SYST 542
Decision Support Systems Engineering

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Unit 2: Models, Cognitive Tools And Decision Making
“All decisions are based on models... and all models are wrong.”

John D. Stearman
“All models are wrong, but some are useful.”

George Box
Outline

• What is a model?
• Using models to support decision making
• Value focused thinking
Why Decision Making is Hard

• **Goal**
  – Disagreement over what is to be accomplished
  – Competing objectives
  – Disagreement about relative importance of objectives

• **Options**
  – Lack of knowledge of options
  – Too many options to be compared

• **Outcomes**
  – Uncertainty about outcomes
  – Disagreement about likelihood of outcomes

• **Deciding**
  – Cumbersome, complex, or unstructured process for deciding
  – Politics of decision making process
  – No one with authority to make decision and/or multiple competing authorities

• **Do It!**
  – Lack of effective process
  – Inability to obtain consensus
  – Subversion by powerful disagreeing parties
  – Coordinating many actors
  – Organizational inertia
Models

• A model is a representation of a system that can be used to answer questions about the system

• Models are constructed from:
  – Past data on the system
  – Past data related to the system
  – Judgment of subject matter experts
  – Judgment of experienced model builders
Models in Engineering

- Engineers design a system by:
  - Building a model to represent the system they want to design
  - Manipulating the model
  - Using behavior of the model to
    » Predict behavior of the system
    » Evaluate and compare alternative design options

- Types of representation
  - Physical
  - Mathematical
  - Computer
  - Verbal

- Examples
  - Wind tunnel and model airplane
  - CAD model of a bridge
  - Computer simulation of traffic flows on highway network
  - Linear program model for inventory planning
  - Bayesian spam filter

- Can you think of other examples?
- How has the information technology revolution changed how engineers do modeling?
Real World
Real World

Representation
A diagram illustrating the relationship between observations, actions, and their representations in the context of real-world events. The diagram shows a globe with various labeled points indicating the phases of a celestial event, such as eclipses and partial eclipses, along with time stamps and percentages representing the extent of the event at different points in time.
Reality and Representation

• Elements of a representation
  – Reality to represent
  – Possible representations of reality
  – Correspondence between aspects of reality and features in representation space

• Important considerations
  – By whom is representation being used?
  – For what purpose?
  – How to measure how good it is?

• DSS uses representation at two levels
  – Object level: help decision maker construct and use representation of a decision problem
  – Meta level: DSS design is based on a representation of the decision making process and how decision makers represent the decision

• How do we study representation?
Decision Theory: Models of Decisions

• **Goal**
  – Hierarchical decomposition of objectives represents structure
  – Utility function quantifies tradeoffs among attributes

• **Options**
  – For simple problems options can be listed
  – For complex problems option space is implicitly represented

• **Outcomes**
  – Features (variables), cause-effect relationships, dependencies represent structure of outcome space
  – Probabilities quantify likelihoods of different outcomes

• **Deciding**
  – Decision theory recommends maximum expected utility option
  – Does that make it “the right answer”? Why or why not?

• **Do It!**
  – Value of decision support may depend on effective implementation!
  – Can decision theory be used to support implementation? If so, how?
Representing Decision Making

• GOOD-D is a verbal representation of the elements of a decision problem
  – Useful mnemonic
  – Too general for a specific problem

• Alternate Terminology:
  – Goal: objective, figure of merit, measure of effectiveness, requirement, benefit, cost, loss, penalty
  – Options: solution space, feasible region, design alternatives, choices, courses of action
  – Outcomes: consequences, results, states, trajectory, observations

• Most approaches to decision support
  – Decompose a decision problem into the GOOD-D elements (or something very similar)
  – Help decision maker to identify options for which the outcomes are expected to do well at achieving the decision maker’s goal
Human Decision Makers and Models

• People are good at
  – Identifying what objectives are important
  – Identifying what features are relevant
  – Identifying the relationships among features and objectives
  – Generating options

• People need support for
  – Bumping out of pre-conceived ideas and established conventions
  – Integrating large numbers of factors
  – Integrating numerical and statistical information with judgmental input
  – Tedious bookkeeping tasks
  – Coordinating multiple actors

• To be effective, models must produce **understandable rationale** for recommendations
Cognitive Tools
(von Winterfeldt and Edwards)

• We would not embark on a construction project without effective physical tools

• We should not make important decisions without effective cognitive tools
  – Name some cognitive tools you use in class, at work, in your life

• An effective DSS provides the decision maker with cognitive tools to assist in any or all of:
  – Problem structuring
  – Elicitation of human judgmental inputs
  – Organizing and displaying relevant data
  – Aggregating inputs to produce
    » Predictions of outcomes for options suggested by decision maker
    » Recommendations of options for decision maker to consider
  – Understanding strengths and weaknesses of candidate solutions
  – Selecting a solution
  – Justifying the selected solution
  – Implementing the selected solution
Figure 3.1. Example of the linear approach to analysis adopted by many, especially inexperienced, analysts.

Figure 3.2. Illustration of the process of “good” policy analysis as discussed in the text. Note the heavy emphasis on iterative refinement. 

Source: Morgan, Hennin (1992)
Waterfall Lifecycle Model

- Requirements
- Analyze
- Design
- Build
- Test
- Operate

Spiral Lifecycle Model

- User need
- Analyze
- Design
- Build
- Test
- Operate
- Retire

...
“A theory should be as simple as possible, but no simpler.”

