Decision Analysis Overview

Indiana IRP Contemporary Issues Technical Conference

Ronald G. Whitfield, Ph.D.

October 17, 2013

Presentation Objectives

- Promote understanding of a decision-aiding methodology that can be applied in various analyses
- Understand desirable properties for a set of metrics
- Illustrate that consequence ranges matter
- Promote explicit incorporation of value judgments because it is appropriate in most complex decision contexts
- Appreciate that a value structure is crucial for addressing complex, multi-objective problems

Plan for this Discussion

- **Please ask questions or raise discussion issues as we proceed**

- **Presentation consists of:**
  - Overview of important principles
  - Methods of analysis
  - A few exercises to illustrate important concepts
  - Example applications

Why Decision Analysis?

- **Decision analysis is an approach that has found wide applicability in real world problems**
- **Decision analysis methods reduce bias and subjectivity**
- **Decision analysis provides a structured approach to complex problems that is defensible, ensures consistency, and reproducibility of results**
- **Decision analysis methods can be useful for measuring risk in the DHS context**

Decision Analysis Concepts Used to Analyze Comparative-Risk Decision Problems

- Common problem characteristics
- Decision analysis paradigm
- Value-focused thinking
- Objectives and objectives hierarchies
- Decision metrics
- Decision-maker risk attitudes
- Portfolio considerations

Most Decision Problems Involve Several Complexities

- Multiple objectives
- Large number of alternatives
- Intangible factors
- Uncertainties
- Impacts over time (generations)
- Many different groups impacted
- Multiple decision makers

Characteristics of Decision Problems That Call for Some Effort to Be Devoted to Quantifying Value Judgments

- High stakes
- Complicated structure (previous slide)
- Multiple experts in multiple domains: no overall expert
- Desire to promote good decisions
- Need to justify and defend decisions

Exercise: Uncertainty and Its Sources

- **Uncertainty: degree to which a calculated, estimated, or observed value may deviate from the true value**
- **Sources of uncertainty**
  - Lack of information or tools – Knowable but unknown to analyst
  - Inherent variability in the system
  - Random influences
- **Explicitly communicate the uncertainty in your analysis and document the source of that uncertainty**

Characterizing Uncertainty

- **Uncertainty can be expressed in multiple ways**
  - Using phrases (e.g., “highly uncertain”)
  - Using numbers (usually probabilities or frequencies)
  - Using graphics (e.g., probability distributions, scatter plots)
- **Likelihood is often expressed in terms of bins or ranges:**
  - Remote, unlikely, even chance, probable/likely, or almost certain
  - High, medium, low
  - 1-5 Scale where 1 represents “unlikely” and 5 represents “certain”
- **Mathematical probability is expressed as a number between zero and one:**
  - Zero indicates that the occurrence is impossible and one indicates definite knowledge that the occurrence has happened or will happen
  - Ratios between numbers reflect and maintain quantitative relationships

Measurement Scales: *Qualitative* versus Quantitative

- **Qualitative**
  - Typically means non-numerical, based on non-quantifiable information, or descriptive in nature

    (e.g., "The facility ABC may have an industrial accident and the consequences of a serious accident are substantial in terms of human health and safety")
  - Makes comparisons difficult
  - Hides uncertainties and judgments, lacks specificity, lacks transparency (in terms of method), and is difficult to defend
  - Should be avoided whenever possible

Measurement Scales: Qualitative versus *Quantitative*

- **Quantitative**
  - Typically means numerical, based on quantifiable information, or expressible in terms of a quantity

    (e.g., "The emissions of sulfur dioxide from facility ABC, located at XYZ, given normal full-power operation, are 3,000 pounds per hour)
  - Facilitates comparisons
  - Can be used to capture uncertainties and judgments, is specific and transparent, and can inform decision making
  - Should be used whenever possible

Types of Quantitative Scales: Key Concepts

- **Significant terminology and nuances in scientific literature (e.g., statistics, social sciences, decision analysis)**
- **Basic concepts**
  - Ordinal scale: ordered values, but differences are not well defined (e.g., degree of satisfaction – low, medium, high)
  - Interval scale: ordered, differences make sense, but ratios do not (e.g., temperature scale: 40°F is warmer than 20°F, and a 20°F difference has a physical meaning. However, 0°F is arbitrary, so 40°F is not twice as hot as 20°F)
  - Ratio scale: ordered and both differences and ratios make sense (e.g., length: 40 meters is twice a long as 20 meters)
- **Ratio scales should be used whenever possible**

Measurement Scales for Decision Metrics

- **"*Natural*" scale**
  - e.g., a dollar scale for costs
- **"*Constructed*" scale**
  - A several-point (-level) scale (5 or 7 is common) with a precise definition for each level
  - Criteria could have customized scales or identical scales
- **"*Proxy*" scale**
  - Indirect measurement

    (e.g., (1) pounds of air emissions instead of a specific human health effect; (2) pounds of nitrous oxides, which are precursors to tropospheric ozone, as a proxy for lesions in the centriacinar region of the human lung)

13

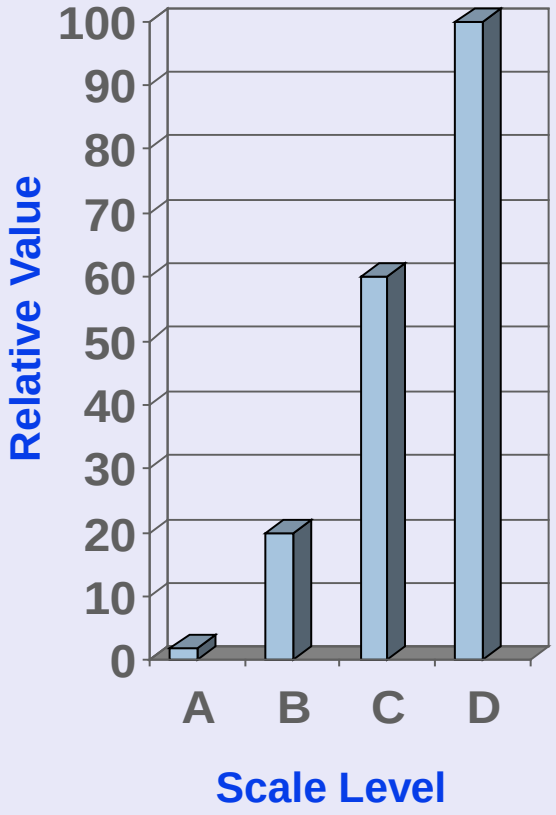
A Constructed Scale for Public Attitudes

Metric Level	Description of Metric Level
5	***Support***: No groups are opposed to the facility and at least one group has organized support for the facility.
4	***Neutrality***: All groups are indifferent or uninterested.
3	***Controversy***: One or more groups have organized opposition, although no groups have action-oriented opposition. Other groups may either be neutral or support the facility.
2	***Action-oriented opposition***: Exactly one group has action-oriented opposition. The other groups have organized support, indifference or organized opposition.
1	***Strong action-oriented opposition***: Two or more groups have action-oriented opposition.

A Constructed Metric for Biological Impacts at Proposed Power Plant Sites

Metric Level	Description of Metric Level
8	Complete loss of 1.0 sq. mile of land which is entirely in agriculture use or is entirely urbanized; no loss of any “native” biological communities.
7	Complete loss of 1.0 sq. mile of primarily (75%) agricultural habitat with loss of 25% of second-growth forest; no measurable loss of wetlands or endangered species habitat.
6	Complete loss of 1.0 sq. mile of land which is 50% farmed and 50% disturbed in some other way (e.g., logged or new second-growth); no measurable loss of wetlands or endangered species habitat.
5	Complete loss of 1.0 sq. mile of recently disturbed (e.g., logged, plowed) habitat plus disturbance to surrounding previously disturbed habitat within 1.0 mile of site border; or 15% loss of wetlands or endangered species habitat.
4	Complete loss of 1.0 sq. mile of land which is 50% farmed (or otherwise disturbed) and 50% mature second-growth forest or other undisturbed community; 15% loss of wetlands or endangered species habitat.
3	Complete loss of 1.0 sq. mile of land which is primarily (75%) undisturbed mature “desert” community; 15% loss of wetlands or endangered species habitat.
2	Complete loss of 1.0 sq. mile of mature second-growth (but not virgin) forest community; or 50% loss of big game and upland game birds; or 50% loss of wetlands and endangered species habitat.
1	Complete loss of 1.0 sq. mile of mature community or 90% loss of productive wetlands and endangered species habitat
0	Complete loss of 1.0 sq. mile of mature virgin forest and/or wetlands and/or endangered species habitat.

