Module H — Making Decisions with Multiple Objectives

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Multiple-objective Tradeoffs

- In this module
  - How structured tradeoffs improve decisions
  - Key steps
    - Simplification
    - Converting different attributes to one scale
    - Weighting by preference or values
  - Some tools, examples and experience

- Why structured methods?
  - Trading "apples for oranges" is hard!
    - Too much information to process informally
    - Even harder with multiple parties involved
  - Structure improves thinking and decisions by focusing on
    - Separate parts ("decomposing" the decision)
    - Fundamental objectives
  - Clear rationale and transparency about tradeoffs increases buy-in, defensibility

What's involved in these methods?

- Clear statement of objectives (independent attributes)
- Viable set of alternatives
- Describe consequences on these different attributes
  - Consequence table
  - Usually 'fixed' outcomes (do not address uncertainty)
- Simplify the problem as much as possible
  - Dominated alternatives
  - Irrelevant objectives
  - Even swaps

Then do one of the following:

- Reduce to a single-objective problem
  - Combine objectives
  - Transform some objectives into constraints
- Quantitative trade-off methods
  - Put consequences on a common scale
  - Weight & sum across all objectives (SMART, AHP)
- Analyze to find the efficient frontier, and negotiate from there

Impoundment Repair

Objectives	Alternatives			
	Status quo	Minor repair	Major repair	Re-build
Cost ($M)	0	2	12	20
Environmental Benefit (0-10)	1	3	10	10
Disturbance (0-10)	0	1	7	10
Silt runoff (k ft3)	5	1	3	3
Water Retention (MG)	41	41	41	39

Simplify the Problem

- Dominated Alternative
  - Other alternatives perform the same or better on all objectives
- “Irrelevant” Objective
  - Performance measures do not vary over alternatives
  - This isn’t to say the objective isn’t important to you, just that it doesn’t help discern among the alternatives
- Even Swap
  - Adjust the consequences of different alternatives to render them equal for a given objective (and then that objective becomes irrelevant)

Dominated Alternatives

Objectives	Alternatives			
	Status quo	Minor repair	Major repair	Re-build
Cost ($M)	0	2	12	20
Environmental Benefit (0-10)	1	3	10	10
Disturbance (0-10)	0	1	7	10
Silt runoff (k ft3)	5	1	3	3
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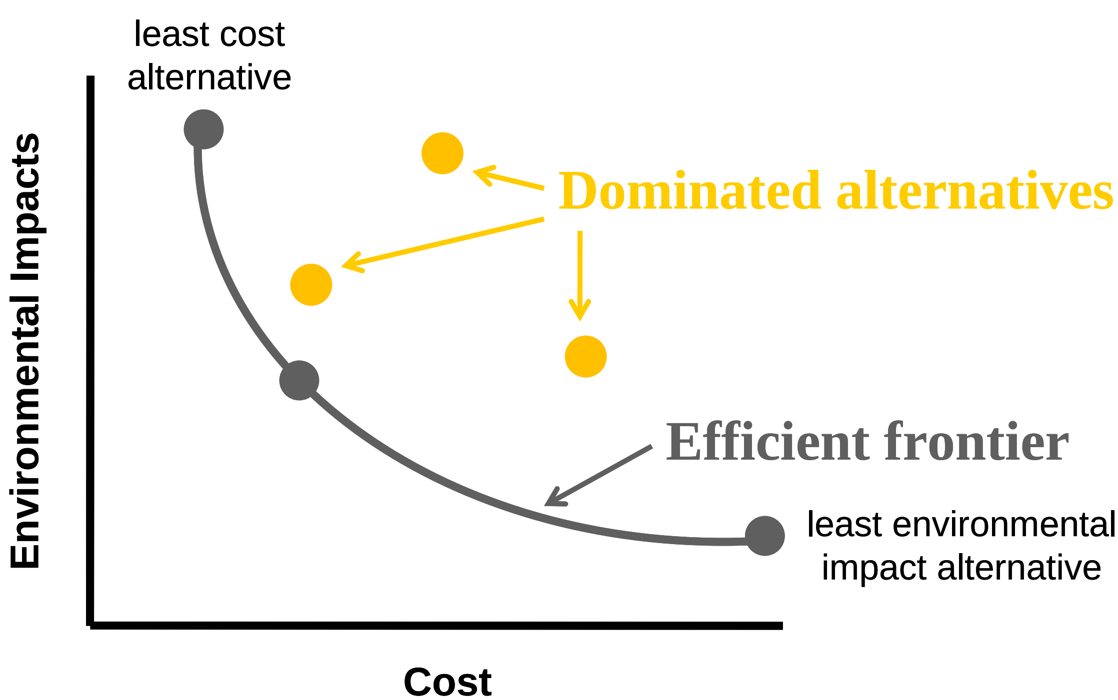


