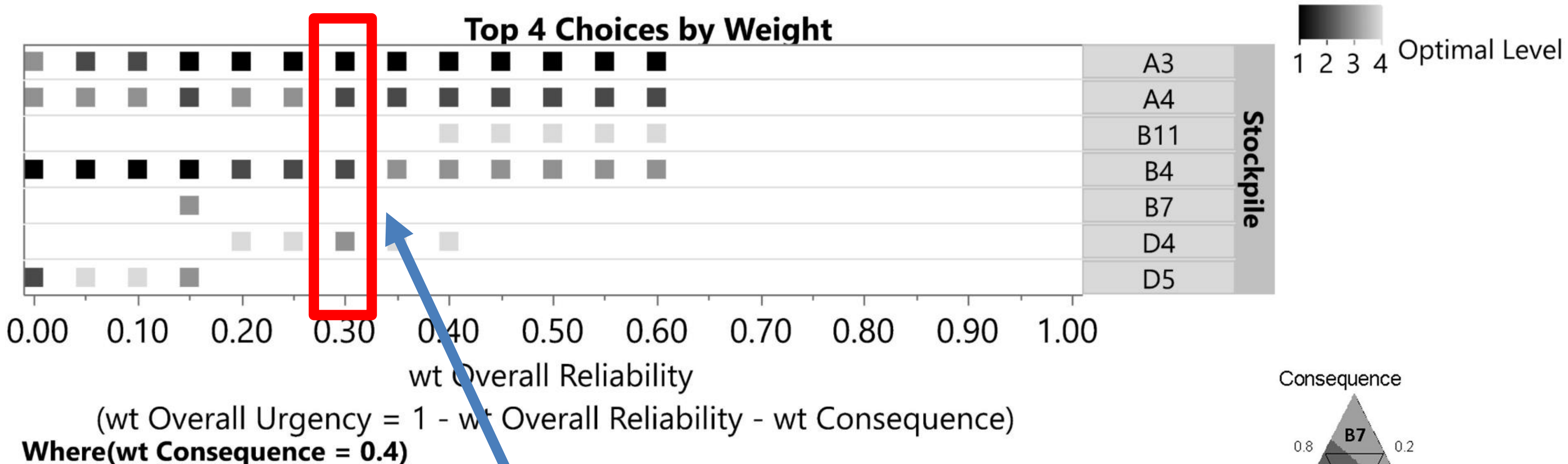
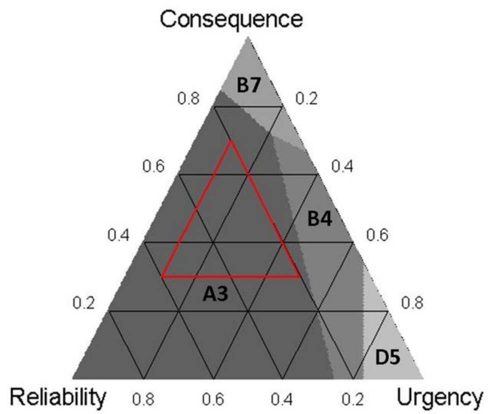
Goal: Identify top **4** critical stockpiles