The Value of Achieving Different Levels of Performance for Each Objective is Assessed



Timeliness

A. Not timely

B. Late result, only partially supportive for negotiations, decisions, projects

C. Late result, but supportive for negotiations, decisions, projects

D. Results will be provided in a timely manner

Expressing Uncertainty

- **Uncertainty can be expressed in multiple ways**
  - Using phrases (e.g., “highly uncertain”)
  - Using numbers (usually probabilities or frequencies)
  - Using graphics (e.g., probability distributions, scatter plots)
- **Likelihood is often expressed in terms of bins or ranges:**
  - Remote, unlikely, even chance, probable/likely, or almost certain
  - High, medium, low
  - 1-5 Scale where 1 represents “unlikely” and 5 represents “certain”
- **Mathematical probability is expressed as a number between zero and one:**
  - Zero indicates that the occurrence is impossible and one indicates definite knowledge that the occurrence has happened or will happen
  - Ratios between numbers reflect and maintain quantitative relationships

Converting Qualitative Likelihood Descriptions into Probability Bins

- **Qualitative information can be translated to numeric probabilities**

Likelihood	Synonyms	Probability (Percent)	Range
Certain	Absolute; Authoritative; Clear; Conclusive; Confirmable; Definite	**100%**	100%
Nearly certain	Virtually (almost) certain; We are convinced; Highly probable; Highly likely	**93%**	87-99%
Probable	Likely; We believe; We estimate; Chances are good; It is probable that	**75%**	60-86%
Even	Chances are even; 50-50	**50%**	37-59%
Improbable	Probably not; Unlikely; We believe…not	**30%**	14-36%
Nearly impossible	Almost impossible; Only a slight chance; Highly doubtful	**7%**	2-13%
Practically impossible	Absurd; Infeasible; No-way; Preposterous	**1%**	1%

Point Estimates

- Estimation refers to the process by which one makes inferences about a population, based on information obtained from a sample
- Point estimation uses sample data to calculate a single value, which is to serve as a 'best guess' for an unknown parameter:
  - e.g., the mean or average, the most likely value, etc.
- Point estimates are sometimes acceptable
  - e.g., when there is no option to gather more information before making a decision
- Uncertainty should be presented:
  - Even if only qualitatively (in phrases)

Decision Analysis Overview

- **Definition: A systematic and logical set of procedures for analyzing complex, multiple-objective problems**
- **Characteristics:**
  - **Utilizes "divide and conquer" approach**
  - **Develops meaningful and useful metrics (attributes) for objectives**
  - **Examines tradeoffs among conflicting objectives**
  - **Incorporates uncertainty and risk attitudes**
- **Applications:**
  - **Prioritization of alternatives (e.g., protective measures in order of greatest vulnerability reduction)**
  - **Resource allocation (e.g., among grant applicants)**
  - **Portfolio selection (e.g., maximize risk reduction within budget limit)**
  - **Policy and strategic analysis (e.g., compare economic and health consequences)**

Good Decisions Should Be Based on …

1. **The possible consequences of each of the alternatives and the likelihoods of those consequences**

2. **The preferences of the decision maker for those consequences**

These considerations are often oversimplified or ignored!

Decision-Aiding vs. Decision-Making Systems

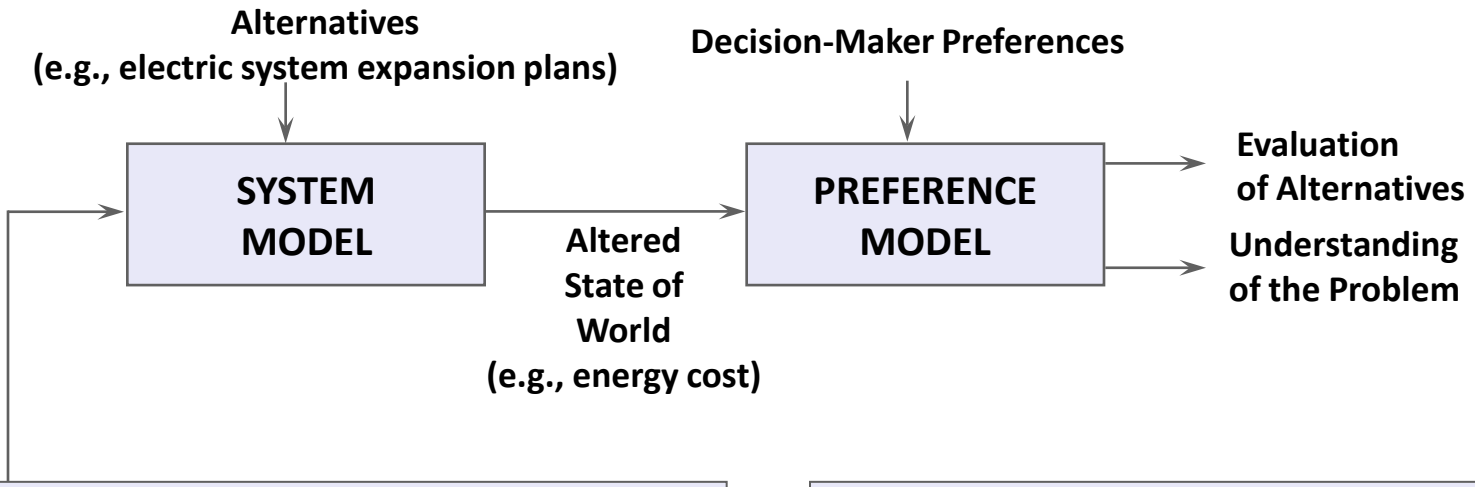
- **Decision-aiding systems:**
  - **Recommend actions and provide decision insights**
  - **Recognize the inherent imperfection of all models**
- **Decision-making systems:**
  - **Are rigorous rules for making decisions**
  - **Eliminate the need for decision makers**
- **With either approach, a good decision can be followed by bad outcomes**

Overview of a Decision-Aiding Philosophy/Approach

- **Apply decision-aiding methodologies and tools that are technically sound — and appropriate for the organization and decision-making environment**
- **Encourage value-focused thinking**
- **Focus on usable decision metrics**
- **Identify cost-effective, defensible decisions**
- **Explore critical "what if" questions**
- **Assess alternative courses of action**

Decision-aiding methodologies provide information to decision makers. They do not make decisions.

Typical Combination of a Systems Model and a Preference Model



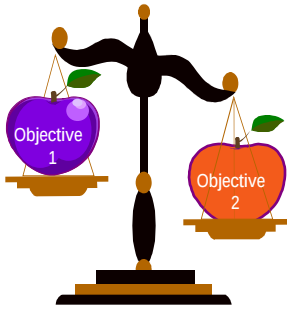
Current State of World:

- Natural measures of energy systems
- Human health & safety
- Economics
- Socio-political
- Environmental
- Other

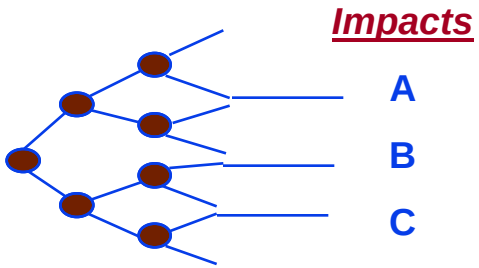
- Input to preference model are costs, environmental impacts, reliability, and other consequence metrics and decision-maker profiles (preferences)
- Output is help in making some complex decisions

Decision Analysis Paradigm

1. Define objectives and measurement scales
2. Specify values (tradeoffs among objectives)
3. Identify and create alternatives
4. Determine impacts of alternatives with respect to objectives
5. Select best alternative



Tradeoffs Among Objectives



(Decision Tree)

Rank	Alternative
1	D
2	P
3	A
⋮	⋮

Multiattribute Utility – Formulation

Objectives	$O_1, O_2, \ldots, O_l$
Decision Metrics	$x_1, x_2, \ldots, x_m$
Consequence	$(x_1, x_2, \ldots, x_m) \equiv \underline{x}$

What We Seek is a Utility Function u(x)

Definition:

A utility function is an objective function (to be maximized) with one special property: in situations involving uncertainty, one should choose the alternative leading to the highest expected (i.e., average) utility.

