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Week 5:

Tradeoffs Step of PrOACT

Instructor: Brielle K Thompson

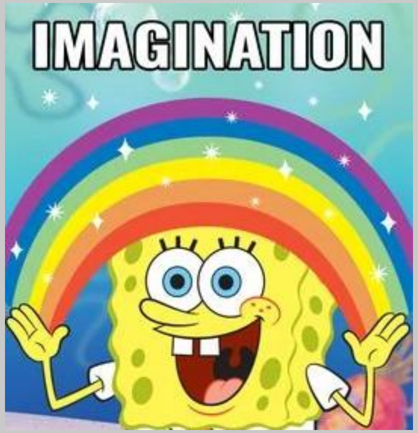
Course: NAT_R 8001 Decision Analysis for Research and Management of Natural Resources

Review of last week

- Discussed the Alternatives and Consequences step of SDM

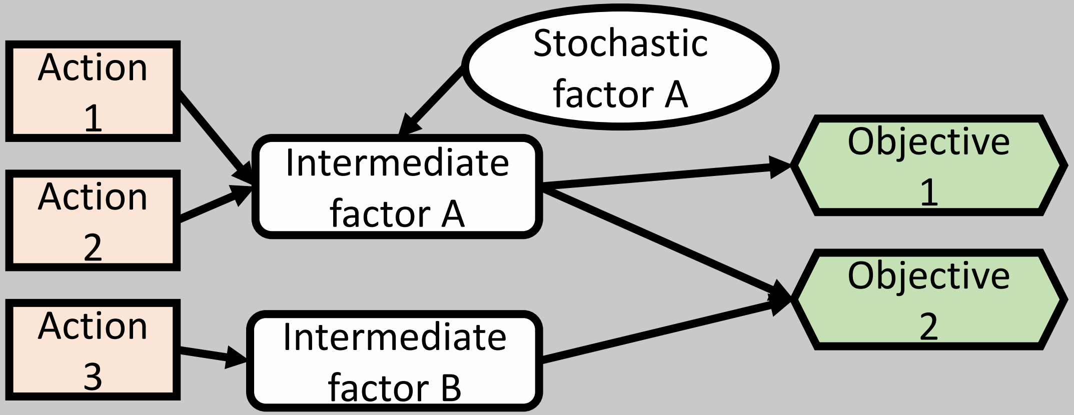
Identifying Alternatives:

1. Focus on fundamental objectives & address conflicting objectives
2. Challenge constraints
3. Create groups of alternatives (portfolios/strategies)
4. Revisit objectives

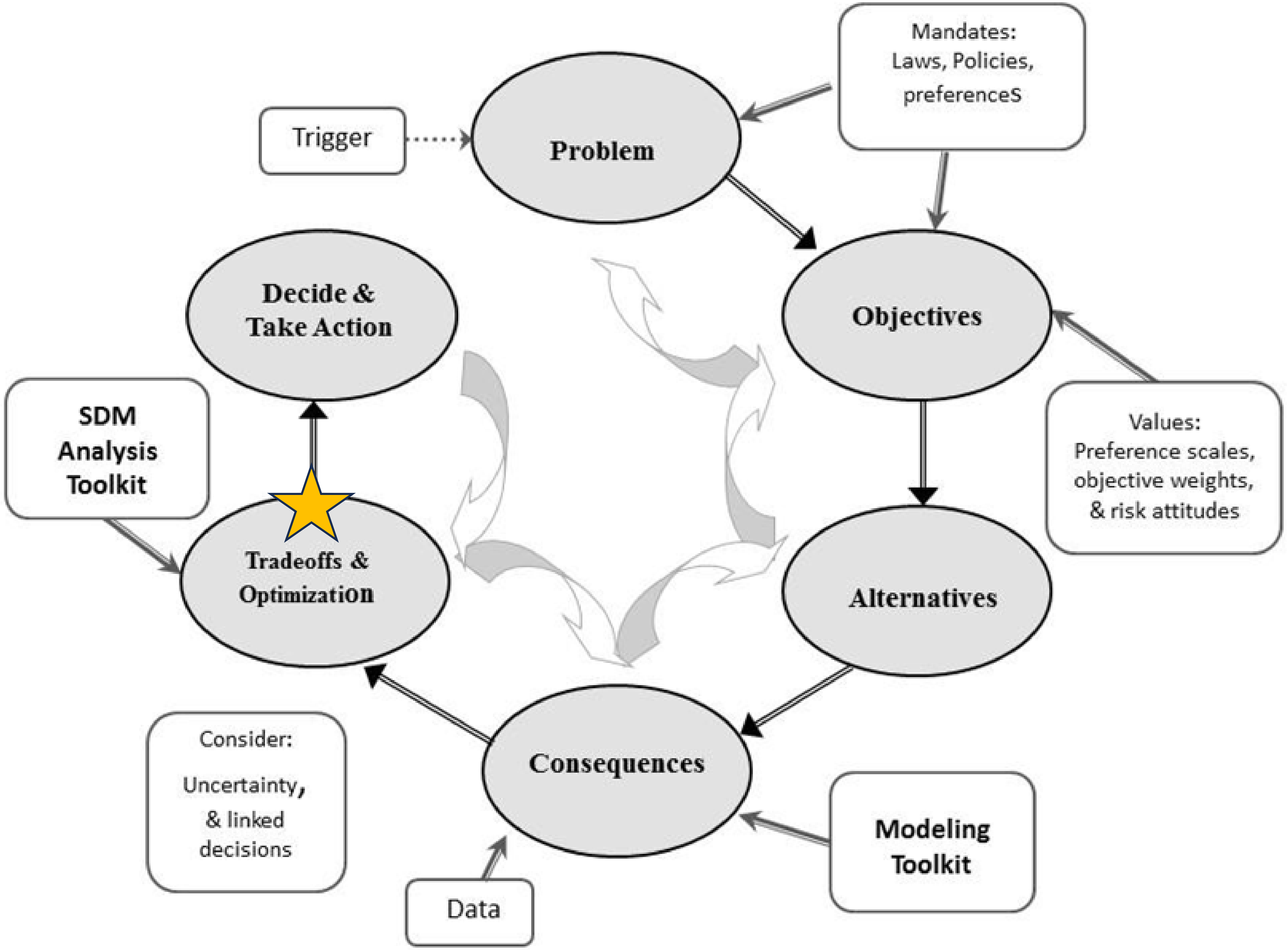


Tips for evaluating consequences:

- Build an influence diagram to help create models
- Identify model type (population model, economic model, expert elicitation, etc.)
- Organize outcomes in a consequence table



Today:
Learn about the Tradeoffs step



Source: Jean Fitts Cochrane

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Tradeoffs

"How much you would give up on one objective in order to achieve gains on another objective"

- Gregory et al. 2012

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

Role of analytical methods in tradeoff analysis

- Identify “best” (optimal) solution
  - Ties together alternatives, objectives, and predicted consequences
  - How do you integrate all the components?
- Easiest with a single objective
- Easiest without uncertainty
- Solution method depends on the structure of the problem

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

Analytical approaches

	Approach
Single Objective	• Deterministic optimization
Multiple Objectives	• Multiple Attribute Utility • Simplification • SMART • Pareto frontier analysis
	Negotiate among most efficient alternatives

Increased complexity

Single objective approach:

- Used when we have a single continuous decision variable (i.e., alternatives)
  - e.g., harvest rate, amount of herbicide to apply, size of biocontrol release, etc.

