

Decision Analysis For System Design

- **The purpose of a design is:**
 - **To solve a problem**
 - **To overcome a shortcoming**
 - **To improve a situation**
- **Design involves decision making**
- **The same procedures that provide a framework for other decision processes work for design decisions as well**
- **We will discuss some simple procedures to help make these decisions**

Measurement

- **Most important step in analysis - What should be measured?**
- **Goes by many names:**
 - **Measure of Effectiveness (MOE)**
 - **Measure of Performance**
 - **Measure of Merit**
 - **Objective**
 - **Measure of Benefit (vice Cost)**
 - **Metric**
- ***Must reflect outcome of decision***

Decision Analysis

What makes a decision hard to make?

- **Competing objectives**
- **Uncertainty**
- **Politics**
- **Lack of information**
- **Differing perspectives of Decision makers**
- **Disagreement over what is to be accomplished**
- **Complexity**

Note: Some of these overlap

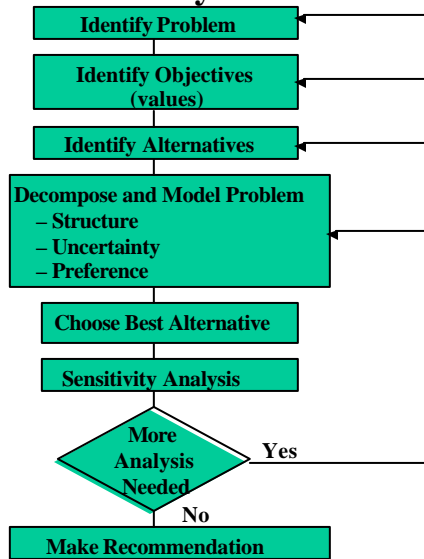
Decision Analysis

What is decision analysis?

A Method to:

- **Organize or structure complex problems for analysis**
- **Deal with tradeoffs between multiple objectives**
- **Identify and quantify sources of *uncertainty***
- **Incorporate subjective judgments**

Decision Analysis Process



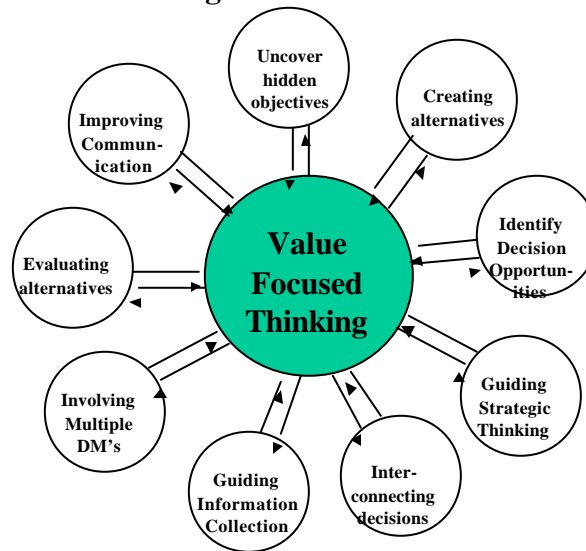
Value Focused Thinking

- Values are fundamental to all we do
- Values should drive decisions
- Alternative-Focused Thinking
 - Standard Approach
 - Problem arises
 - Problem solving begins
 - Alternative solutions listed
 - Best alternative chosen
 - Limited way to think
 - Reactive not proactive
 - Incomplete analysis
 - Backward thinking

Identifying Values

- Interact with decision makers
- Elicit feedback throughout analysis
- Values are stated through objectives
- 3 Features of objectives
 - (1) Decision Context
 - (2) Object
 - (3) Direction of Preference
- ex. Forest products company wants to “minimize environmental impact”
 - (1) Decision Context - *Harvesting Trees*
 - (2) Object - *Environmental Impact*
 - (3) Direction of Preference - *Minimum is best*

Where does thinking about values lead?



Identifying Values

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Techniques or Eliciting Values

- (1) Make a “Wish List”
- (2) Evaluation of alternatives
- (3) Problems and Shortcomings
- (4) Consequences or Outcomes
- (5) Goals, Constraints, Guidelines
- (6) Different perspectives
- (7) Strategic Objectives
- (8) Generic Objectives
- (9) Structure of Objectives
- (10) Quantifying Objectives

Structuring Objectives

- **Initial list has “non-objectives”**
 - Alternatives
 - Constraints
 - Criteria for evaluation
- **Convert “non-objectives” into objectives**
 - Means objectives
 - Fundamental objectives
- **Why is each important?**
 - It leads to something else ➡ **Means Objective**
 - It is essential ➡ **Fundamental Objective**

Creating Alternatives

- **No recipe – but “Values First!”**
- **First alternative thought of:**
 - Readily available
 - Used before
 - Constrained
 - Includes the Status Quo
- **Find alternatives that meet objectives**
- **Consider objectives in groups (2 or 3 at a time)**
- **Focus on strategic objectives**
 - Most important
 - Most broad
 - Will do most good

Evaluating Alternatives - Value Models

- Objectives related to alternatives by *Attributes*
- Attributes are measures of achievement of objectives
 - Quantitative
 - Reflect consequences
- Can be one or many (both objectives and attributes)
 - One is simple and unusual
 - Multiple attributes are more common
 - Multiple attributes more difficult to handle

Value Models

- Notation:
 - $A_j, j = 1, \dots, J$ is the set of alternatives
 - $O_i, i = 1, \dots, n$ is the set of objectives
 - $X_i, i = 1, \dots, n$ is the set of measures or attributes
 - Note: attribute X_i is associated with objective O_i
 - x_i is the outcome of attribute X_i
 - **Example:** O_1 is the objective “Maximize Profit”
 X_1 is “the profit in \$ millions” with x_1 being \$168 million
 - $\mathbf{x} = (x_1, x_2, \dots, x_n)$ is the expected consequences of alternative