Properties of u(x)

1. $u(\underline{x}) > u(\underline{x}') \Leftrightarrow \underline{x} \succ \underline{x}'$ ($\underline{x}$ is preferred over $\underline{x}'$)

2. Alternative A_i for i = 1, 2 has expected utility $E[u_i]$; then

   $E[u_1] > E[u_2] \Leftrightarrow A_1 \succ A_2$ (A_1 is preferred over A_2)

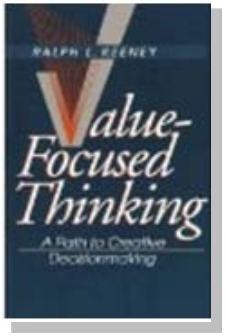
Additive Utility Function

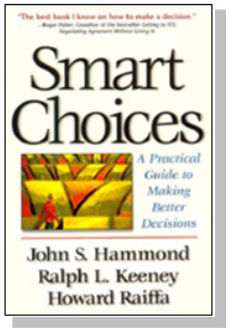
$$u(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{m} k_i \, u_i \, (x_i)$$

where u_i (x_i) is a utility function for decision metric x_i, and the k_i are scaling constants (weights) that specify the relative importance of the decision metrics. The u_i and the k_i are defined for specific ranges of the decision metrics.

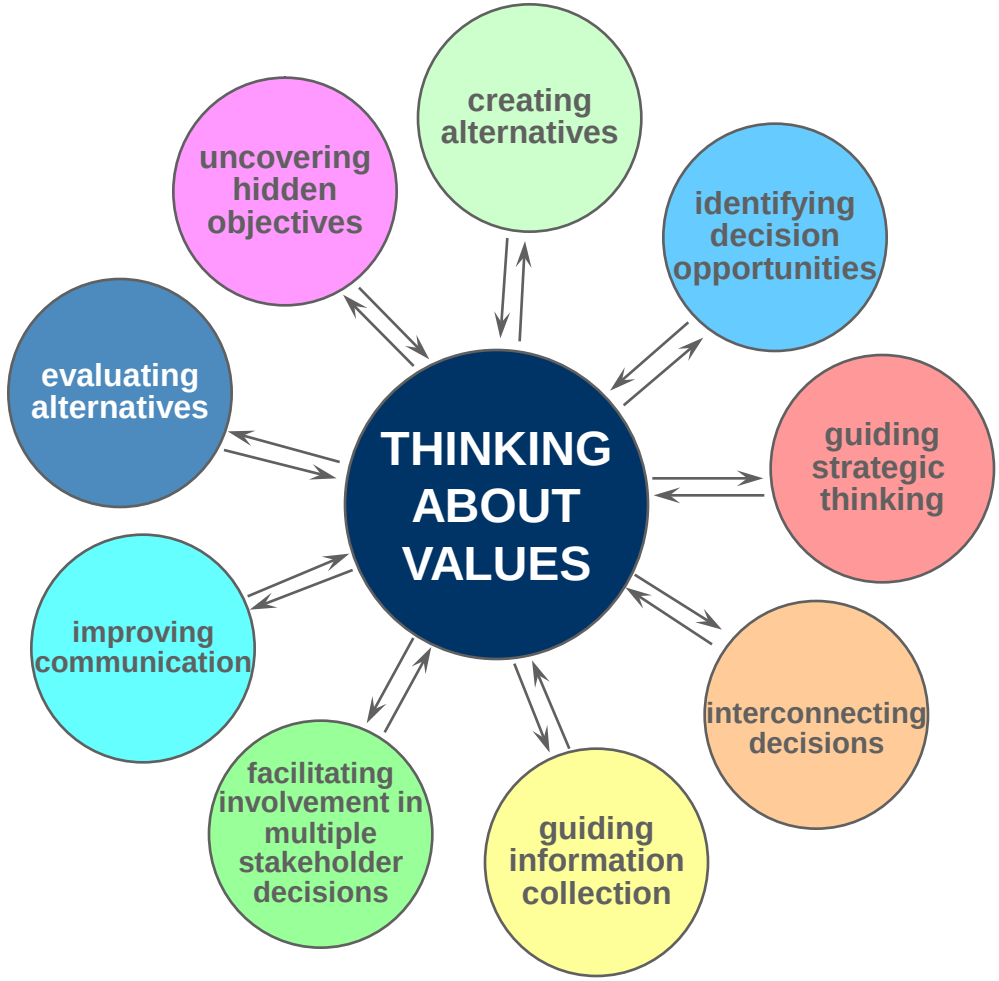
Value-Focused Thinking Is a Subtle but Important Paradigm Shift

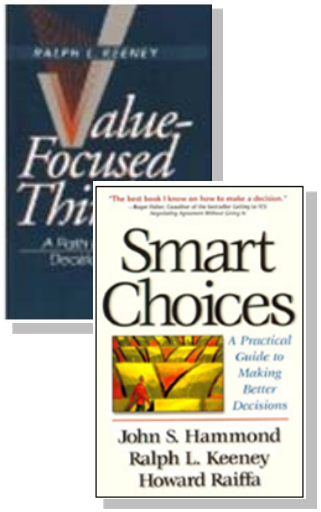
Alternative-Focused Thinking	Value-Focused Thinking
1. Identify alternatives	1. Define objectives
2. Define objectives	2. Specify values
3. Specify values	3. Create alternatives
4. Evaluate alternatives	4. Evaluate alternatives
5. Select an alternative	5. Select an alternative





Value-Focused Thinking Offers Many Benefits

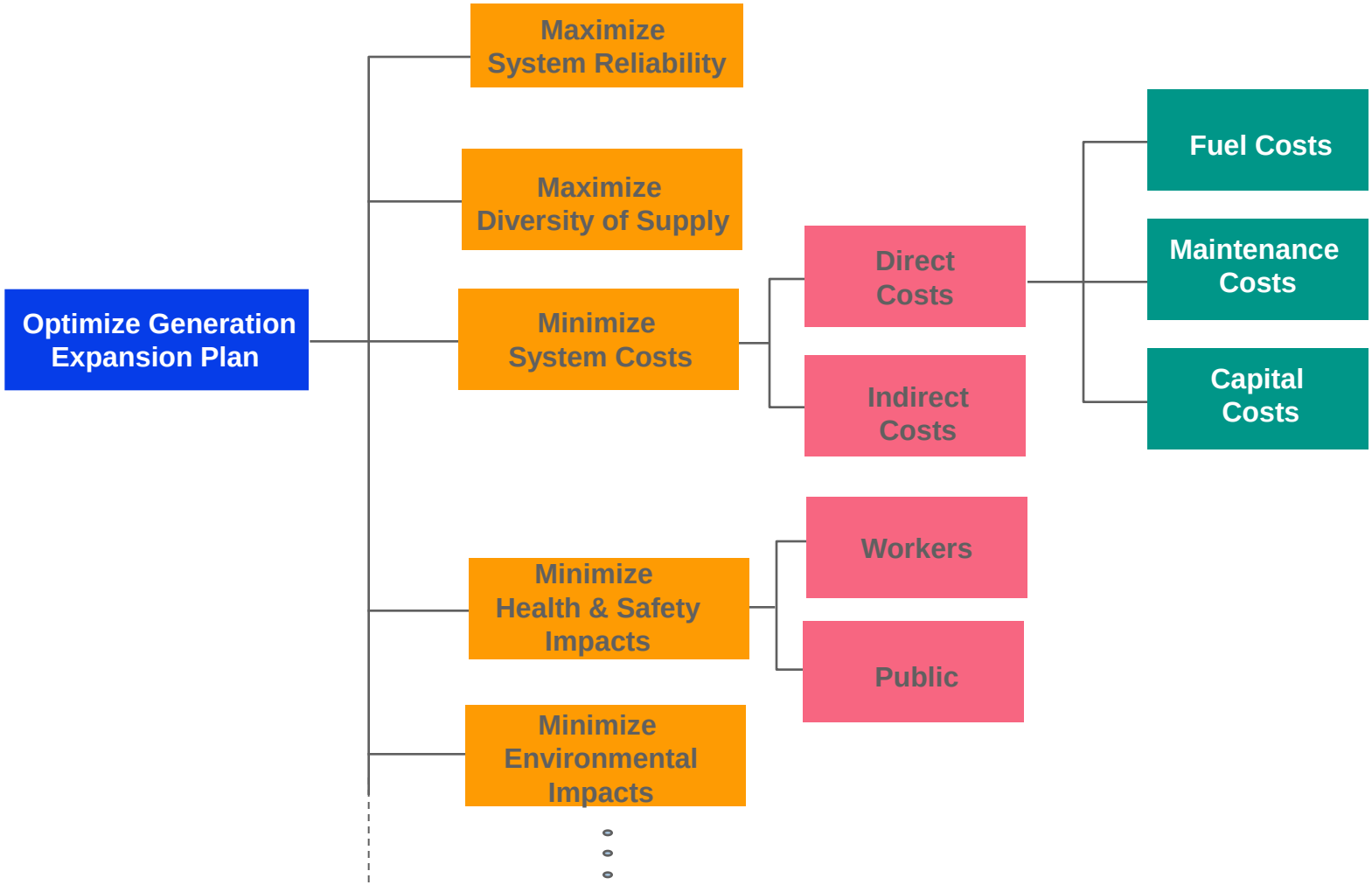




What Are Objectives?