- Predict outcomes (i.e., objective) are a function of the decision variable

- Optimization solution methods:
  - Graphical
  - Closed-formed solutions (calculus/differentiation)
  - Numerical solutions (mathematical search methods)
  - Constrained optimization (mathematical solution)

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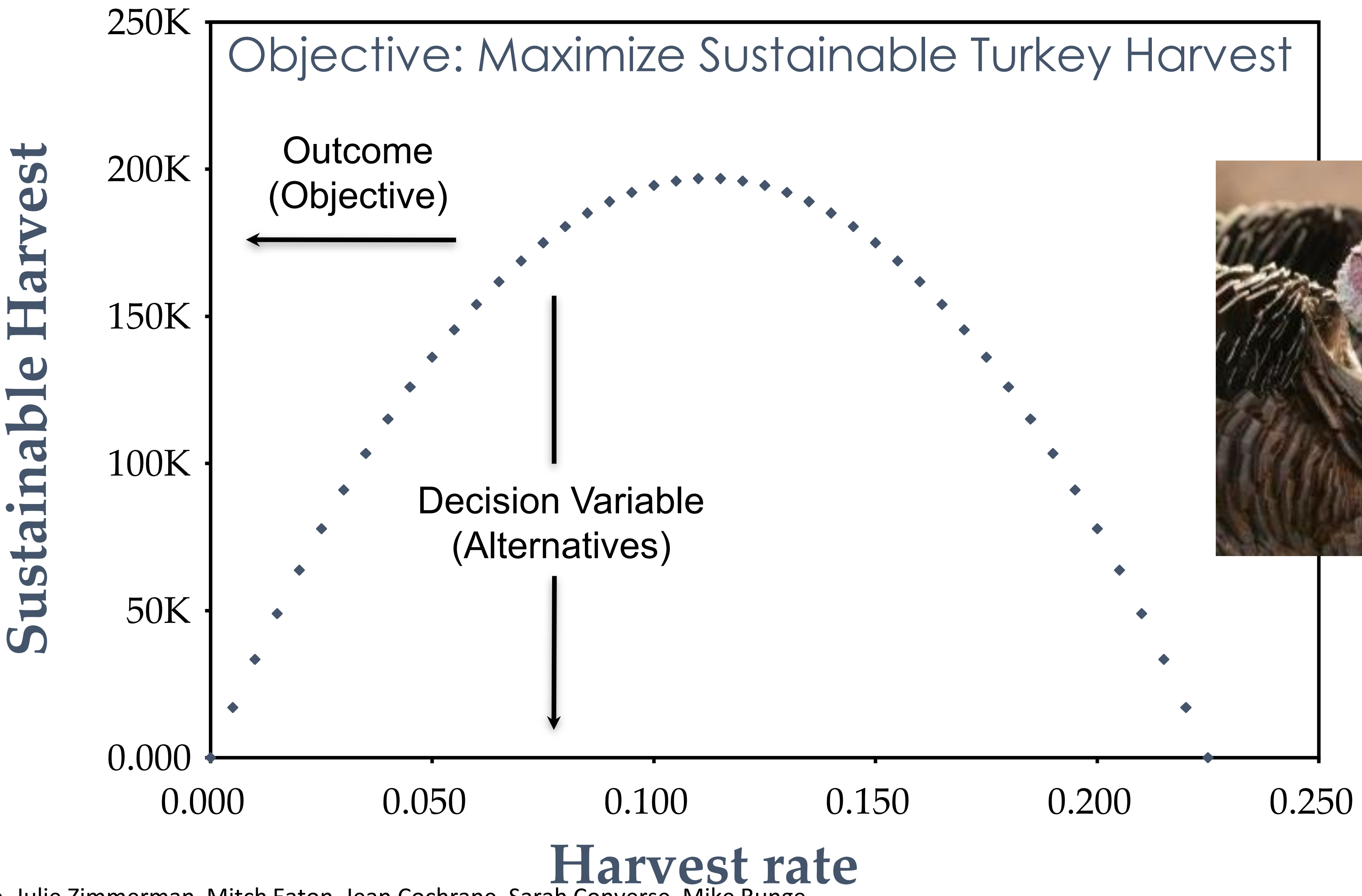
Single objective approach:

- Graphical optimization:



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Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

Single objective approach:

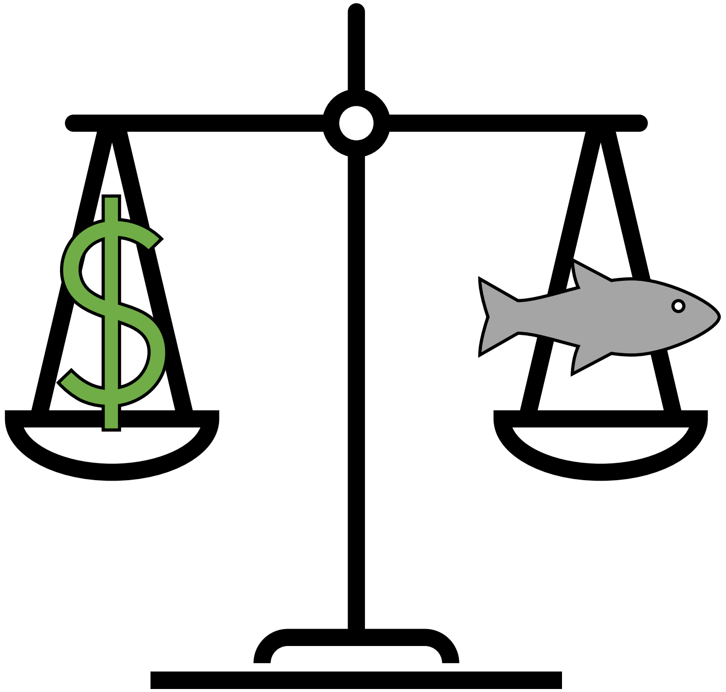
Question: Can you think of an example of a single objective problem?