For (OR, OU, C) = (0.30, 0.30, 0.4), A4 & B4 are tied for 2nd most critical



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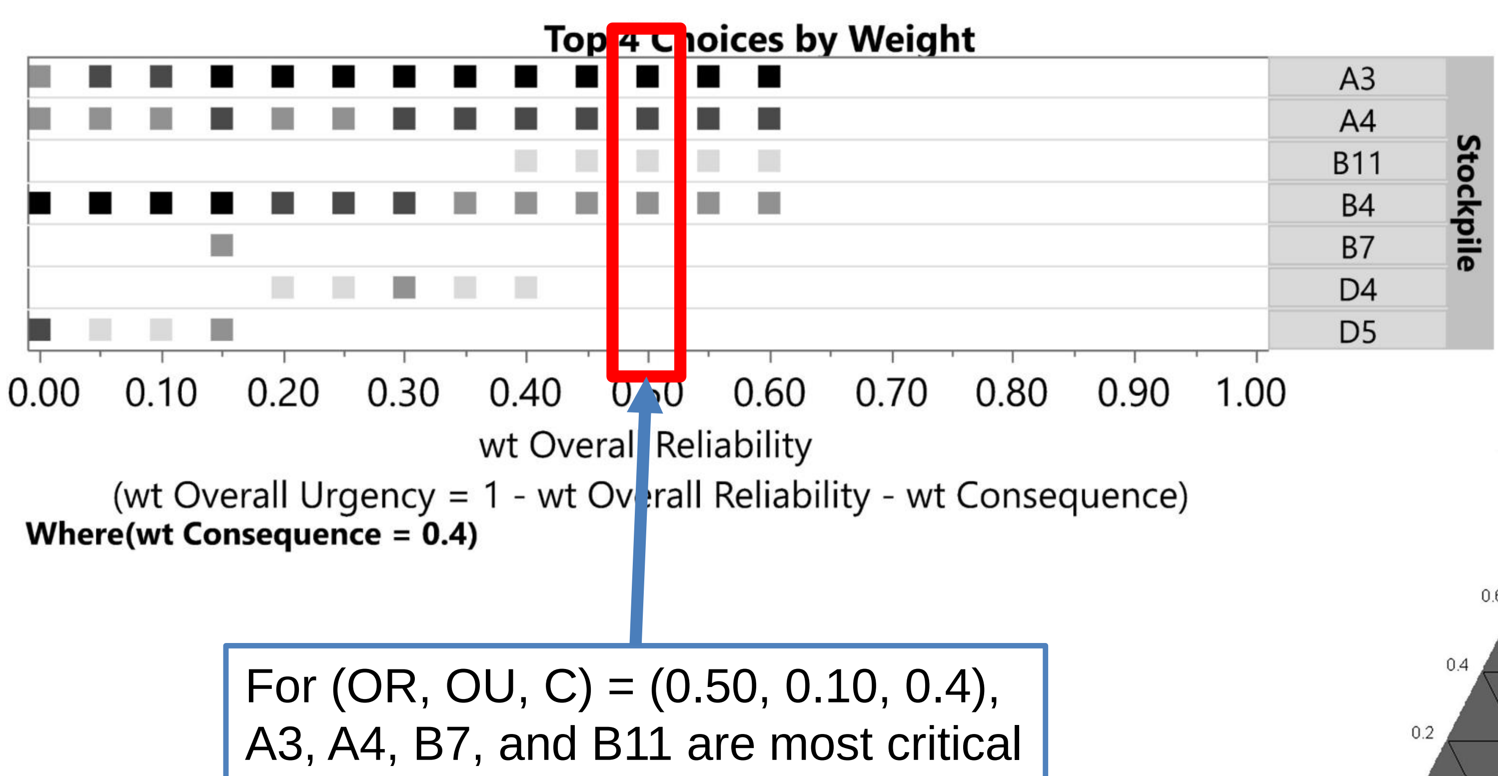
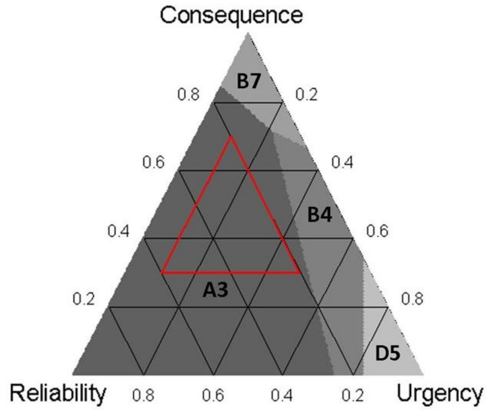
Goal: Identify top **4** critical stockpiles