Irrelevant Objectives

Objectives	Alternatives			
	Status quo	Minor repair	Major repair	Re-build
Cost ($M)	0	2	12	20
Environmental Benefit (0-10)	1	3	10	10
Disturbance (0-10)	0	1	7	10
Silt runoff (k ft3)	5	1	3	3
Water Retention (MG)	41	41	41	39

Even Swap Method

- Express one objective in terms of another
- Set the first objective to the same value for all alternatives by converting the differences into the second objective
- Remove the (now) irrelevant 1st objective
- Remove any dominated alternatives that might result

Even Swap

Even Swap – convert silt runoff to cost

@ $0.5M / k ft^3$

Objectives	Alternatives			
	Status quo	Minor repair	Major repair	Re-build
Cost ($M)	0	2	12	20
Environmental Benefit (0-10)	1	3	10	10
Disturbance (0-10)	0	1	7	10
Silt runoff (k ft^3)	5	1	3	3
Water Retention (MG)	41	41	41	39

Even Swap

Even Swap – convert silt runoff to cost

@ $0.5M / k ft^3$

Objectives	Alternatives			
	Status quo	Minor repair	Major repair	Re-build
Cost ($M)	0 + 2 = 2	2	12 + 1 = 13	20
Environmental Benefit (0-10)	1	3	10	10
Disturbance (0-10)	0	1	7	10
Silt runoff (k ft^3)	5 – 4 = 1 $ 2M	1 $ 0M	3 – 2 = 1 $ 1 M	3
Water Retention (MG)	41	41	41	39

Even Swap (can now be removed)

Reduced Problem

Objectives	Alternatives		
	Status quo	Minor repair	Major repair
Cost ($M)	2	2	13
Environmental Benefit (0-10)	1	3	10
Disturbance (0-10)	0	1	7

>>>>>>>>>>Skill Check, Rolling Thunder, Part 1<<<<<<<<<<

Then, do one of the following:

- Reduce to a single-objective problem
  - Combine objectives
  - Transform some objectives into constraints
- Quantitative trade-off methods
  - Put consequences on a common scale
  - Weight & sum across all objectives (SMART, AHP)
- Analyze to find the efficient frontier, and negotiate from there

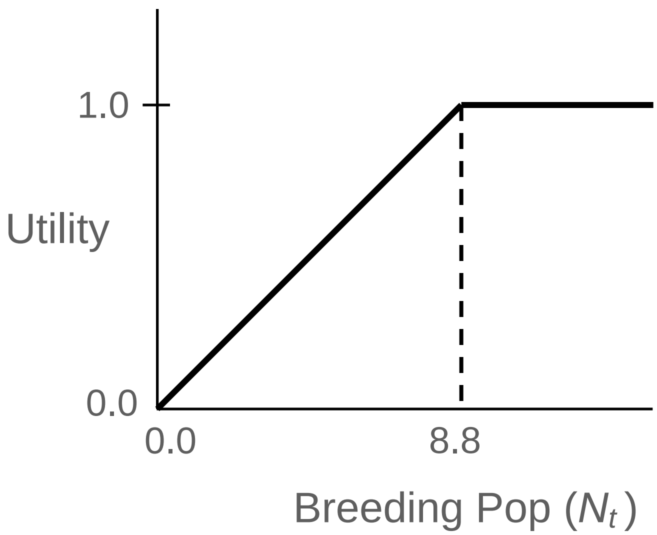
Reduce to a single-objective problem

- Creatively combine objectives
  - “Pricing out”—like even swaps, a way to express one objective in terms of another
- Turn some objectives into constraints
  - That is, seek to satisfy, rather than optimize, some of the objectives