Value Model

- a.k.a. “Objective Function”
- Denoted $v(x)$
- Assigns a number to the consequences, x , of an alternative
- Used to determine preference among alternatives
- Types of value functions
 - Ordinal value function - ranking only
 - Measurable value function - strength of preference
 - Utility function - indicates uncertainty
- Form depends on relationships between attributes
- Convention: $v(x^A) > v(x^B)$ iff we prefer alt A to alt B

Relations Between Attributes

- Attributes will be added together to get value of alternative
- Attributes must not overlap
- Must avoid double counting
- Attributes must be *independent* of each other in some sense
- There is more than one type of independence

Structures of Value Functions

Additive Value Function

$$v(x_1, x_2, \dots, x_n) = \sum_{i=1}^n k_i v_i(x_i)$$

where k_i is a positive scaling constant

v and v_i are value functions scaled from 0 to 1



All combinations of attributes are
Preferentially Independent!

Structures of Value Functions

Multiplicative Value Functions

$$1 + kv(x_1, x_2, \dots, x_n) = \prod_{i=1}^n [1 + kk_i v_i(x_i)]$$



All pairs of attributes are Weak-Difference Independent

– Example:

$$v(x_1, x_2) = k_1 v_1(x_1) + k_2 v_2(x_2) + k_3 v_1(x_1) v_2(x_2)$$

– Looks like regression equation with interactions

– More difficult to use



Bottom Line: Use Additive Independent attributes!

Example - Decision Problem

Which location should be chosen for the new factory?

Procedure:

- (0) Choose Fundamental Objective
 - Profitable enterprise in unpenetrated market
- (1) Determine important Means Objectives
 - Markets
 - Availability of raw materials and supplies
 - Taxes
 - Availability of labor
 - Cost of labor

Example - Decision Problem (continued)

- (2) Find ways of measuring the objectives
 - Markets - *Median family income*
 - Availability of raw materials and supplies
 - *Sufficient or not*
 - Taxes - *Corporate tax rate*
 - Availability of labor - *Population*
 - Cost of labor - *Median hourly wage*

Example - Decision Problem (continued)

(3) Scaling objective measures

- Want each objective measured on scale of 0 to 1
 - 0 means worst
 - 1 means best
 - others measured proportionally

x is raw score

$$S_{\text{other}}(\bar{x}) = \frac{x - \text{worst}}{\text{best} - \text{worst}}$$

- **Limitation: proportional score means “Risk Neutrality”**
 - Ignores riskiness of alternatives
 - Important when considering uncertainty

Example - Decision Problem (continued)

(4) Weighting the objectives (criteria)

Answer the question: How do we tradeoff increased value in one objective for lower value on the others?

- **Methods:**
 - Pricing out
 - Swing weights *
 - Lottery weights
- Often totally subjective
- Avoid “Importance Weights”
- Should be based on range of variation of attributes

Swing Weights

- Based on comparing ranges of variation of attributes
- Can be used for non-quantitative attributes
- Method:
 - (1) Find “Worst Conceivable Alternative”
 - Lowest score in each attribute
 - May be imaginary
 - (2) Pick attribute that gives greatest improvement when “swings” to highest level - remember increase
 - (3) Pick attribute that gives next highest increase when swung
 - by percentage - how does it compare with the first?
 - never greater than 1 since first is best

Swing Weights (continued)

- (4) Repeat for rest of attributes
- (5) Assess weights by noting that:

$$\left. \begin{array}{l}
 k_2 = p_{21}k_1 \\
 k_3 = p_{31}k_1 \\
 \vdots \\
 k_n = p_{n1}k_1 \\
 \sum_{i=1}^n k_i = 1
 \end{array} \right\} \text{ - Solve for the } k\text{'s}$$

where k_i = weight of attribute i ,
 and p_{i1} = percentage of improvement compared
 with attribute 1

Decision Trees

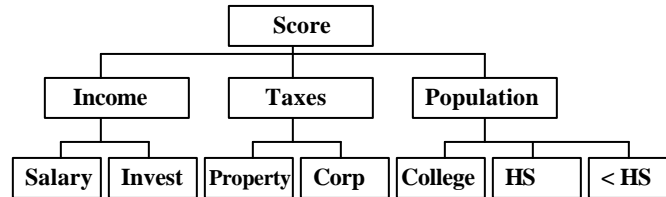
Interpretation 1 – Extension of the Value Function

- We have:

$$V = k_1 u_1(x_1) + k_2 u_2(x_2) + \dots + k_n u_n(x_n)$$

– an additive value function

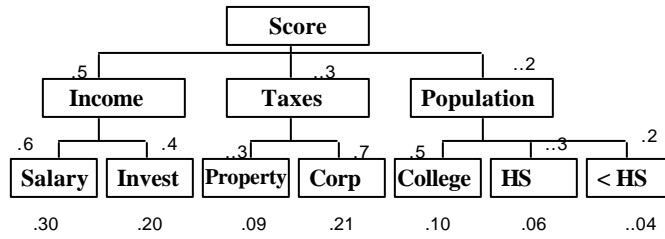
- Suppose x_i for some i in $\{1, 2, \dots, n\}$ is the value from a value function itself
- Gives tree structure or hierarchy
- Example:



Decision Trees (continued)

- Each level has its own weights
 - Weights sum to 1
 - Weights correspond to relative importance of the criteria
 - Weights assessed as in other additive value function
 - Swing weights
 - Lotteries
 - Pricing out
 - Analytical Hierarchy Process (AHP) *in book*
- Each additive value function is independent of the others

Hierarchy



- Bottom row sums to one
- The “real weights”
- Should be shown to DM