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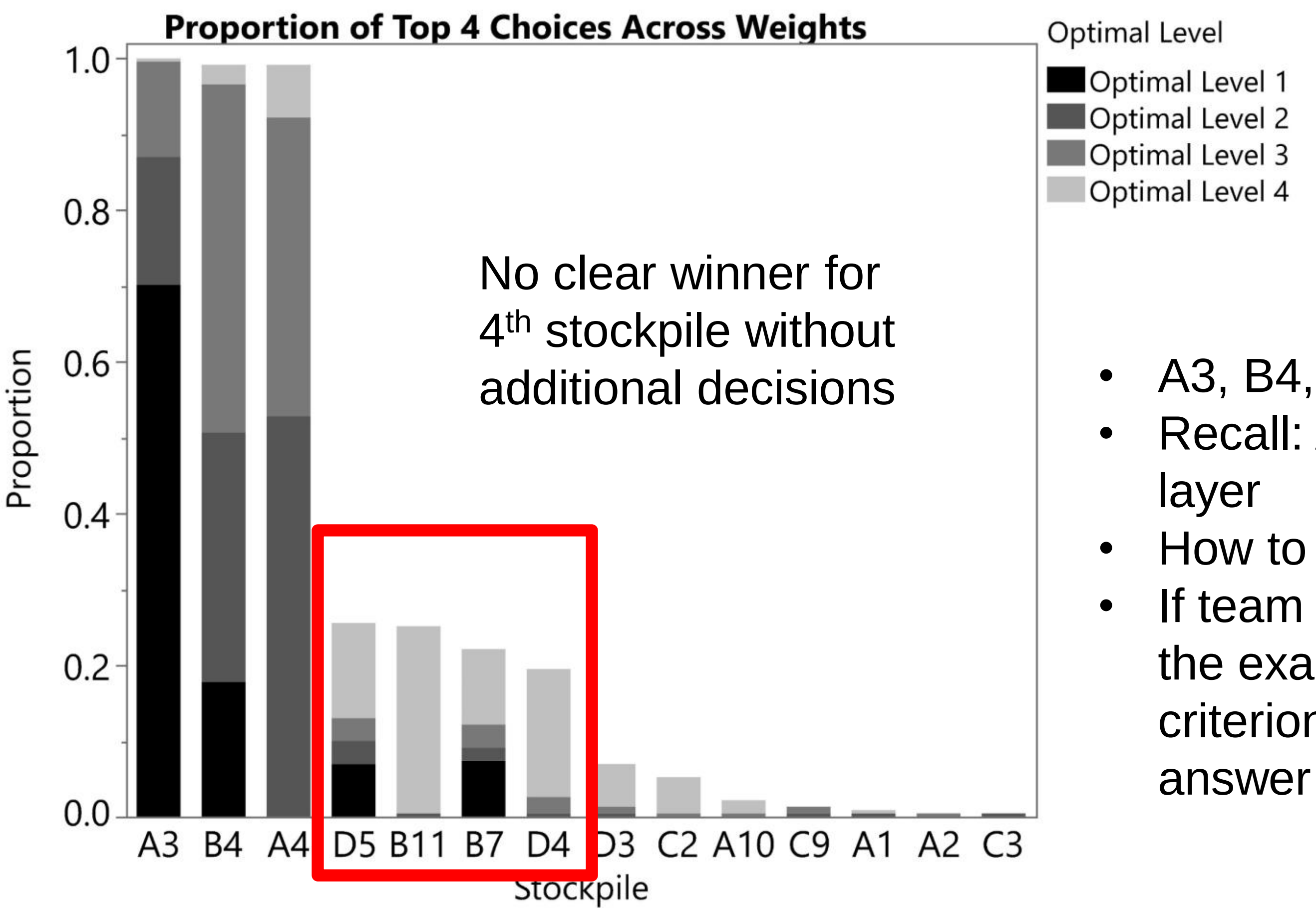