Example: Mallard Harvest

- Objectives
  - Provide substantial harvest opportunity
  - Conserve mallard populations indefinitely
  - Meet the NAWMP population goal (G)
- Stated quantitatively
  - Maximize H_t
  - $N_t > 0$ for all t
  - Minimize G-N_t, if N_t is below goal

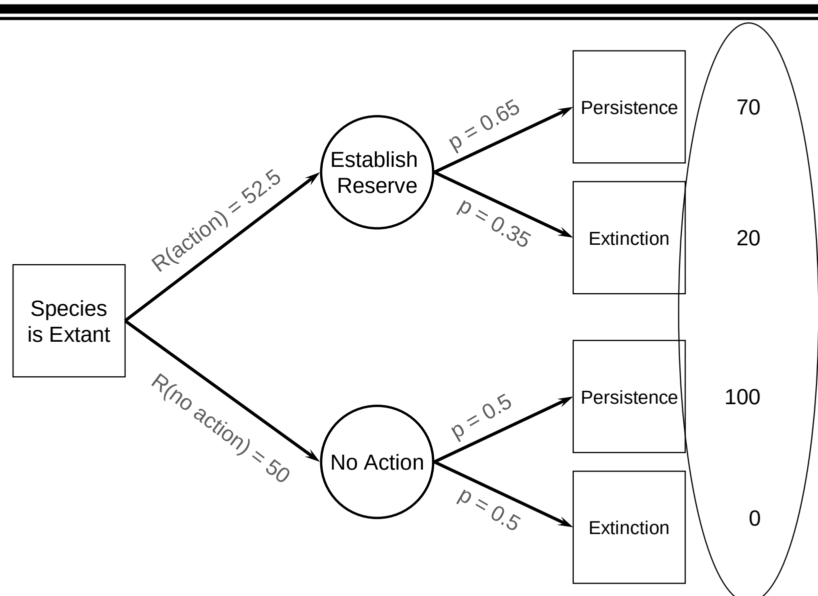
- Maximize cumulative long-term harvest,
- While devaluing harvest when the projected N_t < NAWMP goal



$$\therefore \max \sum_{t=0}^{\infty} u(N_t) * H_t$$

Decision Tree

Constructed scale with multiple objectives embedded



2. Treat as Weighted Objective

- A variety of methods essentially turn a multiple-objective problem into a single-objective problem by
  - assigning weights to each objective, and
  - calculating a weighted score for each alternative
- There are different strategies for doing this
  - SMART (Simple Multi-Attribute Rating Technique)
  - AHP (Analytic Hierarchy Process)
  - Goal Programming
  - Etc.

SMART Tradeoff Method

- Simple Multi-Attribute Rating Technique
  1. Normalize all attributes to 0-1 scale
  2. Assign weights to each attribute
  3. Calculated weighted sum of scores for each alternative
  4. Recommend alternative with highest weighted score
  5. Sensitivity analysis!

SMART Spreadsheet

			Alternatives						
			Consequence Matrix				Normalized & Weighted Scores		
Objectives	**Goal**	**Units**	**Status Quo**	**Minor Rep**	**Major Rep**	**Wt**	**Status Quo**	**Minor Rep**	**Major Rep**
Cost	Min	$M	2	2	13	.25	.25	.25	0
Environ Benefits	Max	0 - 10	1	3	10	.50	0	.11	.5
Disturbance	Min	0 - 10	0	1	7	.25	.25	.21	0
						Final Score:	0.5	0.58	0.5

Normalized score = $(s_{ij} - \min(s_j)) / (\max(s_j) - \min(s_j))$

Spreadsheet

SMART spreadsheet example:

CONSEQUENCE MATRIX		**Alternatives**			
Objectives	**Goal**	**Status Quo**	**Minor Rep**	**Major Rep**	**Units**
Cost	Min	2	2	13	$M
Environ Benefits	Max	1	3	10	0 - 10
Disturbance	Min	0	1	7	0 - 10

NORMALIZED SCORES		**Alternatives**		
Objectives	**Goal**	**Status Quo**	**Minor Rep**	**Major Rep**
Cost	Min	1.000	1.000	0.000
Environ Benefits	Max	0.000	0.222	1.000
Disturbance	Min	1.000	0.857	0.000

"1" = the best,
"0" = the worst

To normalize (by row)
(x – min) / (max – min)
(x – max) / (min – max)

WEIGHTED SCORES		**Alternatives**			
Objectives	**Goal**	**Status Quo**	**Minor Rep**	**Major Rep**	**Weight**
Cost	Min	0.25	0.25	0	0.25
Environ Benefits	Max	0	0.111111111	0.5	0.50
Disturbance	Min	0.25	0.214285714	0	0.25
					1.00
Sum of weighted scores					
Final Score (sum wt scores/sum wts)					

How do you assign weights?

- Weights represent the relative values a decision maker places on different objectives
  - Must be elicited from the decision maker
- Variety of methods
  - Direct elicitation
  - Swing weighting
  - Pairwise weighting (Analytic Hierarchy Process, AHP)
- Weights are context-dependent
  - If you change the range of scores for an attribute, its weight may need to change

Why use Swing Weights?

- Multiple-objective methods require converting all objectives to the same scale (normalized or 0-100) in order to sum up consequences across different objectives (for a 'total' score for each alternative)
- But with normalized scores, direct importance weights are misleading
- Better to elicit "Swing Weights." The relative weight or preference for an objective often depends upon the particular values available to us (e.g., the actual alternatives)
    - In other words, preferences among objectives are context specific – not just the abstract importance of an objective
- Swing weights use the "swing" or range from worst to best consequence values across the actual alternatives *(not the normalized or 0-100 values)* to help elicit context-specific preferences

Swing Weights — Steps

To elicit swing weights, you will compare scenarios or hypothetical "alternatives" – one (the benchmark) with all objectives at their worst level (from the range in your actual alternatives), and a set of others each with only *one* attribute 'swung' to its best level.

1. Identify the worst case (=benchmark) & the best case for each objective
2. Ranks: Now compare a series of scenarios in which one objective at a time is set to its best value
    - "If just one of the attributes could be moved to its best level, which would it be?" This scenario is ranked 1.
    - Repeat the question until all scenarios have been ranked (benchmark should have the worst rank).
3. Convert to 0-100 scores: Assign a score of 100 to the Rank 1 scenario and 0 to the benchmark. Then ask,
    - "How important is the *range or swing* from worst to best level of the Rank 2 scenario compared with the range or swing from worst to best on the Rank 1scenario?"
    - Repeat sequentially for remaining ranks
4. Normalize the scores - divide each score by the sum of all scores & multiply by 100 – these are the 'swing weights'

Swing Weights Example: **Picking a Puppy**

Objective				**Range**		**Hypothetical Scenarios (Puppy)**			
	Description	**Attribute**	Goal	**Worst**	**Best**	**Benchmark**	**1**	**2**	**3**
A	Large dog personality	pounds	max	20	85	20	85	20	20
B	Non-annoying hair	inches	min	6	1	6	6	1	6
C	Friendliness	constructed	max	1	4	1	1	1	4
	Rank	(1 is best; 4 is worst)				4			
	Score	(100 is best; 0 is worst)				0			
	Weight (normalized)	[score/(sum of scores)]*100				0			

3. Negotiated Solution

- These techniques are all meant to provide some rational way to deal with multiple objectives
  - But sometimes, you just cannot reduce the problem to a single objective
- The alternative is to simplify the problem as much as you can, then examine the trade-offs directly
  - Note the efficient frontier
  - Negotiate a palatable solution