- Not very common in natural resource management.
- Single objectives are easier to optimize, so we may want to reduce multiple objective problems to make them easier to solve.

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

Multiple objective tools

- Nearly all natural resource management problems are multiple-objective problems



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Multiple objective tools

A. Simplify the problem as much as possible
   1. Remove dominated alternatives
   2. Remove irrelevant objectives
   3. Make even swaps

B. Reduce to a single objective if possible

C. Negotiate a solution from a set of best compromises

D. Evaluate trade-offs explicitly

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem

1. Remove dominated alternatives:

- i.e., another alternative performs the same or better on all objectives

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem (EXAMPLE)

1. Remove dominated alternatives (another alternative performs the same or better on all objectives)

Objectives	Direction	Alternatives			
		Status quo	Minor repair	Major repair	Re-build
Cost ($M)	Min				
Environmental Benefit (0-10)	Max				
Disturbance (0-10)	Min				
Silt runoff (k ft^3)	Min				
Water Retention (MG)	Max				

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem (EXAMPLE)

1. Remove dominated alternatives (another alternative performs the same or better on all objectives)

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

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem (EXAMPLE)

1. Remove dominated alternatives (another alternative performs the same or better on all objectives)

Objectives	Direction	Alternatives			Dominated Alternative
		Status quo	Minor repair	Major repair	Re-build
Cost ($M)	Min	0	2	12	20
Environmental Benefit (0-10)	Max	1	3	10	10
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A. Simplify the problem

1. Remove dominated alternatives:
    - i.e., another alternative performs the same or better on all objectives

2. Remove irrelevant objectives:
    - i.e., performance measures of that objective does 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 <u>currently considered.</u>

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A. Simplify the problem (EXAMPLE)

2. Remove irrelevant objective

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

Dominated Alternative

A. Simplify the problem (EXAMPLE)

2. Remove irrelevant objective

Dominated Alternative

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

Irrelevant Objective

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem (EXAMPLE)

- **Simplified problem:**

Objectives	Direction	Alternatives		
		Status quo	Minor repair	Major repair
Cost ($M)	Min	0	2	12
Environmental Benefit (0-10)	Max	1	3	10
Disturbance (0-10)	Min	0	1	7
Silt runoff (k ft^3)	Min	5	1	3

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem

1. Remove dominated alternatives:
    - i.e., another alternative performs the same or better on all objectives

2. Remove irrelevant objectives:
    - i.e., performance measures of that objective does 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 <u>currently considered.</u>

3. **Make even swaps:**
    - If two objectives are in the same unit, then combine outcomes

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem (EXAMPLE)

3. Even swaps

Convert silt runoff to cost @ \$0.5M / k ft^3

Objectives	Direction	Alternatives		
		Status quo	Minor repair	Major repair
Cost (\$M)	Min	0	2	12
Environmental Benefit (0-10)	Max	1	3	10
Disturbance (0-10)	Min	0	1	7
Silt runoff (k ft^3)	Min	5	1	3

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A. Simplify the problem (EXAMPLE)

3. Even swaps

Convert silt runoff to cost @ $0.5M / k ft^3

Objectives	Direction	Alternatives		
		Status quo	Minor repair	Major repair
Cost ($M)	Min	0	2	12
Environmental Benefit (0-10)	Max	1	3	10
Disturbance (0-10)	Min	0	1	7
Silt runoff (k ft^3)	Min	~~5~~ 2.5 M	~~1~~ 0.5 M	~~3~~ 1.5 M

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

A. Simplify the problem (EXAMPLE)

3. Even swaps

Convert silt runoff to cost @ \$0.5M / k ft^3

Objectives	Direction	Alternatives		
		Status quo	Minor repair	Major repair
Cost (\$M)	Min	0 + 2.5	2 + 0.5	12 + 1.5
Environmental Benefit (0-10)	Max	1	3	10
Disturbance (0-10)	Min	0	1	7
Silt runoff (k ft^3)	[redacted]			

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B. Reduce to a single objective

- Tip: Convert all objectives but one to constraints
  - Example: don't spend more than $2.5M
  - Keep disturbance at or below 3
  - Then take the maximum environmental benefit

Objectives	Direction	Alternatives		
		Status quo	Minor repair	Major repair
Cost ($M)	Min	2.5	2.5	13.5
Environmental Benefit (0-10)	Max	1	3	10
Disturbance (0-10)	Min	0	1	7

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Activity: Evaluate tradeoffs

Hint: Are there any irrelevant objectives, dominated outcomes, even swaps?

Objective [measurable attribute] {Direction}

	Alternative	Respect Life	HBC Recovery	Wilderness Disturbance	Cost
		[0-10 scale]	[P(N>6000)]	[User-days]	[M$/5-yr]
		{Max}	{Max}	{Min}	{Min}
A	**No action**	**6**	**0.2**	**0**	**0**
B	**Alternative B**	**7**	**0.3**	**30**	**2.5**
C	**Alternative C**	**6**	**0.3**	**40**	**3**
D	**Alternative D**	**9.5**	**0.3**	**50**	**4.5**
E	**Alternative E**	**9**	**0.25**	**60**	**2**