- An objective is a statement of something that one desires to achieve
- An objective is characterized by three features:
  - A decision context
  - An object
  - A direction of preference
- Examples:
  - Minimize vulnerability
  - Minimize cost
  - Maximize return on investment for risk reduction options

Illustrative Hierarchy of Objectives for for Optimizing Expansion of Electrical Generating Systems



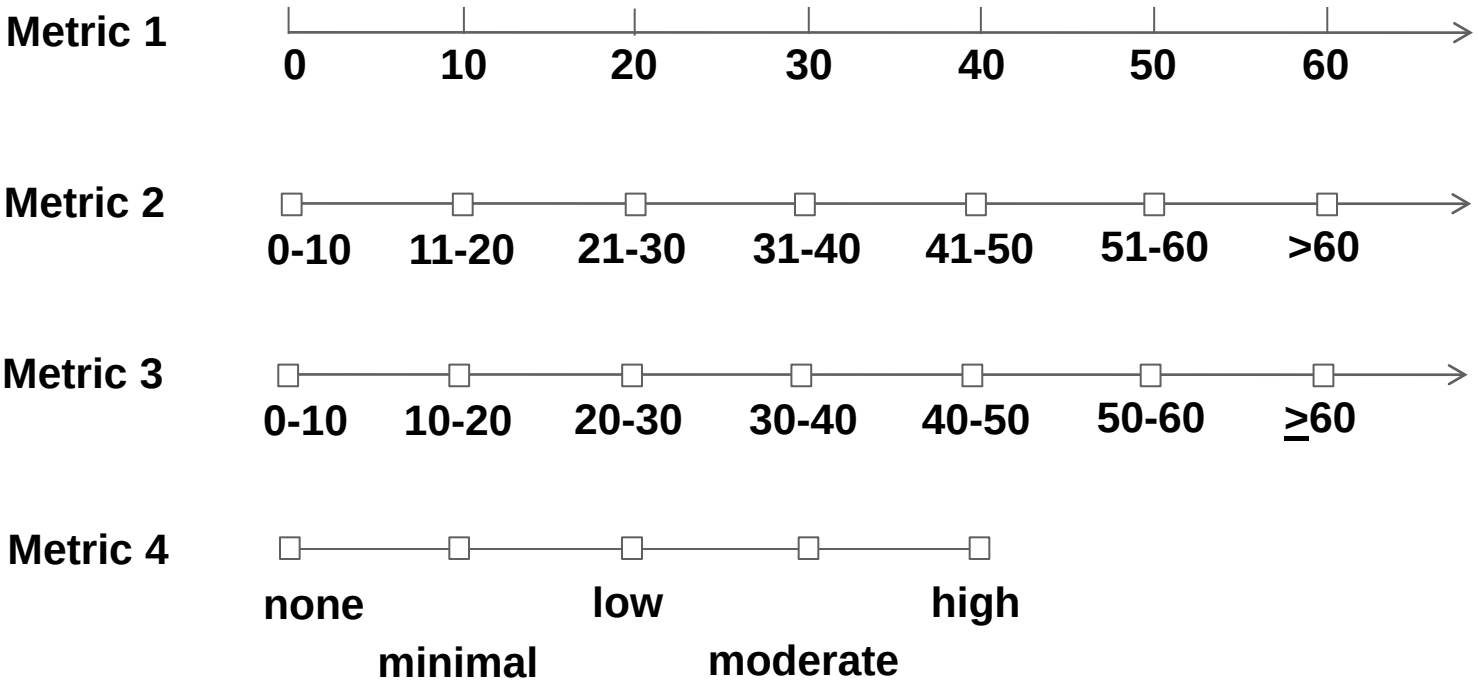
Desirable Properties for Decision Metrics (Attributes)

- ***Measureable*** **(Define the objective in more detail than that provided by the objective alone. Example: "Annual number of fatalities" for "minimize the loss of life.")**

- ***Operational*** **(Describes the possible consequences and a sound basis for value judgments about the desirability of various degrees of achievement. Discriminates among alternatives under consideration, i.e., different alternatives have different levels of achievement. Potential issue: We can't use metrics that are desirable but are too difficult or expensive to utilize)**

- ***Understandable*** **(No ambiguity in describing and interpreting consequences in terms of metrics. No loss of information when one person assigns a metric level to describe a consequence and another person interprets that level – see next slide)**

Four Possible Metrics for the Objective "Minimize Fatalities" that Measure Number of Fatalities (Metric 1 is much better than Metric 4)



Exercise to Calibrate Probability Estimates (Origin: Calibrating Weather Forecasters)

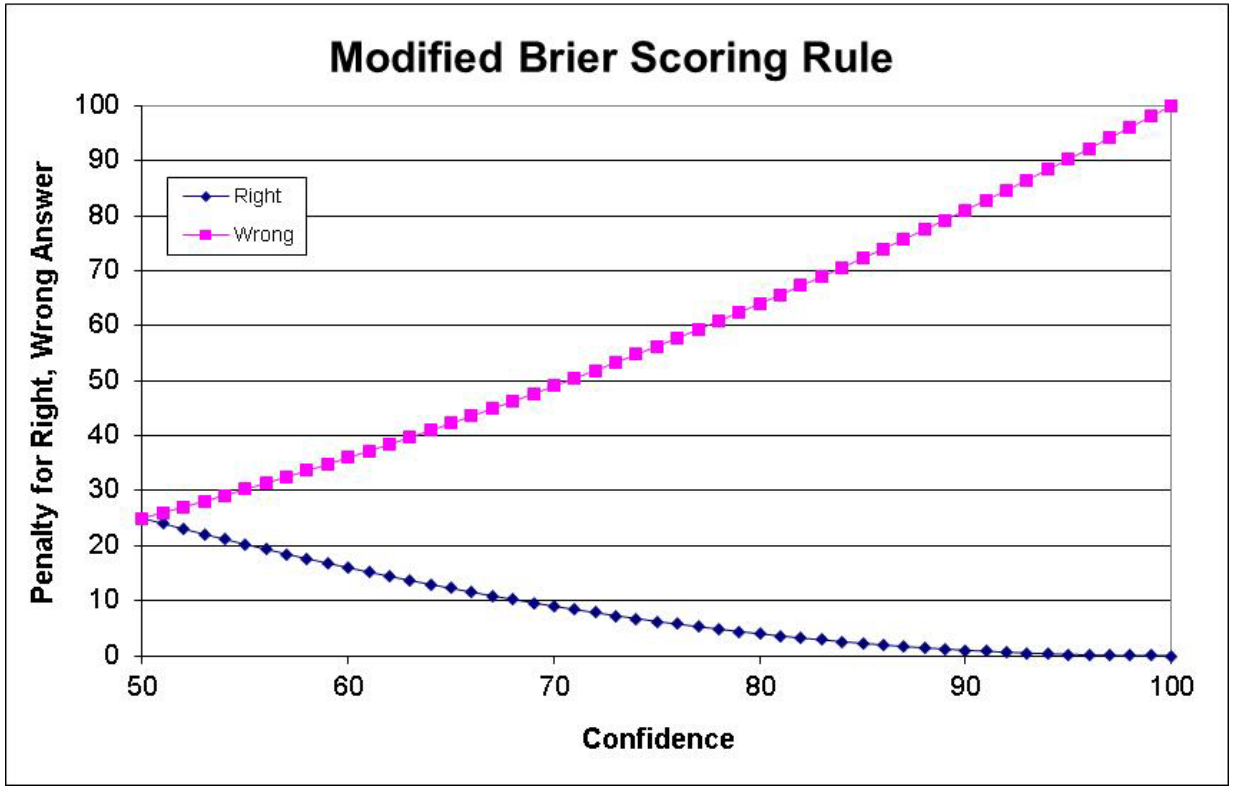
- 15 questions (history, geography, etc.)
- 2 choices per question
- Choose your answer (1 or 2)
- State your confidence (50 to 100) in your answer (100= high confidence; 50 = no confidence)
- A penalty is assigned to your answer based on your confidence; for a given question, wrong answers receive a higher penalty than correct answers
- The penalty is given by a modified Brier Scoring Rule