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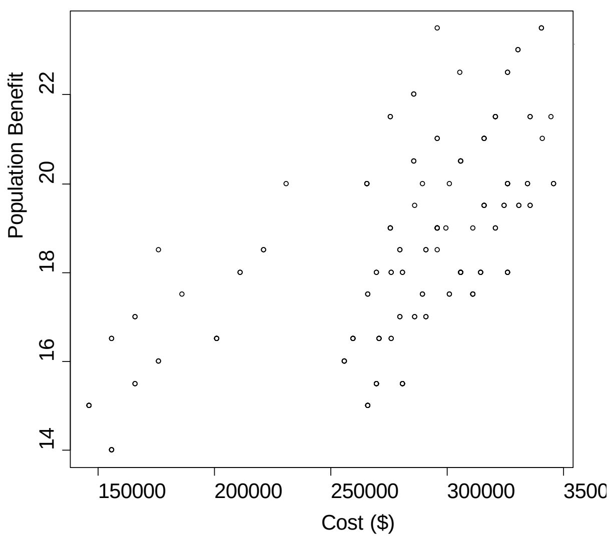

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Sensitivity Analysis

- How do you handle uncertainty in a multiple-objective problem?
- The most straightforward way is sensitivity analysis
  - Repeat the analysis, varying the scores and weights over their ranges of uncertainty
  - Check for robustness of recommended alternative

>>>>>>>>>>Skill Check, Rolling Thunder, Part 2<<<<<<<<<<

Skill Check – Multiple Objectives Tradeoffs
Rolling Thunder Prairie Management

You've just become the biologist at Rolling Thunder NWR in the upper Midwest. Years ago, the refuge acquired several prairie parcels to protect rare orchids. These plants only grow in open grasslands, usually requiring direct habitat manipulation to limit the invasion of woody species. Management objectives on these parcels have also included maintaining habitat for game birds, especially winter vegetation cover. More recently, conservation objectives have been expanded to include sustaining rare butterfly and beetle populations, which are also endemic to these prairie habitats. Meanwhile, residential development has increased and is now in proximity to these areas, prompting new constraints on management to avoid conflicts with local residents.

Multiple Objectives Trade-Off Exercise: The refuge manager has asked you to tell her the best options for managing the grassland vegetation. You need to select the vegetation treatment alternative that performs best across the seven objectives.

Objectives: Minimizing costs and neighbor complaints, while maximizing rancher support (grazing opportunity), and of course, conservation of birds, plants, butterflies, and beetles.

Alternatives: The refuge has five treatment options: Spring Burning, Fall Burning, Mowing, Grazing, and No Action.

Performance Attributes: The refuge has collected some data on the effects of different management strategies, such as grazing, mowing and controlled burning, on a variety of species. Your predecessor as refuge biologist has already compiled a 'Consequences Matrix' summarizing the performance of the five treatment alternatives on the seven objectives. He used 'proxy measures' for the objectives, such as 'stem density' as the index for effects on plants, 'estimated number of complaints' for neighbor complaints (from a survey), and 'grazing units' or number of permitted cattle-months as an index for rancher support (see full matrix, attached).

Additional Background Information:

- The most influential habitat factor predicting bird population density is the presence of over-winter grass cover. Thus, the bird conservation objective can be considered through winter vegetation cover.
- Except in wet years or locations, fall burning leaves the prairie relatively bare of standing vegetation until spring regrowth.
- Plants benefit most from burning, which not only limits woody plant encroachment but releases nutrients into the soil.
- Butterflies suffer direct mortality from burning, yet are strongly dependent on several species of plants that thrive with burning. Burn timing affects butterfly survival, with losses greater in spring burns as eggs die or fail to emerge. Because they can fly between patches, adult butterflies are able to recolonize habitat patches after treatments provided source populations are maintained.

- Beetles are relatively non-vagile and therefore suffer direct mortality in burning and some mortality from cattle trampling, and also are slow to recolonize areas where local populations are eliminated. Fall burning also leaves beetles exposed to winter mortality.
- Mowing causes the least direct mortality to beetles and also orchids (which cattle eat), but is also logistically most challenging and cannot be implemented across all patches consistently to control woody vegetation. Mowing during butterfly hatch can reduce populations.
- Failing to conduct any vegetation management (no action alternative) has the fewest direct impacts, but by allowing woody encroachment, harms prairie species conservation in the long term.
- Rancher revenue stems from the issuance of grazing permits on the refuge, thus, can be considered an economic or monetary value.
- Grazing permits generate $120/grazing unit in revenue.