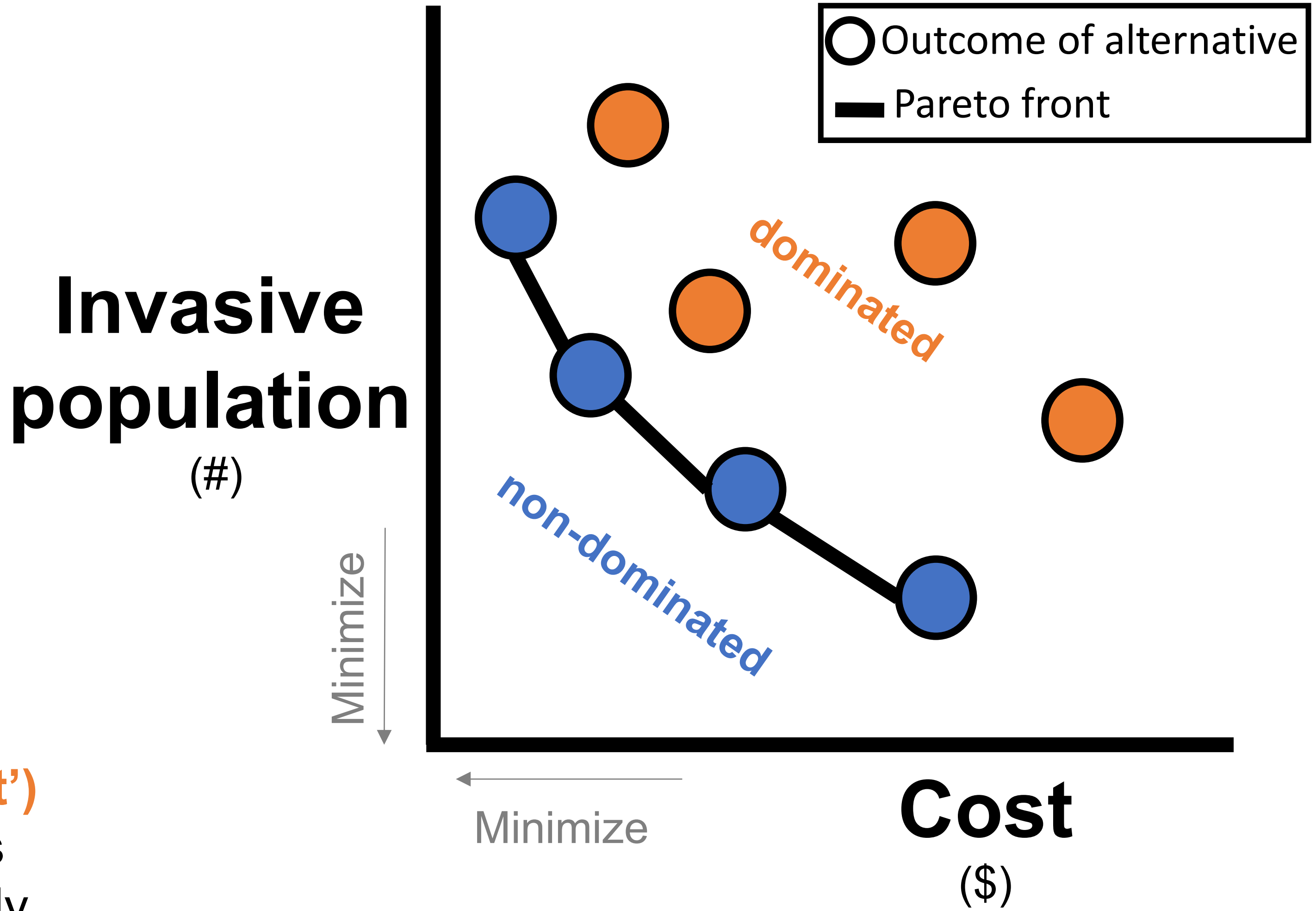
The consequence table was inspired by Runge et al. 2011
but the values in the table were altered for simplicity

C. Negotiate a solution from a set of best compromises

With ≥ two objectives we can do **pareto frontier analysis**

Pareto optimal alternative (non-dominated or 'efficient')
outcome on one objective cannot be improved without a reduction in another objective

Pareto inefficient alternative (dominated alternative or 'not efficient')
Another alternative performs at least as well on all objectives and performs strictly better on at least one



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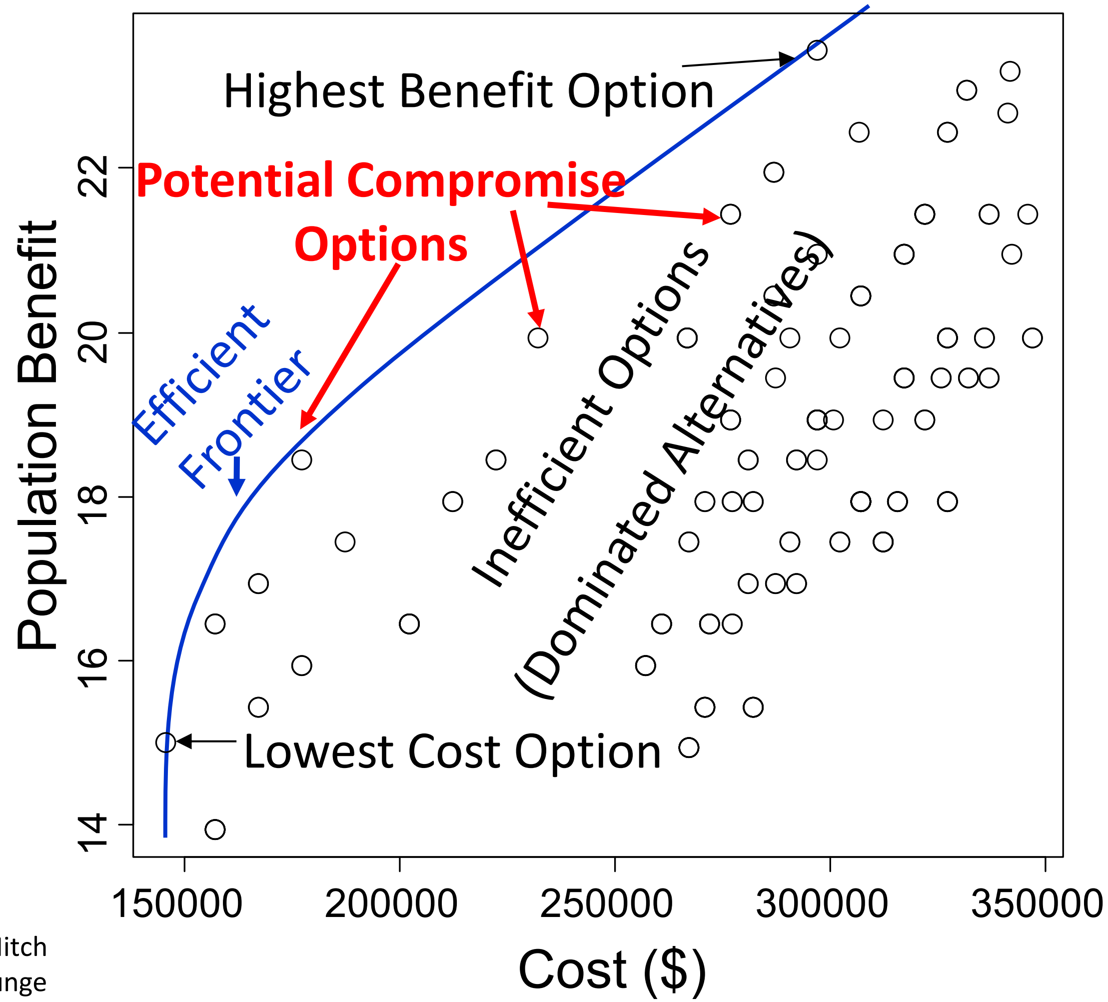
C. Negotiate a solution from a set of best compromises