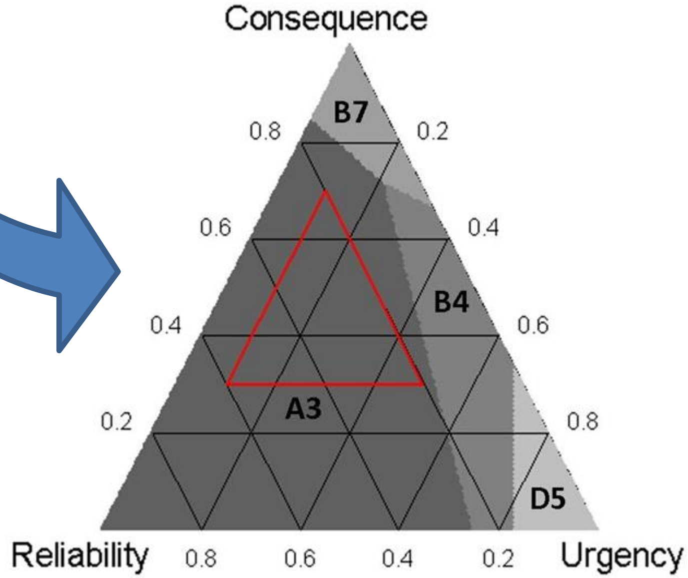
How often is each stockpile in the top 4 across all weights?

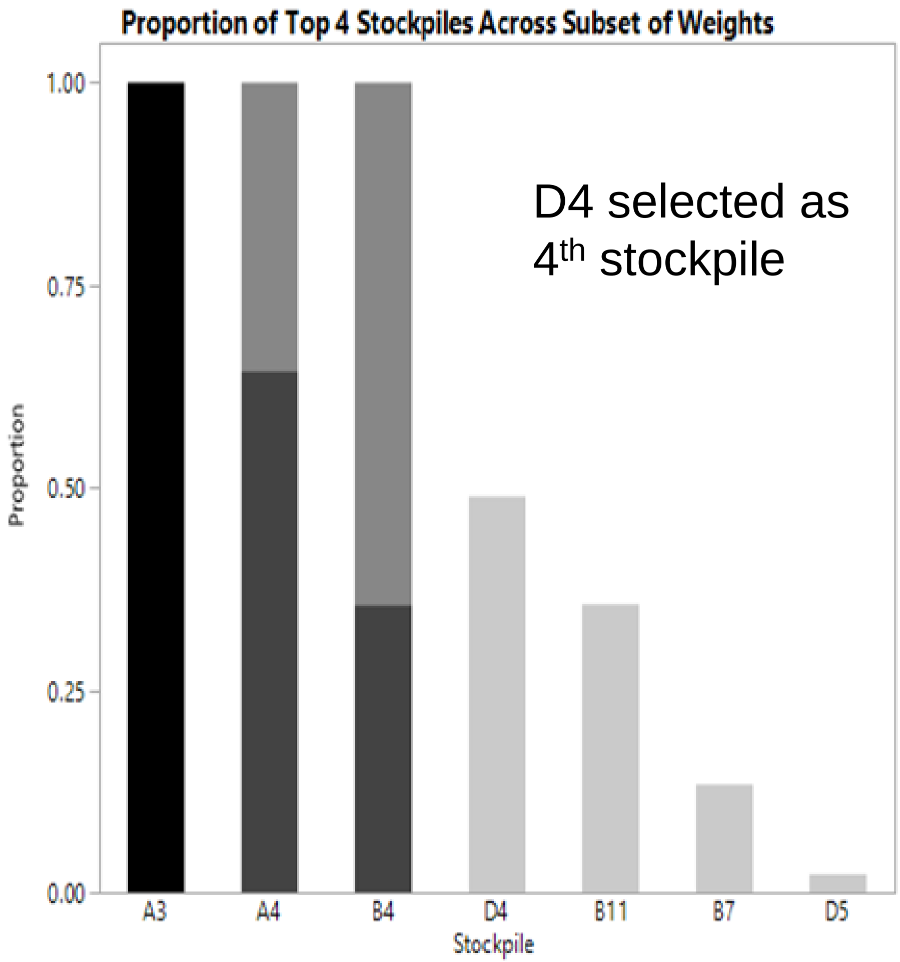
- A3, B4, A4 are clear winners
- Recall: A4 is on the 2nd PF layer
- How to choose 4th stockpile?
- If team members agreed on the exact weighting of each criterion, arrive at easy answer