-A. Einstein
Exploratory and Consolidative Modeling  
(Bankes, 1993)

• **Consolidative modeling** uses the model as a surrogate for the system  
  – consolidates known facts about the system  
  – for purposes of analysis the model adequately represents the system

• **Exploratory modeling** explores how the world would behave if various hypotheses were correct  
  – many details and mechanisms of system are uncertain  
  – model is not a reliable image of the world  
  – paucity of relevant “ground truth” data for evaluating model

• **Exploratory and consolidative modeling** differ in  
  – purpose of modeling  
  – methodology
Examples of Exploratory and Consolidative Models

• Consolidative:
  – Stress analysis to determine whether a structure will support the design load

• Exploratory
  – Six-month economic forecast
Goals of Exploratory Modeling

- Identify an ensemble of plausible models and modeling assumptions
- Identify the range of outputs predicted by plausible models under plausible assumptions
- Identify the relationship between modeling assumptions and model outputs
- Find assumptions that have a large impact on model outputs
- Identify predictions that are robust across different sets of modeling assumptions.
Exploratory Models and Decision Making

• Consolidative models may be possible only for some subsystems or parts of problems

• Exploratory models must be used for
  – subsystems or subproblems for which there are no consolidative models
  – tying together subsystem or subproblem models

• Multiple stakeholders often have different beliefs and preferences
Pitfalls of Exploratory Modeling

• Treating an exploratory model as if it were consolidative
  – Accepting model output as “the answer”
  – Failure to question assumptions
  – Failure to perform sensitivity analyses and model diagnosis

• Focusing too much on parts of problem for which consolidative models are possible
How to Use Exploratory Models

• As an argument for policy options
  – When it can be argued that a model differs from reality in a way that even more strongly favors option in question
  – When changes in modeling assumptions fail to change the recommendation

• As a communication device
  – Illustrates relationships between assumptions and conclusions
  – Facilitates “what-if” arguments
  – Gives insights about a problem
  – Helps focus discussion among multiple stakeholders
    » focus on areas of agreement and disagreement
    » avoid counterproductive arguing over who is right

• As a bookkeeping device

(see Bankes, 1993)
Model Test & Evaluation

- Models fail because: (Stearman, 2002)
  - Basic questions of suitability to purpose not considered
  - Narrow boundary cut critical feedbacks
  - Assumptions kept hidden from clients
  - Important stakeholders not included in process

- How can test and evaluation help to prevent these failures?

- Types of test
  - Verification
  - Validation
  - Acceptance

- How to test
  - Consolidative models?
  - Exploratory models?
Models and Sensitivity Analysis

• Basic idea of sensitivity analysis
  – Vary assumptions and model parameters
  – Examine how conclusions change
  – Evaluate robustness of conclusions to changes in model

• Applying sensitivity analysis in DSS
  – Computing variations on model
    » Analytical approaches
    » Simulation / numerical approaches
    » Single parameter / multiple parameter variation
  – Displaying results
    » Tabular, graphical
  – Effect of variation on model recommendations

• Remember the “unknown unknowns”
Value Focused Thinking

• Alternative-Focused Thinking
  – Notice problem and begin problem solving
  – List alternative solutions
  – Compare alternatives
  – Choose best alternative

• Value-Focused Thinking
  – Focus problem solving on decision maker’s values
  – Generate alternatives based on decision maker’s values
  – Choose alternative that best serves decision maker’s values

• Problems with alternative-focused thinking
  – Reactive not proactive
  – Tendency to incomplete analysis
  – Tendency to focus on immediately obvious alternatives and dimensions of comparison

Thanks to Andy Loerch
Where does thinking about values lead?

ValueFocusedThinking

- Uncover hidden objectives
- Creating alternatives
- Identifying decision opportunities
- Guiding strategic thinking
- Interconnecting decisions
- Evaluating alternatives
- Improving communication
- Involving Multiple DM’s

Thanks to Andy Loerch
Identifying Values

- Interact with decision makers
- Elicit feedback throughout DSS development
- 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
Techniques for Eliciting Values

(1) Make a “Wish List”
(2) Compare & contrast alternatives
(3) Identify problems and shortcomings
(4) Predict outcomes & consequences
(5) Examine goals, constraints, guidelines
(6) Adopt different perspectives
(7) Consider strategic objectives
(8) Enumerate generic objectives
(9) Structure objectives
(10) Quantify objectives
Structuring Objectives

- Initial list has “non-objectives”
  - Alternatives
  - Constraints
  - Criteria for evaluation

- Convert “non-objectives” into objectives

- Types of objective
  - Fundamental objectives -- essential to decision maker’s concerns
  - Means objectives -- important only because of relationship to fundamental objectives

- It is important not to confuse means objectives with fundamental objectives

Thanks to Andy Loerch
Value-Focused Thinking, Models, and DSS

- Decision support should be focused on helping decision makers to identify and select alternatives that serve values
- DSS can provide support for
  - Identifying and structuring values
  - Incorporating values appropriately into decision models
  - Generating alternatives likely to serve values
  - Comparing alternatives on key dimensions of value
  - Identifying and adjusting for problems or inadequacies with models
Communicating Model Results

• “Because the model said so” is not a justification for a decision

• The decision maker is ultimately responsible

• The challenge: communicate to decision maker
  – What the model recommends
  – Why the model recommends what it does
  – What are the underlying assumptions
  – What is the sensitivity to
    » Changes in parameter values
    » Violations of structural assumptions

• Effective communication is often more difficult than building the model
In Summary...
References


• Keeney, R. *Value Focused Thinking*, 1993