Exercise to Calibrate Probability Estimates

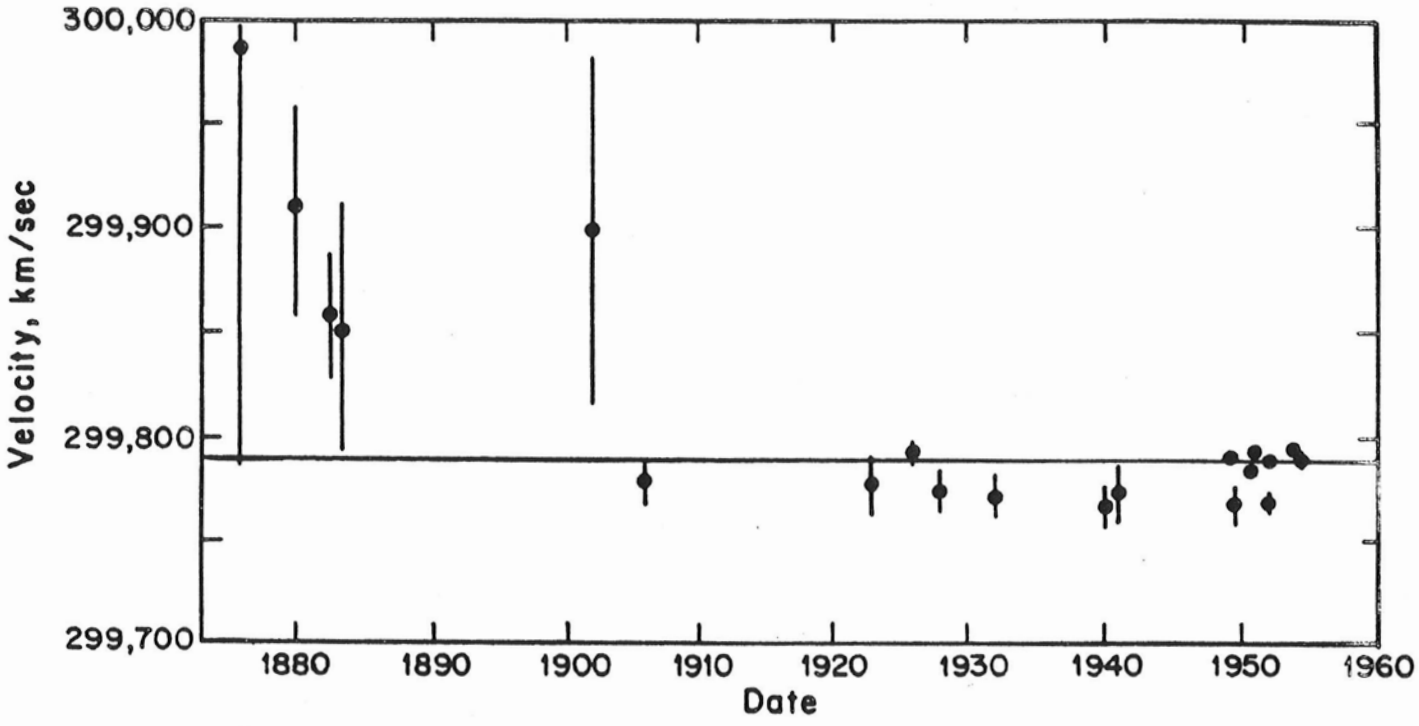
Answer	Confidence	Correct Answer	Penalty	
				The battle of Quebec was won by the:
1 or 2	50	✓	25	1) French
				2) British
				Which country has the largest debt to the U.S. arising from World War I?
1 or 2	100	✓	0	1) Russia
				2) Great Britain
				Which state was a part of the Louisiana Purchase of 1803?
1 or 2	50	X	25	1) Iowa
				2) Michigan
				Which country suffered more battle deaths in World War II?
1 or 2	75	X	56.25	1) Germany (excluding Austria)
				2) Japan
				The Tigris and Euphrates Rivers empty into:
1 or 2	75	✓	6.25	1) The Persian Gulf
				2) The Red Sea
				Which president was known as "Old Rough and Ready"?
1 or 2	100	X	100	1) Zachary Taylor
				2) Andrew Jackson

Modified Brier Scoring Rule (Penalty): Table and Graph

Confidence	Correct	Wrong
50	25	25
55	20.25	30.25
60	16	36
65	12.25	42.25
70	9	49
75	6.25	56.25
80	4	64
85	2.25	72.25
90	1	81
95	0.25	90.25
100	0	100

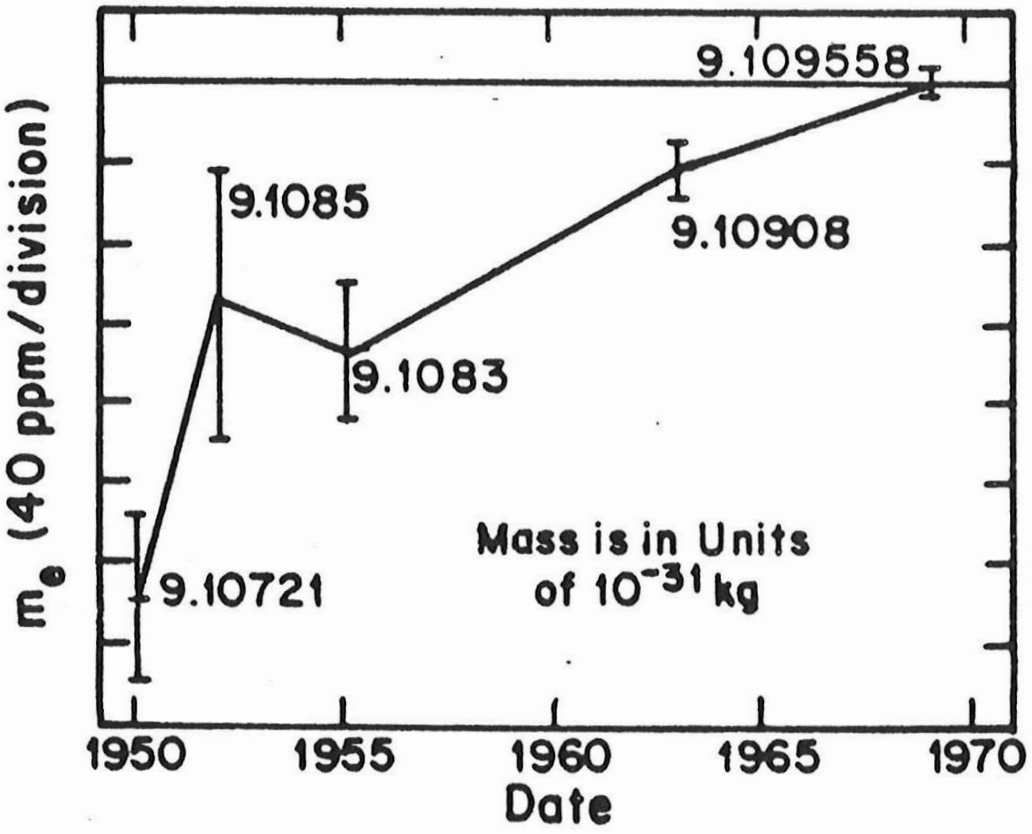


Even in the 20th Century, Scientists Exhibited Overconfidence in Estimating the Speed of Light



Redrawn from J.H. Rush, "The Speed of Light", Scientific American, 62-67, August 1955.

Similarly, Estimators of the Rest Mass of the Electron Were Overconfident Until the Late 1960's



Redrawn from "Physical Constants"
Encyclopedia Britannica 5, 75-84, 1974

An Exercise in Estimating Uncertain Results:

Give Your Best Point Estimate and Construct Central 90% Confidence Intervals That You Believe Contain the Answers to the Following Questions

(Note: A central 90% confidence interval means that there is a 1 in 20 chance that the correct answer is less than the "Low" and that there is a 1 in 20 chance that the answer is greater than the "High")

	Questions (Fascinating Facts)	Low	Point Estimate	High
1	Number of people killed at Nishapur in 1 hour in 1221			
2	Height of world's largest pyramid (feet)			
3	Top speed of the peregrine falcon (mph)			
4	Pulse rate of a whale (beats per minute)			
5	Number of volumes in 15th century Chinese encyclopedia			
6	Unwrapped length of Kandahar, Afghanistan, native's turban (feet)			
7	Area of the Sahara Desert (square miles)			
8	Number of spider webs needed to weigh 1 pound			
9	Number of grooves on a U.S. dime			
10	Longest recorded time at a single location without precipitation (months)			

Fascinating Facts – Answers

	Questions	Correct Answer	Comment
1	**Number of people killed at Nishapur in 1 hour in 1221**	1,748,000	Gengis Khan's Army
2	**Height of world's largest pyramid (feet)**	195	Pyramid of the Sun, Mexico, base >40 acres, V=113M ft^3; Cheops h=449', A=13 acres, V=88M ft^3
3	**Top speed of the peregrine falcon (mph)**	217	
4	**Pulse rate of a whale (beats per minute)**	9	
5	**Number of volumes in 15th century Chinese encyclopedia**	11,095	
6	**Unwrapped length of Kandahar, Afghanistan, native's turban (feet)**	20	
7	**Area of the Sahara Desert (square miles)**	3,565,565	50 states = 3,700,000; Alaska = 660,000
8	**Number of spider webs needed to weigh 1 pound**	27,000	0.017 g/web
9	**Number of grooves on a U.S. dime**	118	
10	**Longest recorded time at a single location without precipitation (months)**	168	Arica, Chile, ending in Jan. 1918