Rolling Thunder Prairie Management

Part I

Reduce the number of alternatives in this table by finding and eliminating any dominated alternatives, in the process also deleting any irrelevant objectives that result as alternatives are dropped.

CONSEQUENCES TABLE		Treatment (Alternative)				
Objective	**Goal**	**Spring Burn**	**Fall Burn**	**Mowing**	**Grazing**	**No Action**
Cost (**$/year**)	Min	10,000	10,000	15,000	7,000	2,000
Rancher Revenue (# of Grazing Units)	Max	0	0	0	50	0
Neighbor Complaints (Estimated Number)	Min	5	5	0	1	1
Maintain Cover for Birds (Yes = 1, No = 0)	Max	1	0	1	1	1
Effects on Listed Plants (Stem density / m^2)	Max	10	9	2	1	1
Effects on Butterflies (Emergence Index % hatch)	Max	0.05	0.03	0.1	0.2	0.01
Effects on Beetles (% Area Occupied)	Max	0.02	0	0.35	0.2	0.02

Tip for finding dominated alternatives and irrelevant objectives: Look for an alternative (*column*) that 'can't win' because at least one of the other alternatives ranks better (or ties) on ***all*** objectives. Cross that alternative off the table and then see if any objectives have become irrelevant (no difference between the remaining alternatives). Repeat (we've set this up so you can reduce the table to three alternatives, if you find an even swap to perform).

Rolling Thunder Prairie Management

(Multiple Objectives Tradeoffs Exercise)

Part II.

Good work! The refuge manger liked your earlier work, went to the Regional Office for funding and was told to come back with a single proposal. So, she's asked you to provide her with the single best option with a full explanation.

Your task, using the 'reduced' consequences table, is to complete the SMART ranking method:

1) Put the information in the reduced consequences matrix (attached) into the appropriate places in the blank spreadsheet provided: "SkillCheck_5_Students.xls";
2) Enter formulas to normalize the consequences to a (0-1) scale;
3) Assign and enter weights to the objectives; and
4) Enter formulas necessary to calculate the sum of the weighted scores for each alternative.

Now, perform some sensitivity analysis (by adjusting the weights), and come up with your recommendation for the 'best' option and explain it to the refuge manager.

We want you to explain a single 'best' solution from the existing options. If you want you can also go farther and develop new alternatives, using your insights from the results and sensitivity analysis.

Rolling Thunder Prairie Management

(Multiple Objectives Tradeoffs Exercise)

Part II Reduced Consequences Matrix to enter in spreadsheet for SMART method ranking.

SIMPLIFIED TABLE		Treatment (Alternative)		
Objective	**Goal**	**Spring Burn**	**Mowing**	**Grazing**
Cost ($/year)	Min	10,000	15,000	1,000
Neighbor Complaints (Estimated Number)	Min	5	0	1
Effects on Listed Plants (Stem density / m^2)	Max	10	2	1
Effects on Butterflies (Emergence Index % hatch)	Max	0.05	0.1	0.2
Effects on Beetles (% Area Occupied)	Max	0.02	0.35	0.2

Math Tip:

One formula to normalize, or convert a series of numbers to their relative ranks on a 0-1 scale is: [(value – min) / (max-min)]
For example, for the series 1, 2, 10, the normalized score for 2 is: [(2 – 1)/(10 – 1)] = [1/9] = 0.11 on a 0-1 scale.

Showing these scales visually:

Original ranks:	**1**	**2**	**10**
Normalized ranks:	0	0.11	1

For objectives you want to *minimize* (cost, complaints), convert so the 'best' performing alternative gets the number 1. You can do this easily by calculating the normalized scores as above, then subtracting each score from 1, e.g., 1 - [(value – min) / (max-min)]