Example: Cost vs Population Benefit



○ = outcome of each alternative

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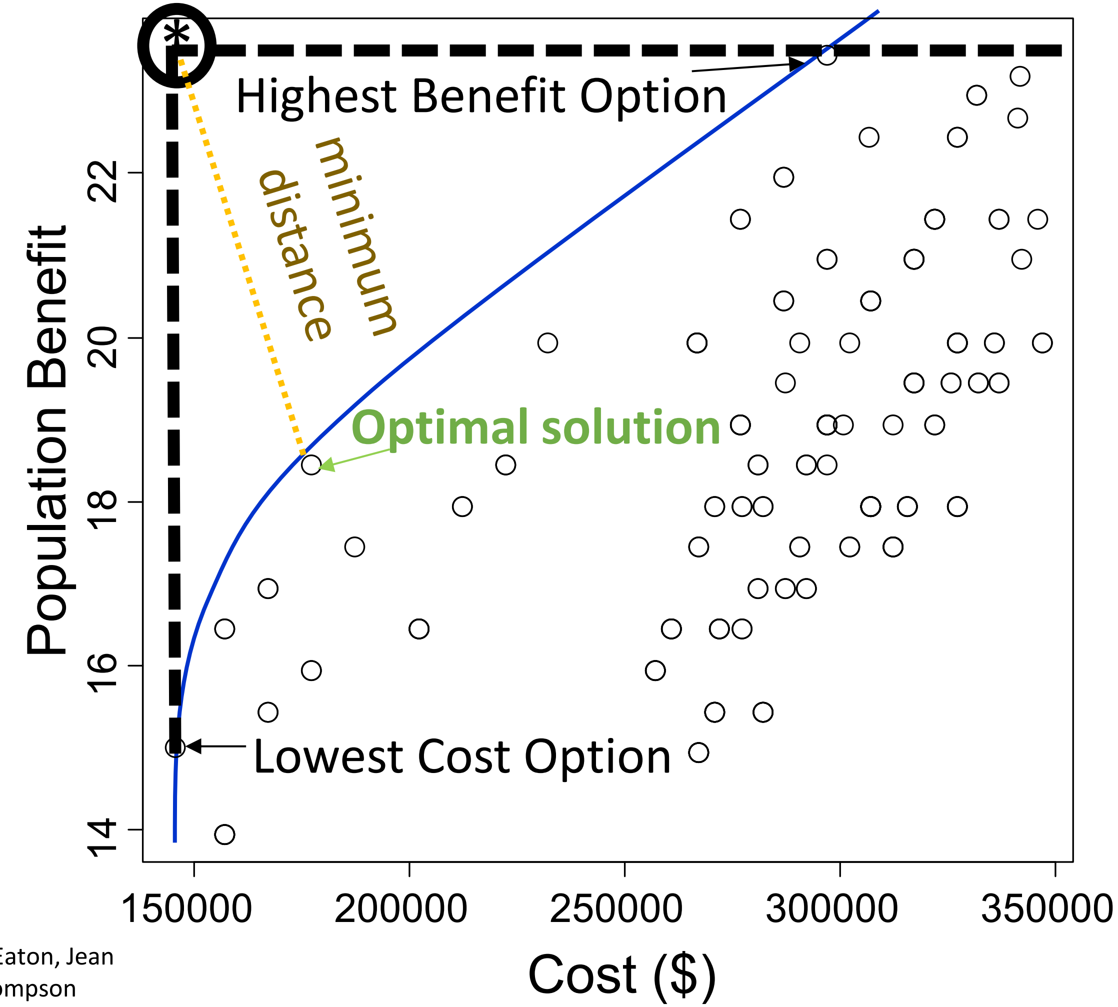
C. Negotiate a solution from a set of best compromises

Example: Cost vs Population Benefit



○ = outcome of each alternative

If cost and population benefit are deemed equal, we can find the **optimal solution** as the minimum distance between the ideal point (*)

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Example: Consequence table + tradeoffs

Thompson, Olden, & Converse 2024 *NeoBiota*

Alternative management strategy, no. segments of removal effort	Objective (expected value)			Dominated by X Alternative
	Suppression (in millions)	Containment (%)	Prevention (in millions)	
No removals, 0	21.13 M	90.3%	1.15 M	None
Abundance, 1	**20.52 M**	90.2%	1.15 M	None
Growth, 1	20.83 M	**89.7%**	1.15 M	None
Edges, 1	20.68 M	90.0%	0.83 M	None
Downstream, 1	20.81 M	90.1%	**0.48 M**	None
Random, 1	20.61 M	90.0%	1.10 M	None
Abundance, 4	**18.82 M**	89.6%	1.14 M	None
Growth, 4	20.05 M	87.2%	1.01 M	Downstream, 4
Edges, 4	19.24 M	88.1%	0.48 M	None
Downstream, 4	19.37 M	**86.2%**	**0.18 M**	None
Random, 4	19.00 M	88.6%	0.96 M	None
Abundance, 8	**16.67 M**	85.7%	1.02 M	None
Growth, 8	18.34 M	83.1%	0.58 M	Downstream, 8
Edges, 8	17.92 M	85.1%	0.31 M	Downstream, 8
Downstream, 8	17.32 M	**81.4%**	**0.15 M**	None
Random, 8	16.93 M	85.7%	0.83 M	None
Abundance, 16	**11.81 M**	74.1%	0.67 M	None
Growth, 16	14.25 M	72.9%	0.22 M	Edges, 16
Edges, 16	14.24 M	**71.4%**	0.22 M	None
Downstream, 16	13.17 M	73.7%	**0.15 M**	None
Random, 16	12.78 M	78.3%	0.56 M	None

Example: Consequence table + tradeoffs

Thompson, Olden, & Converse 2024 *NeoBiota*

Subset of the table: management alternatives to control invasive rusty crayfish

4 alternatives to compare

Alternative management strategy, no. segments of removal effort	Objective (expected value)			Dominated by X Alternative
	Suppression (in millions)	Containment (%)	Prevention (in millions)	
Abundance, 8	**16.67 M**	85.7%	1.02 M	None
Growth, 8	18.34 M	83.1%	0.58 M	Downstream, 8
Edges, 8	17.92 M	85.1%	0.31 M	Downstream, 8
Downstream, 8	17.32 M	**81.4%**	**0.15 M**	None
Random, 8	16.93 M	85.7%	0.83 M	None