Only 14 stockpiles ever in the top 4 for scaling & DF selections. Combining criteria into overall score has further reduced choices

Select – Narrow Weight Region

- Team members narrowed down to universally agreeable region of weights
  - – Overall Reliability ≥ 20%
  - – Overall Urgency ≥ 10%
  - – Consequence ≥ 30%

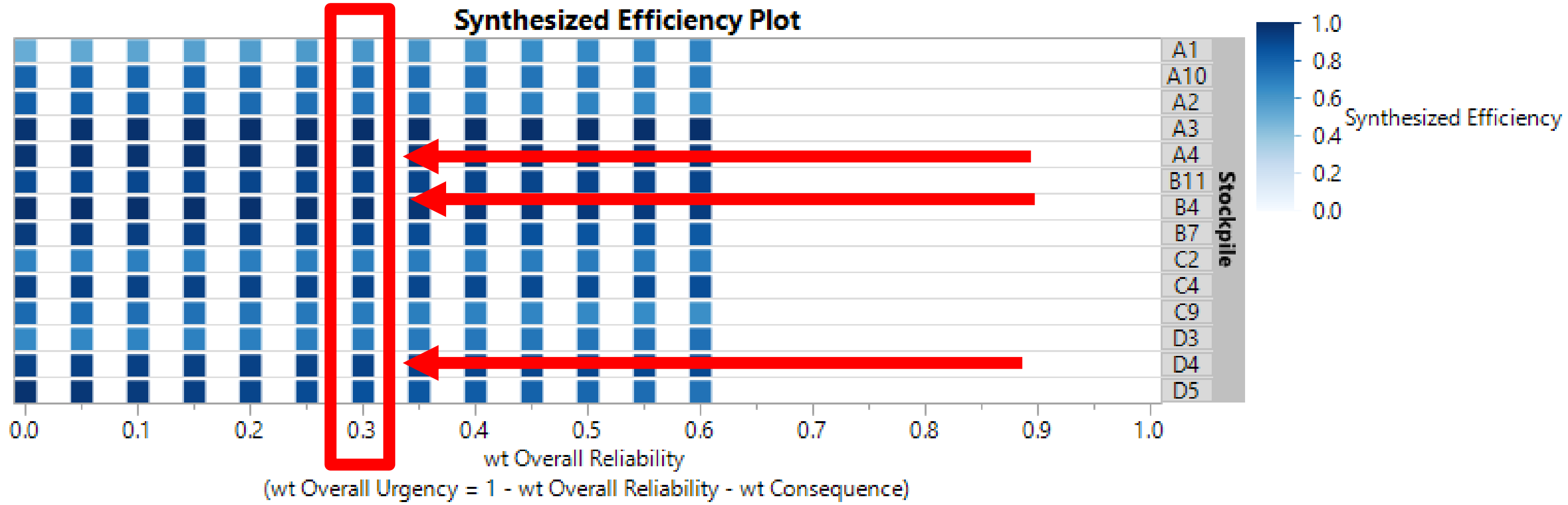




D4 selected as 4^{th} stockpile

Examining the Final Solution

Synthesized Efficiency Plot – how do solutions compare to best possible solution at given weight combo?