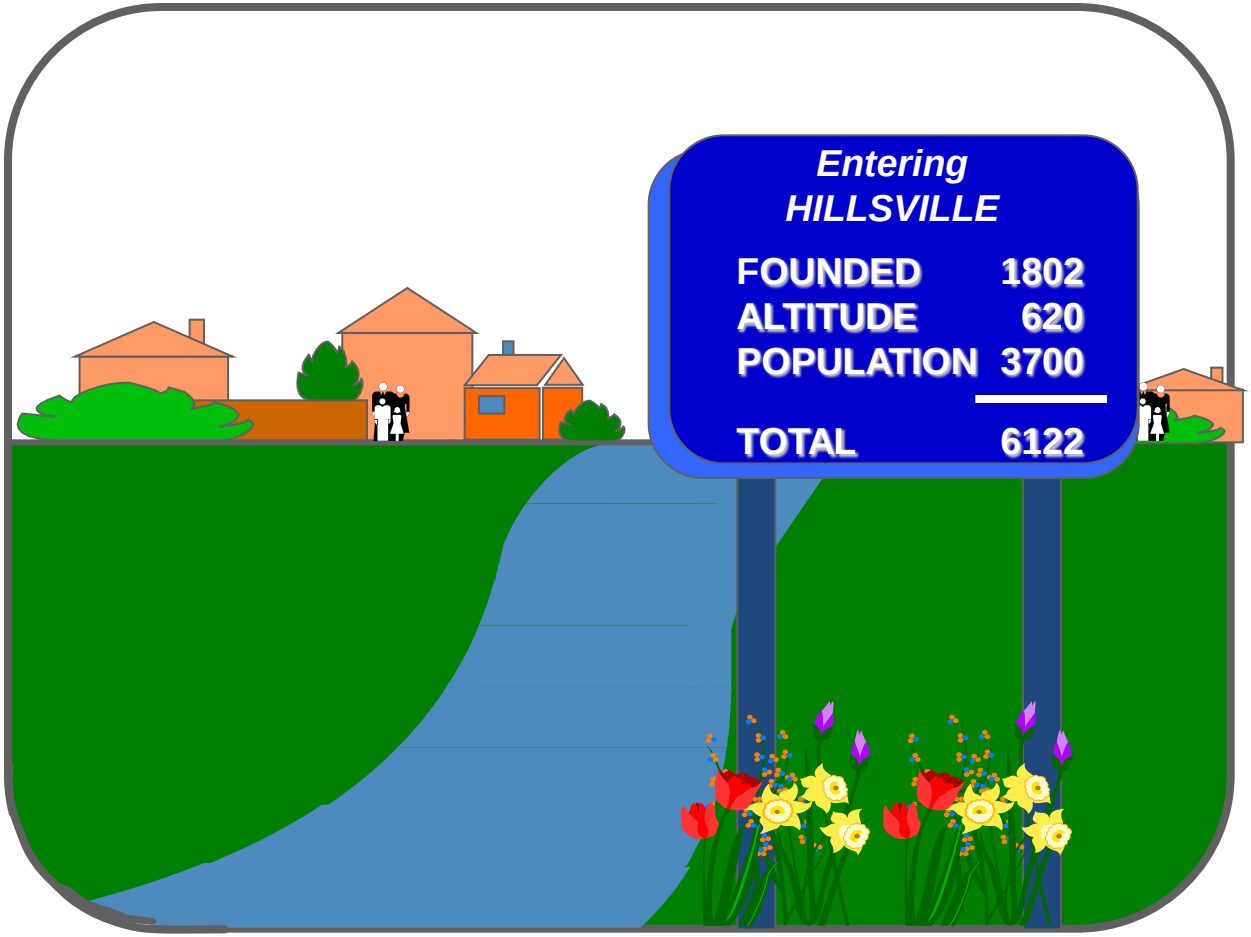
Desirable Properties for the Final Set of Decision Metrics (Attributes)

- ***Completeness*** **(Cover all significant aspects of the problem.)**
- ***Practical*** **(It is possible to obtain the information necessary to proceed with the analysis, which would then provide insights for making the best decision and justifying the choice to others.)**
- ***Decomposable*** **(If high-level metric is difficult to use, complexity may be reduced by breaking that objective/metric down into more understandable components.)**
- ***Non-redundant*** **(Avoid double counting of possible impacts.)**
- ***Minimal*** **(Reduce the time and cost necessary for the analysis.)**
- ***Defensible*** **(Good achievement on the 5 properties above yields this.)**

Decision Analysis - Elicitation Process

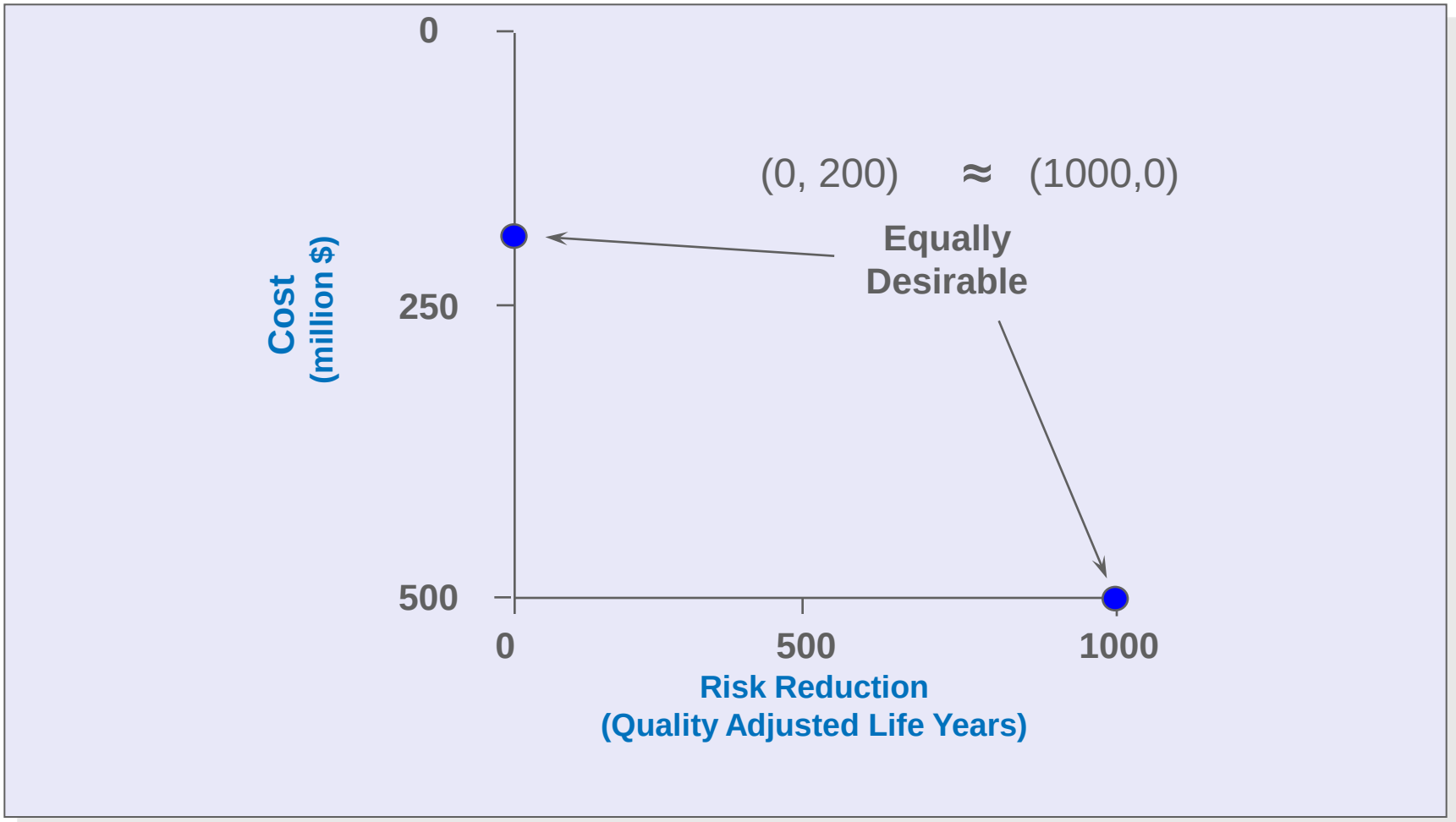
- Identify Key Factors
  - Gas Mileage
  - Cost
  - Comfort
  - Cup Holders
- Rank Factors from 1 to 5
- Select Relative Importance
  - 1=100%
  - 2=?
  - 3=?
  - 4=?
- Aggregate

Hillsville Has Devised an Alternative Approach to Combine Different Factors (not recommended)!