Best in having low # of crayfish *(**suppression objective**)*

*But worse than Downstream, 8 in the other 2 objectives

Best alternative in having low % coverage of crayfish & low # of crayfish entering an important area ***(Containment & Prevention objectives)***

*But worse than Abundance, 8 in the first objective

"Middle ground outcome"

Better than Abundance,8 in Prevention & better than Downstream,8 in Suppression

Means we should not conduct Growth, 8 or Edges, 8

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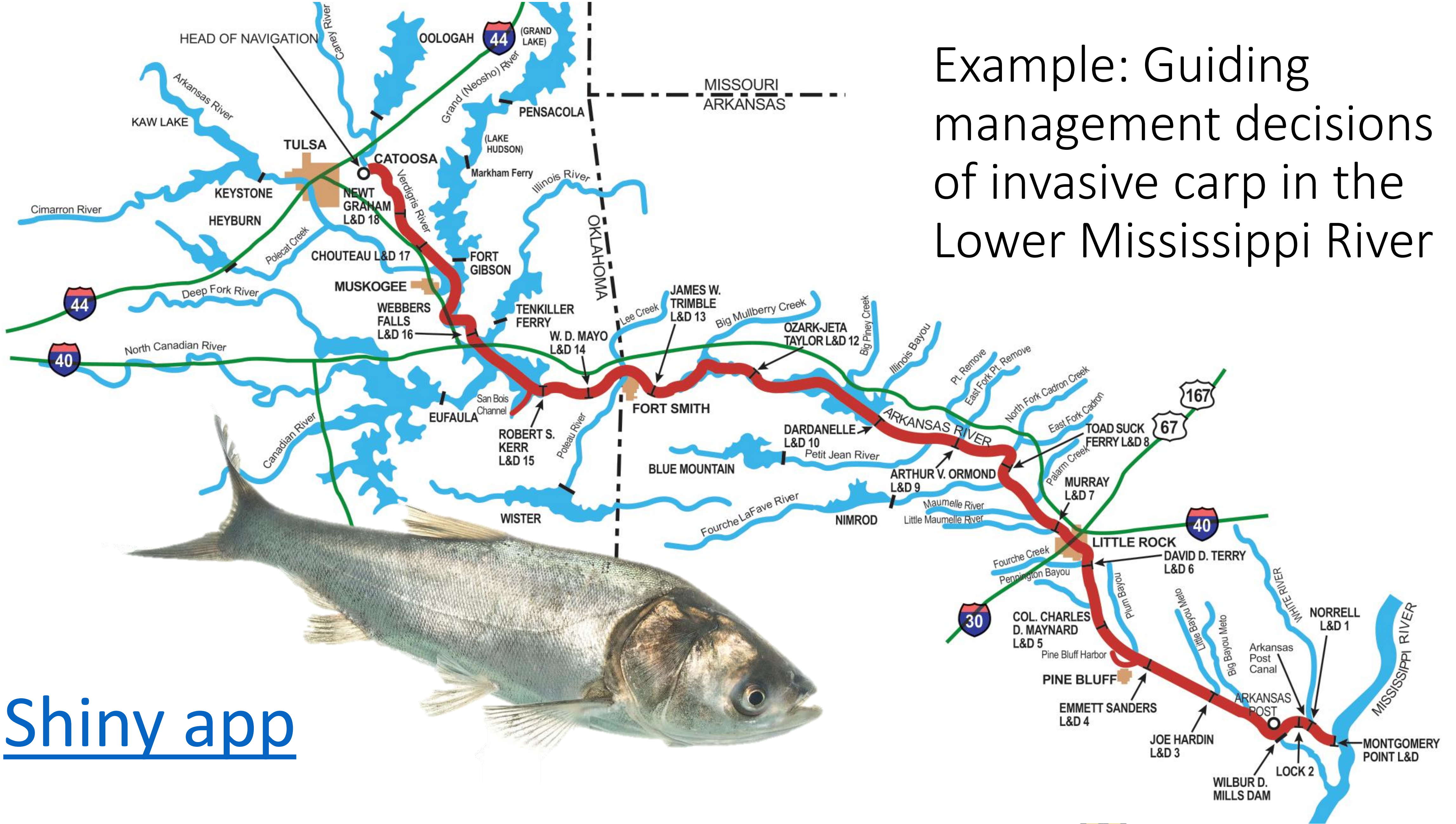
Example: Guiding management decisions of invasive carp in the Lower Mississippi River



[Shiny app]

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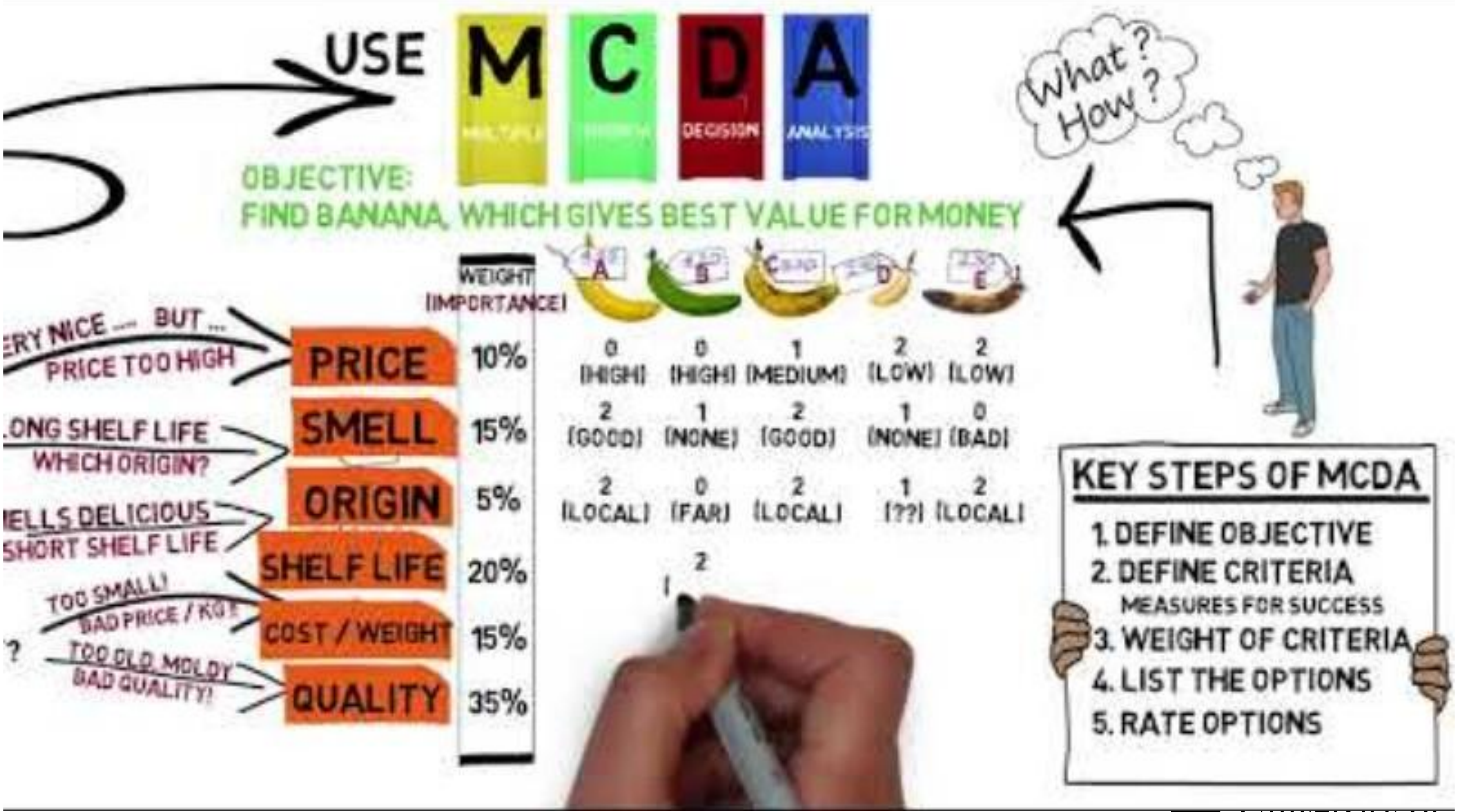
D. Evaluate trade-offs explicitly