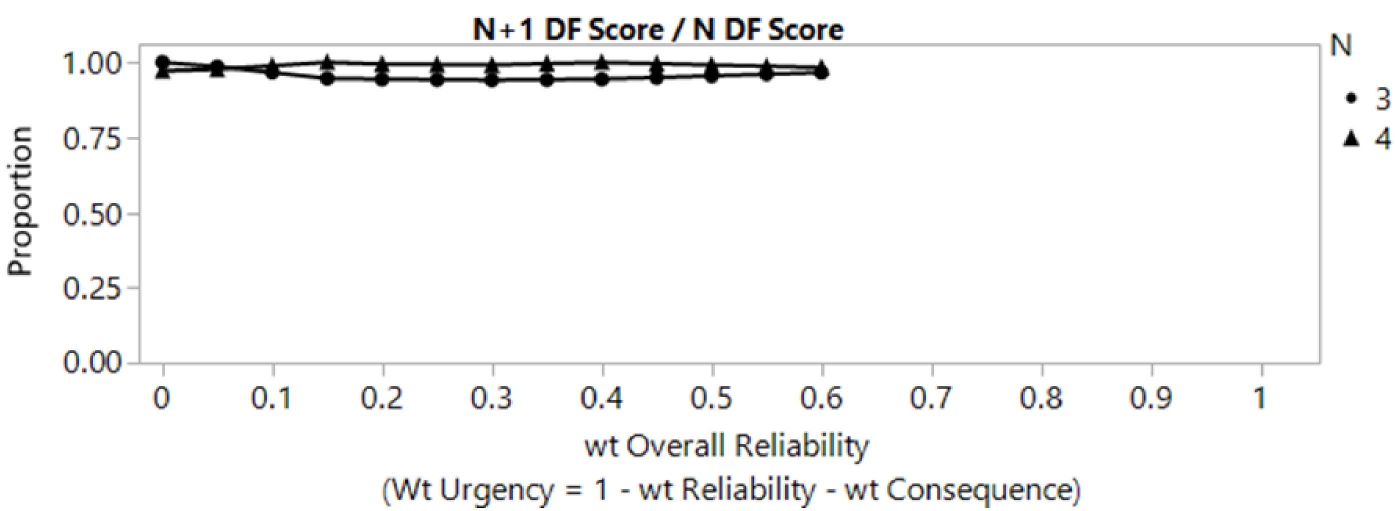


Where(wt Consequence = 0.4)

- A3 is most critical, so darkest shade of blue
- A3 has dark blue across all weight region shown: near optimal performance regardless of weight
- A4, B4, and D4 also dark blue -> DF score close to most critical (A3)

Was 4 the right choice?

- There is evidence that >4 stockpiles would greatly benefit from funding
- N+1 comparison plot shows ratio of DF scores for (N+1)th solution vs Nth best solution
- High value means (N+1)th solution is close to Nth best
- For N = 4, there is very little difference between 4th most critical and 5th most critical stockpile across weights
- Evidence for sponsor to find additional funding??