Gold Hill, Colorado, Has Devised an Identical Approach to Combine Different Factors (also not recommended)!

Weights Are Determined By Examining Tradeoffs between Pairs of Criteria



Exercise: Uncertainty And Risk Attitudes Are Important Considerations In Preference Assessment

Example:

Suppose you receive a lottery ticket at no cost to you. The lottery will be held tomorrow. You have a 50 percent chance of winning $100 and a 50 percent chance of winning nothing. I would like to buy that lottery ticket from you. Think about the lowest amount I would have to offer you for you to sell me the ticket.

Representation of the Lottery Ticket Sale

	Probability	Payoff
	0.5	$100
	0.5	$0

Expected Value of Lottery = Probability x Payoff = $50

What Is the Lowest Amount of Money You Would Accept Today For The Lottery Ticket (to be drawn tomorrow)?

$1 ?
$2 ?
$5 ?
$10 ?
$20 ?
$30 ?
$40 ?
$50 ?
$60 ?
$70 ?
$80 ?
$90 ?

The lowest value you would accept is your certainty equivalent (CE) for the lottery.

If the Range of Potential Outcome Levels is Large, Risk Attitudes Should be Considered

Example 2:

Suppose you receive a lottery ticket at no cost to you. The lottery will be held tomorrow. You have a 50 percent chance of winning $1,000,000 and a 50 percent chance of winning nothing. I would like to buy that lottery ticket from you. Think about the lowest amount I would have to offer you for you to sell me the ticket.

Some Consequences Span Large Ranges

	Probability	Payoff
	0.5	$1,000,000
	0.5	$0

Expected Value of Lottery = Probability x Payoff = $500,000

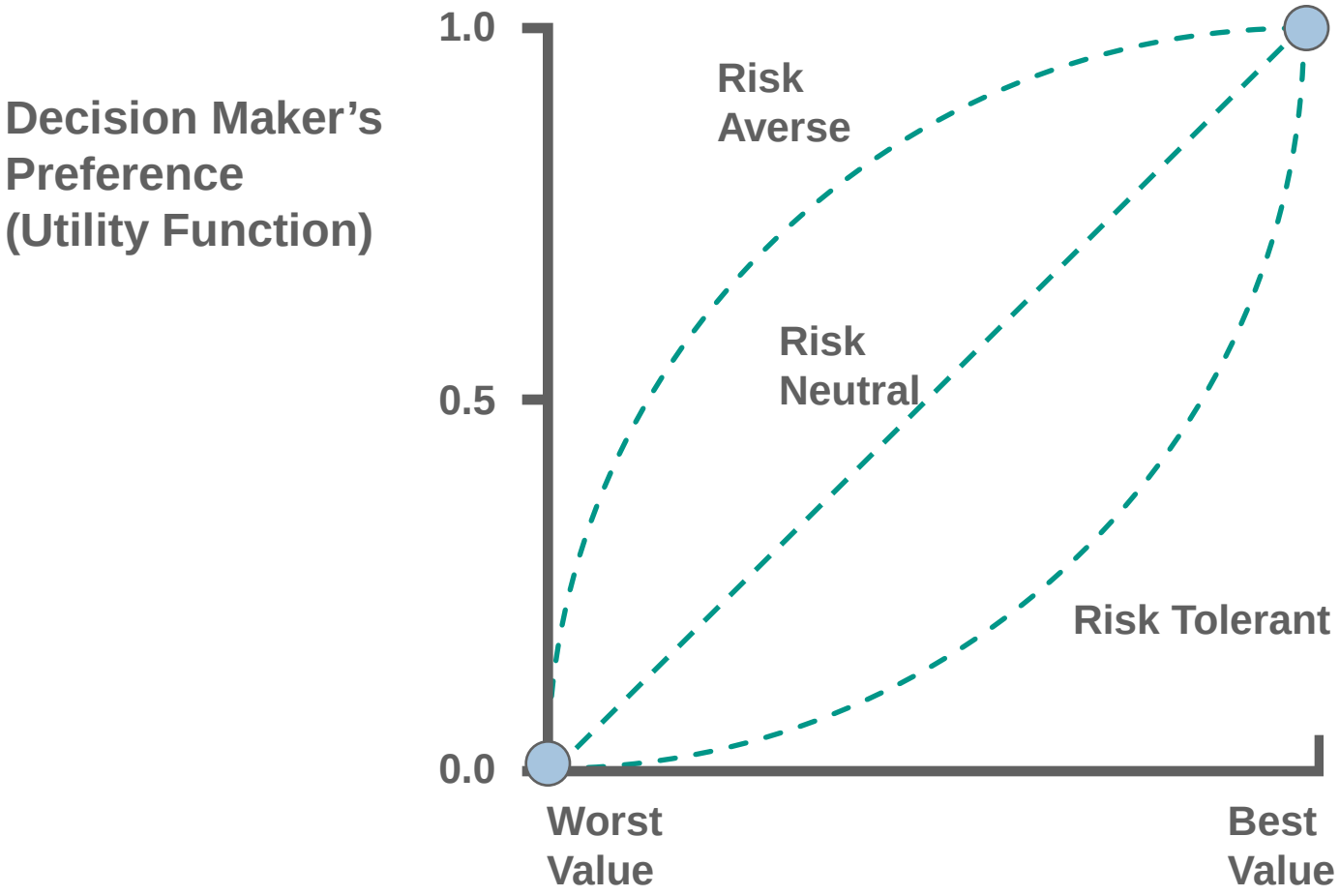
What is the Lowest Amount of Money You Will Accept Today for this Lottery Ticket (to be drawn tomorrow)?

$10,000 ?
$20,000 ?
$50,000 ?
$100,000 ?
$200,000 ?
$300,000 ?
$400,000 ?
$500,000 ?
$600,000 ?
$700,000 ?
$800,000 ?
$900,000 ?

Risk Attitude Is Important in Determining the Desirability of an Alternative Course of Action that Involves Uncertain Consequences

Risk Averse:	**The certainty equivalent is less desirable than the expected value of the lottery ($50 in the first lottery and $500,000 in the second lottery).**
Risk Neutral:	**The certainty equivalent is equal to the expected value of the lottery.**
Risk Tolerant:	**The certainty equivalent is more desirable than the expected value of the lottery.**

A Utility Function Describes the Risk Preferences of the Decision Maker



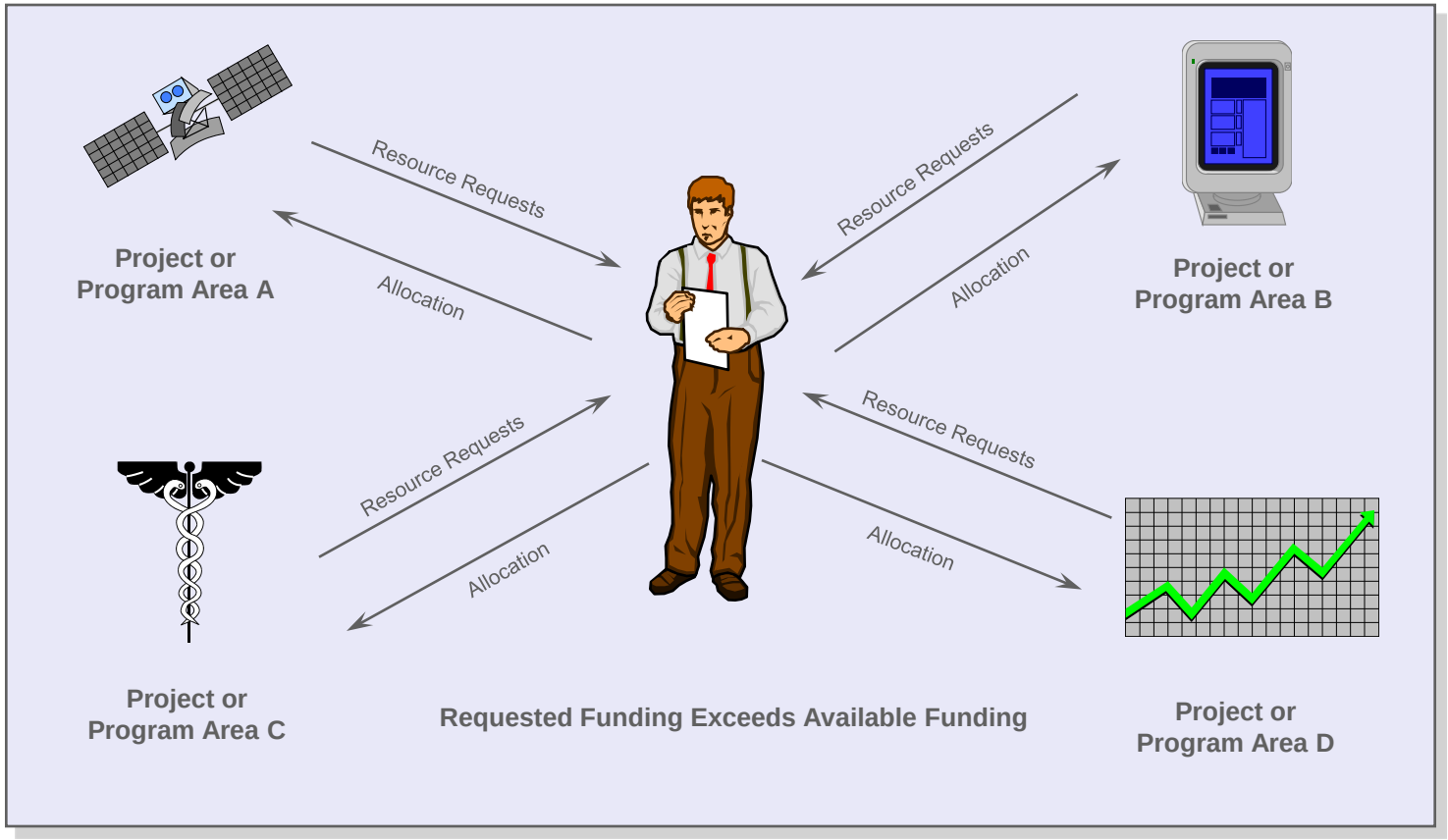
Consequence Ranges Are Important!