- Multicriteria decision analysis:
  - Offers tools to evaluate multiple objective problems
- A variety of tools exist (beyond the scope of this workshop)
  - Outranking methods
  - Analytic Hierarchy Process
  - Multi-attribute value/utility theory
  - SMART (simple multi-attribute rating technique)
- *See this week's reading for more examples*

[3-minute intro to MCDA]



SMART (simple multi-attribute rating technique)

1. Normalize all attributes to 0-1 scale within each objective

   For Goal to Maximize the attribute:

   (x – minimum)/(maximum-minimum)

   For Goal to Minimize the attribute:

   1-(x – minimum)/(maximum-minimum)

2. Assign weights to each fundamental objective
3. Calculate weighted sum of scores for each alternative
4. Recommend alternative with highest weighted score
5. Sensitivity analysis! (Is the recommendation sensitive to the weights and predictions?)

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

Activity: SMART Practice

EXCEL LINK

- Given our simplified impoundment repair problem (see consequence table), solve it using SMART for two different sets of weights:
  - Weights for cost/environmental benefit/disturbance are: 0.6, 0.3, 0.1
  - Weights for cost/environmental benefit/disturbance are: 0.2, 0.6, 0.2

- What if my weights are 0.6, 0.3, 0.1, but I am uncertain about the environmental benefit of the minor repair? It could be as small as 1 or as large as 5. Is my decision sensitive to this uncertainty?

Developed by Justin Gude, Julie Zimmerman, Mitch Eaton, Jean Cochrane, Sarah Converse, Mike Runge

Where do objective weights come from?

- Represent relative *values* of a decision maker
- Some methods
  - Direct elicitation- importance weights
  - Swing weighting
  - Pairwise weighting (AHP)
- Weights are context-dependent
  - If you change the range of predictions for an attribute, its weight may need to change

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Importance weights

- These reflect the **relative importance** of each criterion in a decision-making process and are used in SMART
- Example:

	Weight	Translocations	Habitat Restoration
Maximize Pr (persistence)	0.9	0.5	0.9
Minimize cost	0.1	$1,000,000	$100,000,000

This is a common weighting scheme we see from the level of biologists- not as worried about the costs as the biological outcome.

Importance weights

- These reflect the **relative importance** of each criterion in a decision-making process and are used in SMART
- Example:

	Weight	Translocations	Habitat Restoration
Maximize Pr (persistence)	0.9	0.5	~~0.9~~ 0.51
Minimize cost	0.1	$1,000,000	$100,000,000

But what if this is the new outcome? Should we update the weights?

Importance weights

- These reflect the **relative importance** of each criterion in a decision-making process and are used in SMART
- Example:

	Weight	Translocations	Habitat Restoration
Maximize Pr (persistence)	0.9	0	1
Minimize cost	0.1	1	0

How about now when we standardize outcomes?

We may want a new method to assign weights that considers the absolute range of the predicted values

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Swing weighting

- Summing normalized scores (i.e., using SMART) with direct importance weights can be misleading.

- Swing weights consider the particular values available (range of actual alternatives).
  - Preferences are context specific, not abstract.
- Use the ‘swing’ or range from worst to best values across the alternatives.

Swing weighting – Buying a car example

Displays possible outcomes for each objective

Objective				Range	
	Description	Attribute	Goal	Worst	Best
A	Life span	years	max	6	12
B	Price	$(1,000)	min	24	8
C	Color	natural	max	yellow	red

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Swing weighting – Buying a car example

Objective				Range		Hypothetical Alternatives (car)			
	Description	Attribute	Goal	Worst	Best	Bench mark	1	2	3
A	Life span	years	max	6	12	6			
B	Price	$(1,000)	min	24	8	24			
C	Color	natural	max	yellow	red	Yellow			

Write down worst-case alternative

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Swing weighting – Buying a car example

	Objective			Range		Hypothetical Alternatives (car)			
	Description	Attribute	Goal	Worst	Best	Bench mark	1	2	3
A	Life span	years	max	6	12	6	12	6	6
B	Price	$(1,000)	min	24	8	24	24	8	24
C	Color	natural	max	yellow	red	Yellow	Yellow	Yellow	Red

These alternatives have outcomes that are the worst for each objective except one

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Swing weighting – Buying a car example

Objective				Range		Hypothetical Alternatives (car)			
	Description	Attribute	Goal	Worst	Best	Bench mark	1	2	3
A	Life span	years	max	6	12	6	12	6	6
B	Price	$(1,000)	min	24	8	24	24	8	24
C	Color	natural	max	yellow	red	Yellow	Yellow	Yellow	Red
	Rank	(1 is best; 4 is worst)				4	2	1	3

Next, rank each of the 4 alternatives (including worst-case benchmark) from 1 to 4

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Developed by Sarah Converse, Brielle Thompson

Swing weighting – Buying a car example

Objective				Range		Hypothetical Alternatives (car)			
	Description	Attribute	Goal	Worst	Best	Bench mark	1	2	3
A	Life span	years	max	6	12	6	12	6	6
B	Price	$(1,000)	min	24	8	24	24	8	24
C	Color	natural	max	yellow	red	Yellow	Yellow	Yellow	Red
	Rank	(1 is best; 4 is worst)				4	2	1	3
	Score	(100 is best; 0 is worst)				0	70	100	5

Using the ranks, score the alternatives from 0 to 100
(we rank then score for some cognitive help!)