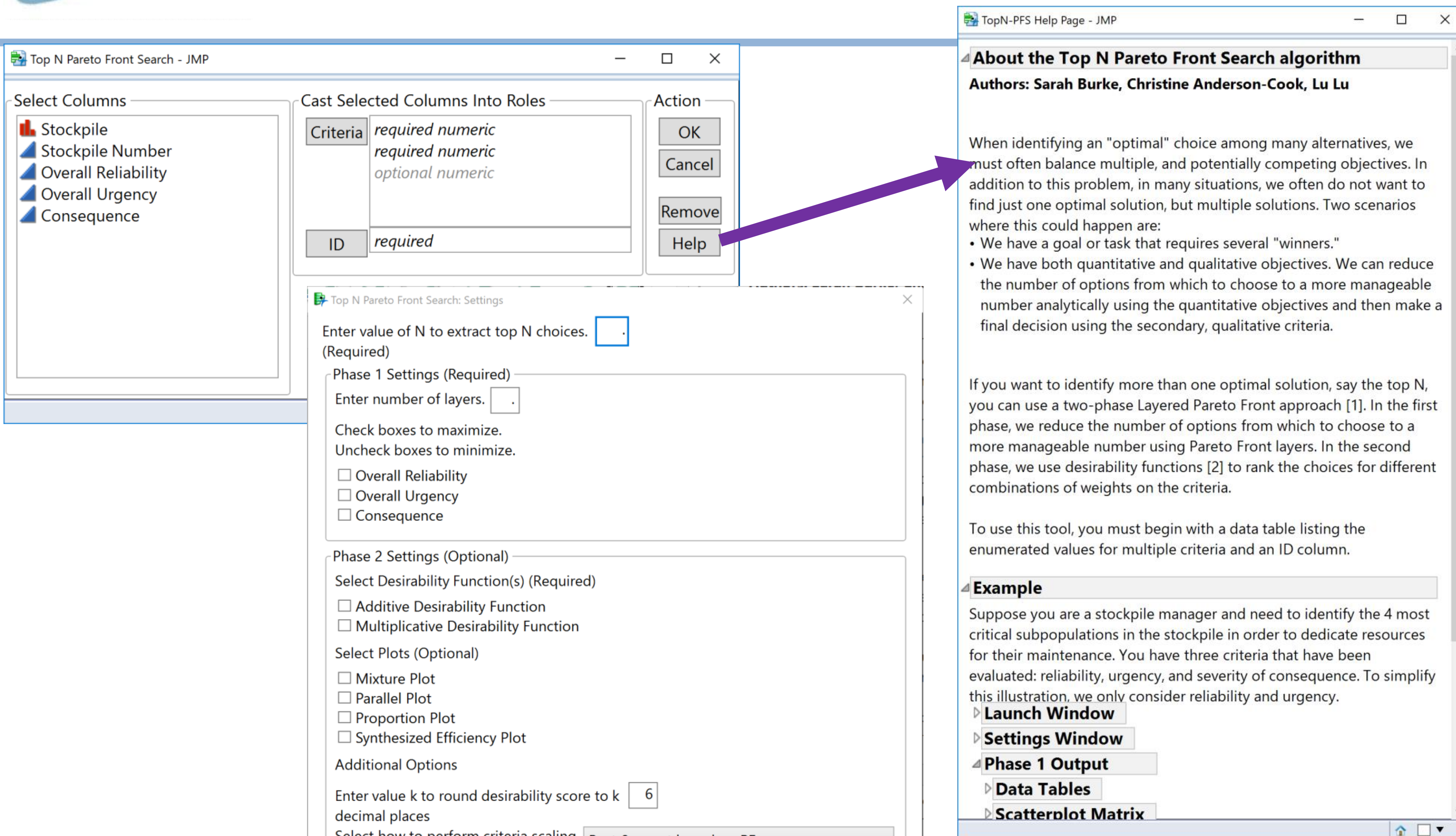


Where (wt Consequence = 0.4)

Final Decision

- A3, B4, A4, and D4 were selected as recipients of the additional funding
- All team members agreed that the right decision had been made (although manager C did not receive any additional funding)
- Subjective choices made can be assessed using the JMP Add-In
  - Can quickly recreate the analysis with a different desirability function and/or scaling approach
  - The final stockpile selections in this example were robust to the choices of DF and scaling

JMP Add-In



https://community.jmp.com/t5/JMP-Add-Ins/Top-N-Pareto-Front-Search-for-Structured-Decision-Making/ta-p/36527

Summary

- Using a structured decision process (DMRCS) allowed for a defensible and rigorous process
- Facilitate decision making for a complex process with many criteria
- Better buy-in on final decision because of participation in Define-Measure steps
- Longer decision process, but more informed & data-driven decision is made

THE PERDUCO GROUP

Questions?

STAT

RETURN OF THE SCIENTIFIC METHOD

COE