- For most people, the value of (preferences for) an additional dollar depends on the location on the dollar scale
- Expected values for uncertain outcomes often are not a good representation when consequences span large ranges and preferences for those outcomes are being considered
- Explicitly examining preferences for outcomes is important in such situations

Observations

- There is no such thing as an objective, value-free analysis that models a policy decision
- Subjective aspects and value judgments are an important part of these problems and should be taken into account
- The choice is to treat the subjective aspects and value judgments explicitly or implicitly

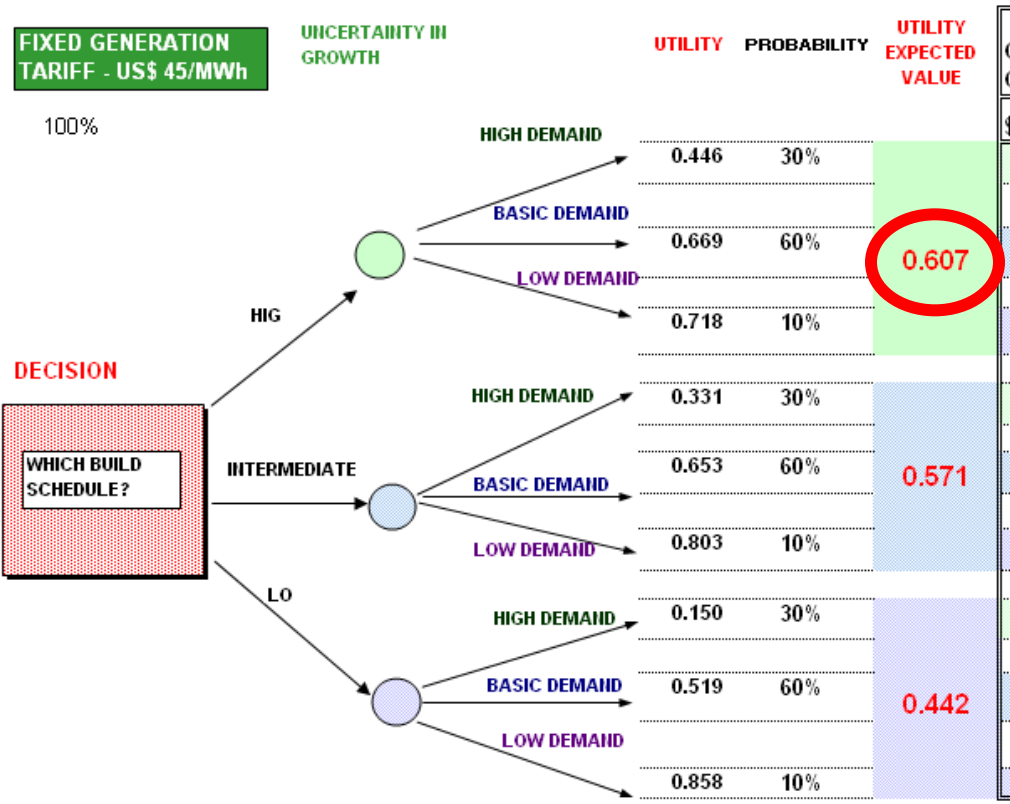
Decision Analysis Can Help Prioritize and Allocate Limited Resources in a Portfolio



Decision Analysis Was Used for Energy Planning for the State of Minas Gerais, Brazil (1995-96)

- The International Atomic Energy Agency (IAEA) agreed to implement the project.
- The basic objective of the project was to provide assistance to the Energy Utility of Minas Gerais (CEMIG) to carry out planning studies for evaluation of the long-term energy requirements and establishment of balanced supply systems, including electricity and the potential role of nuclear power.
- Environmental and resource impacts relating to the different options were also taken into account.
- The studies were carried out by a team comprising CEMIG and other agencies responsible for energy/electricity planning in the State of Minas Gerais.

Each of the 9 Build-Demand Scenarios Resulted in Estimates for Each of the 6 Attributes



Generation Cost	Probability of Load Not Served	Rate of Return on Equity	Annual Capital Investment	Max Annual SO2 Emissions	Land Taken by Power Plants
$/MWh	%/year	%/year	10E9 $/year	tons/year	10E3 km2/year
39.17	0.764	9.510	1.647	12.300	2.700
35.68	0.003	12.070	0.846	0.090	2.700
42.86	0.000	9.480	0.778	0.030	0.500
45.90	6.090	7.140	1.647	12.300	2.700
34.46	0.255	12.610	0.782	0.090	2.700
34.55	0.167	12.350	0.468	0.030	0.500
58.66	11.390	1.480	1.596	12.300	2.700
38.35	2.080	10.850	0.915	0.150	2.700
30.54	0.187	15.380	0.307	0.030	0.800

The Utility of Each Build-Demand Scenario Combined with Scenario Probabilities Yields Expected Utility for Each Scenario; Build High Is Optimal (but not by much).

Typical Decision Problems and Agencies That Have Used Decision Analysis to Help

Type of Problem	Selected Agencies That Have Used Decision Analysis
▪ Prioritization	▪ Department of Energy
▪ Resource allocation	▪ Department of Defense
▪ R&D portfolio selection	▪ White House Office of Science and Technology Policy
▪ Strategic planning	▪ Federal Aviation Administration
▪ Policy formulation	▪ Environmental Protection Agency
▪ Technology evaluation	▪ Department of Homeland Security
▪ Protective measures evaluation	
▪ R&D Roadmapping	

Decision Analysis Helps Structure the Problem

- Objectives have been stated in a measurable way
- The process is traceable and reproducible
- The decision maker's willingness to trade off one objective for another has been explicitly considered
- The decision maker's preferences have been incorporated and they explicitly consider consequence ranges
- Whether or not the expected value for uncertain outcomes is an appropriate representation with respect to preferences is explicitly addressed

Some Useful References

- Hammond, John S., Ralph L. Keeney, and Howard Raiffa, *Smart Choices: A Practical Guide to Making Better Decisions*, Harvard (1999)
- Keeney, R. L., *Value-Focused Thinking: A Path to Creative Decisionmaking*, Harvard (1992)
- Keeney, R.L., *Siting Energy Facilities*, Academic (1980)
- Peerenboom, J.P., W.A. Buehring, and T.W. Joseph, "Selecting a Portfolio of Environmental Programs for a Synthetic Fuels Facility," *Operations Research,* Vol. 37, No. 5, Sept.-Oct. 1989 (pp.689-699)
- Raiffa, Howard, *Decision Analysis: Introductory Lectures on Choices Under* Uncertainty, Addison-Wesley (1968)
- Stokey, Edith and Richard J. Zeckhauser, *A Primer for Policy Analysis* , W.W. Norton (1978)
- von Winterfeldt, Detlof, and Ward Edwards, *Decision Analysis and Behavioral Research*, Cambridge (1986)

Questions/Comments