The Value of Modeling in Systems Engineering and Design

Chris Paredis
Georgia Institute of Technology
George W. Woodruff School of Mechanical Engineering
H. Milton Stewart School of Industrial and Systems Engineering
Director, Model-Based Systems Engineering Center
chris.paredis@me.gatech.edu
Context: Framing SE&D

A normative perspective:

Can we understand and explain why engineers use models and argue for how they should use models?

- What is a model?
- Why do engineers model?
- What kinds of models do engineers use?
- Which models should engineers use?
“Everyone designs who devises courses of action aimed at changing existing situations into preferred ones”
— Herbert Simon, The Sciences of the Artificial

How do engineers change existing situations?
→ By creating or improving artifacts…

Value is a measure of preference
– The most preferred outcome is assigned the largest value
→ Aim to maximize value

SE&D is a purposeful search for value
Models Add Value in SE&D
Models Enable Efficient Search for Valuable Artifacts

If you fail to plan, you are planning to fail!

Benjamin Franklin

Potential Value Opportunity

Models for Planning & Prediction

Valuable Artifact

https://lotusproactive.wordpress.com/2013/01/15/determining-the-crashworthiness-of-a-lightweight-vehicle/

http://cuicardeeporange.com/project/do4/
SE&D as Learning
Strategy: Incremental Refinement & Uncertainty Reduction

Vision → Learn → Reality

Plan → Act

Reflect → Observe

Potential Value Opportunity

Models for Planning & Prediction

Valuable Artifact

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SE&D in an Organizational Context
Strategy: Divide & Conquer through Decomposition & Delegation

- No individual has all the knowledge about the system… instead, many individuals have deep knowledge about different, specialized aspects of the system
  - How do we integrate all the knowledge such that we develop successful, valuable systems?

→ distributed cognition, decomposition, delegation
Summary: Framing SE&D

Efficient Learning in an Organizational Context

Vision

Plan
Act

Learn

Reality

Engineering Organization

Potential Value Opportunity

Models for Planning & Prediction

Valuable Artifact

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Presentation Outline

- Context: Framing SE&D

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What is a Model?

- Definition by F. Cellier based on M. Minsky:
  
  A model (M) for a system (S) and an experiment (E) is anything to which E can be applied in order to answer questions about S

- In an SE&D context:
  
  Models are artifacts — expressions of human thought...about the artifacts being engineered, most commonly in a (formal) modeling language
Why Do Engineers Model?
Formally expressing and representing thoughts help with…

- Communication
- Memorization
- Ideation
- Inference or reasoning
- Decision making

- Understanding, explaining & theorizing
- Learning

- Simulation
- Prediction
- Logical inference
- Formal verification

Object → Model Creator → Model of Object → Model Interpreter → Object*
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Models expand the cognitive abilities of engineers

Models used by Teams = Distributed Cognitive Environment

Object

Model Creator

Model of Object

Model Interpreter

Object*
Modeling as a Transformation Process

Incrementally and collaboratively refining a plan

- Additional Viewpoint
- Model of Domain Knowledge
- Inferred Information

$i^{th}$ Model of Object

Transform Model
- Inference or Reasoning
- Abstraction, Elaboration
- Augmentation, Integration

$(i+1)^{st}$ Model of Object

Enabling More Efficient Search for Value
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What Kinds of Models Do Engineers Use?

Descriptive Models — Describe What Is

- **Examples**
  - Describe what is measured or observed
  - Describe what is preferred

- **Purpose of descriptive models**
  - To “change existing situations into preferred ones,” it is important to be able to describe the situation as-is
  - To enable communication among stakeholders
  - To provide context for reasoning about to-be states

- **Nature**
  - Reflects what is observed
  - Requires a conceptualization, ontology — language & vocabulary
  - Propositions — could be true or false
What Kinds of Models Do Engineers Use?
Prescriptive Models — Prescribe What Shall Be

- **Examples**
  - Requirement models
  - Functional models
  - CAD models — prescribe geometry
  - Behavior specification models

- **Purpose of prescriptive models**
  - Specification of a plan for how to move from the current situation to a different/improved situation

- **Nature**
  - Reflects what is imagined — not observed
  - Reflects a choice — not a true/false proposition
  - Constrains, directs, and guides future SE&D actions
What Kinds of Models Do Engineers Use?

Predictive Models — Predict What Will Be

- **Example**
  - Predict the cost or performance of an artifact
  - Predict how the state of a system will evolve over time

- **Purpose of predictive models**
  - To reason consistently about the consequences of a prescribed plan executed in a described context
  - Is indispensable for efficient search

- **Nature**
  - Reflects a belief
  - Is inherently uncertain — we are not clairvoyant
  - But should be coherent — internally consistent, but also externally consistent with scientific knowledge
  - Engineers rely on the generality of scientific knowledge to predict future situations in new contexts
  - But engineers don’t necessarily care about making (the most) accurate predictions — good enough to make a good choice
What Kinds of Models Do Engineers Use?
Models of Heuristics — Suggest How to Get There

- **Example**
  - When designing an outer-planets spacecraft, rely on nuclear energy rather than solar
  - When designing a consumer-product, first aim to understand the value proposition to the user — empathize

- **Purpose**
  - To provide guidance — based on previous experience, it suggests how to act in particular context

- **Nature**
  - Reflects learning — engineering knowledge
  - When engineers search, they capture knowledge about the search space and about how to search efficiently
  - Often suggests how to use scientific models to achieve engineering goals
  - Could become prescriptive — e.g., a handbook of best practices
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Which Models **Should** Engineers Use?

The Models that Add the Most Valuable

- Goal of engineering is to add value — to arrive at more preferred situations efficiently
  \[\rightarrow\] A good engineering model supports the addition of value efficiently

- Do we care whether it is “right” or “valid”?  
- In the end, I care whether it “works,” i.e., “adds value”

- Difficult to know in advance which models add most value \(\rightarrow\) rely on heuristic
Summary

- It is human nature to aim to improve one’s situation
- Since the resources needed to improve a situation are valuable themselves, engineers aim to arrive at improved situations efficiently
- Models add value by allowing engineers to expand their cognitive abilities (as a team), and hence to search for improved situation more systematically and efficiently
- Models serve different purposes in search for value
  - Descriptive models — describe existing situations
  - Prescriptive models — specify plans for future situations
  - Predictive models — predict the consequences of the plans
  - Models of heuristics — capture what we have learned