Developed by Sarah Converse, Brielle Thompson

Swing weighting – Buying a car example

Objective				Range		Hypothetical Alternatives (car)			
	Description	Attribute	Goal	Worst	Best	Bench mark	1	2	3
A	Life span	years	max	6	12	6	12	6	6
B	Price	$(1,000)	min	24	8	24	24	8	24
C	Color	natural	max	yellow	red	Yellow	Yellow	Yellow	Red
	Rank	(1 is best; 4 is worst)				4	2	1	3
	Score	(100 is best; 0 is worst)				0	70	100	5
	Weight	score/(sum of scores)				0	0.40	0.57	0.03

Calculate your weights!

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Developed by Sarah Converse, Brielle Thompson

Swing weighting – Buying a car example

Objective				Range		Hypothetical Alternatives (car)			
	Description	Attribute	Goal	Worst	Best	Bench mark	1	2	3
A	Life span	years	max	6	12	6	12	6	6
B	Price	$(1,000)	min	24	8	24	24	8	24
C	Color	natural	max	yellow	red	Yellow	Yellow	Yellow	Red
	Rank	(1 is best; 4 is worst)				4	2	1	3
	Score	(100 is best; 0 is worst)				0	70	100	5
	Weight	score/(sum of scores)				0	0.40	0.57	0.03

These are your weights for objective A,B,C!!!!

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Swing weighting activity

SEE EXAMPLE

[EXCEL LINK]

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Skills Check

SEE SKILLS CHECK

[EXCEL LINK]

Activity: think about your decision problem

- For your final project presentation, you will provide a slide of your <u>Tradeoffs</u>
- Some hints:
  - Review your consequence table from last week (or make one now)
  - Do you have any irrelevant objectives? Dominated alternatives? Can you make even swaps?
  - Can you use smart or swing weighting to help make your decision?

- **Feel free to go back to your problem framing, objectives, alternatives, and consequences steps!**

Developed by Brielle Thompson

Looking ahead:

Next week: T step of PrOACT

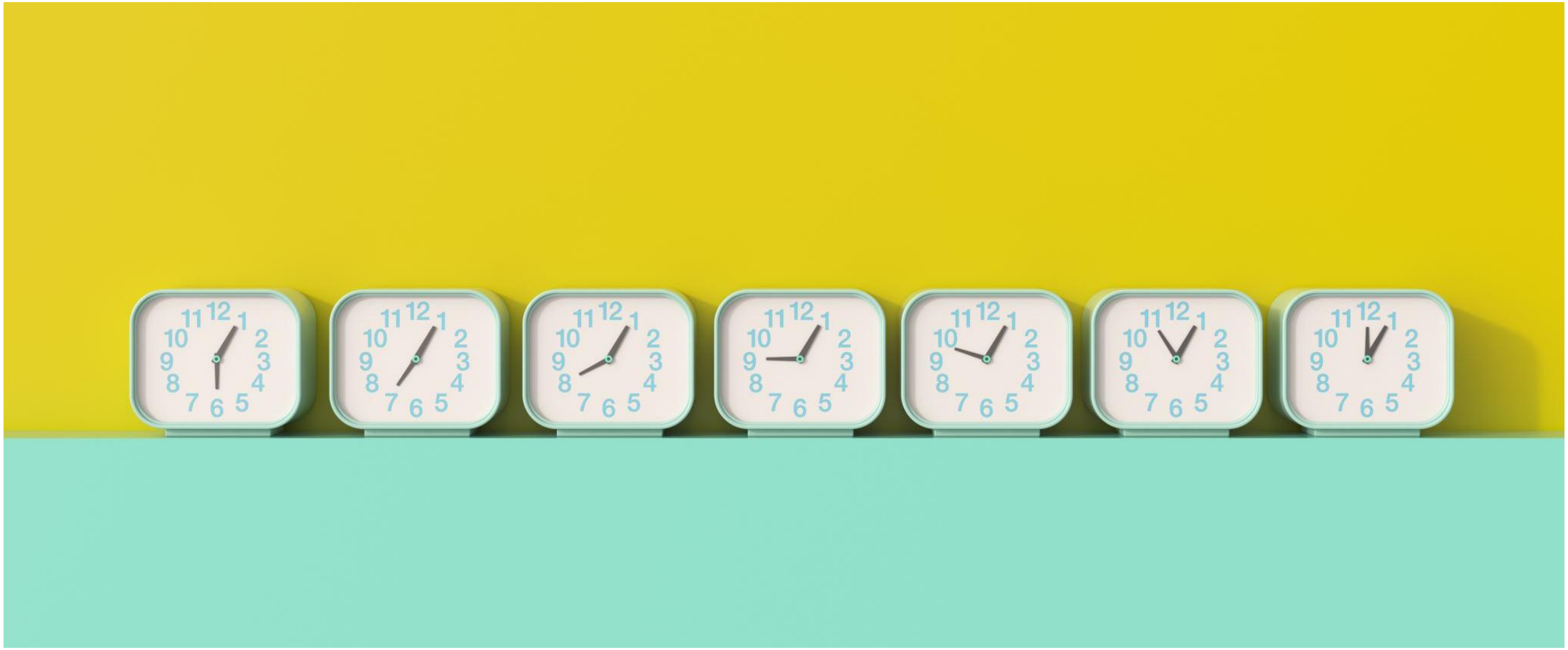
Weekly: Work through a step of the PrOACT process/ learn extra tools

Last week of class:

Elevator pitch of your research project in terms of SDM/PrOACT

Note: Abridged PrOACT story slides with a star on the upper right are good examples to use for your presentation

Extra time activities:



Reading discussion: Runge et al. 2020 Chapter 5 (Converse)

- Why do you think multi-criteria decision analysis is useful?
- Compare the pros/cons of structured discussions over quantitative techniques to examine trade-offs
- What are some pitfalls of MCDA?
- What happens if we miss an objective?