SEAri Short Course Series

Course: PI.27s Value-driven Tradespace Exploration for System Design

Lecture: Lecture 1: Why Use Tradespace Exploration?

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[PI.27s] Value-Driven Tradespace Exploration for System Design

Lecture 1
Why Use Tradespace Exploration?

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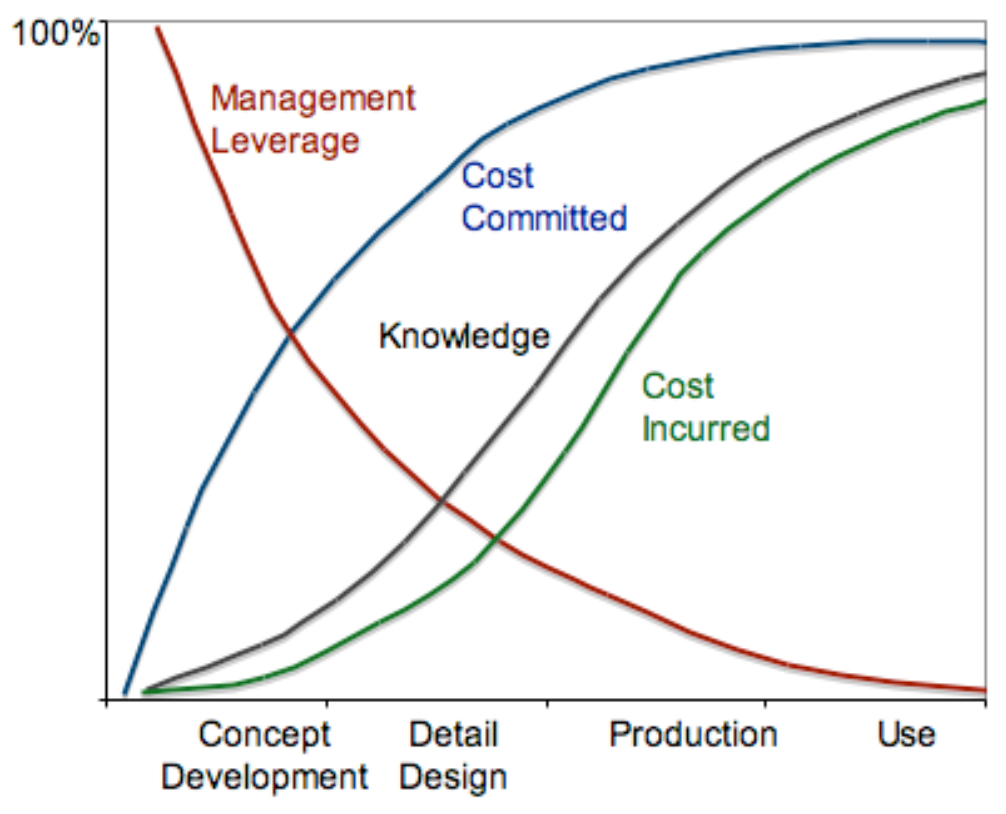
The Design Knowledge Gap

Value is primarily determined at the beginning of a program



Adapted from Fabrycky and Blanchard 1991

How can we make good decisions?

Three Keys to Good Upfront Decisions

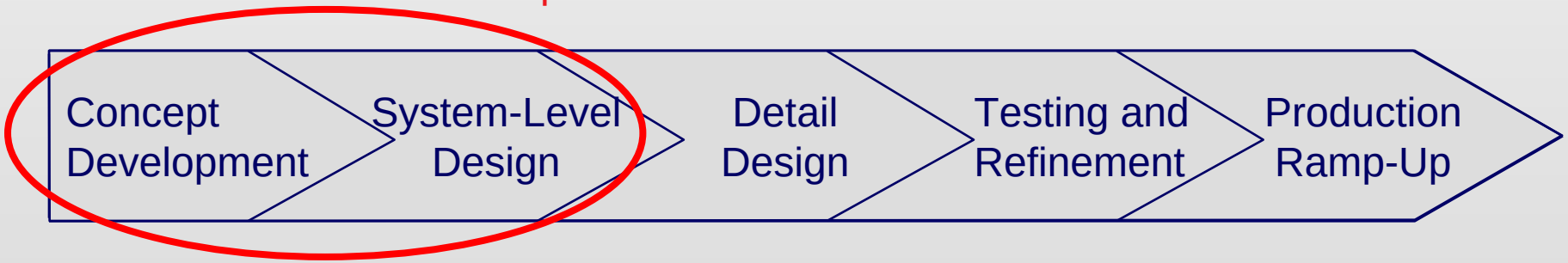
- Structured program selection process
  - Choosing the programs that are right for the organization's stakeholders
- Systems Engineering*
  - Determining stakeholder needs and translating them into functional requirements

    * In some industries, systems engineering activities are performed but may be called product development, system design, product design, or other
- Conceptual design practices
  - Finding the right form to maximize stakeholder value over the product (or product family) lifetime

MATE: A Tradespace Exploration Method for Early Lifecycle

- Multi-Attribute Tradespace Exploration (MATE)
  - Method for understanding complex solutions to complex problems
  - May be used in conjunction with other methods such as Integrated Concurrent Engineering (a rapid conceptual/preliminary design method) and MonteCarlo Simulation
- Goals is to have better informed upfront decisions and planning

Most relevant to processes in these phases

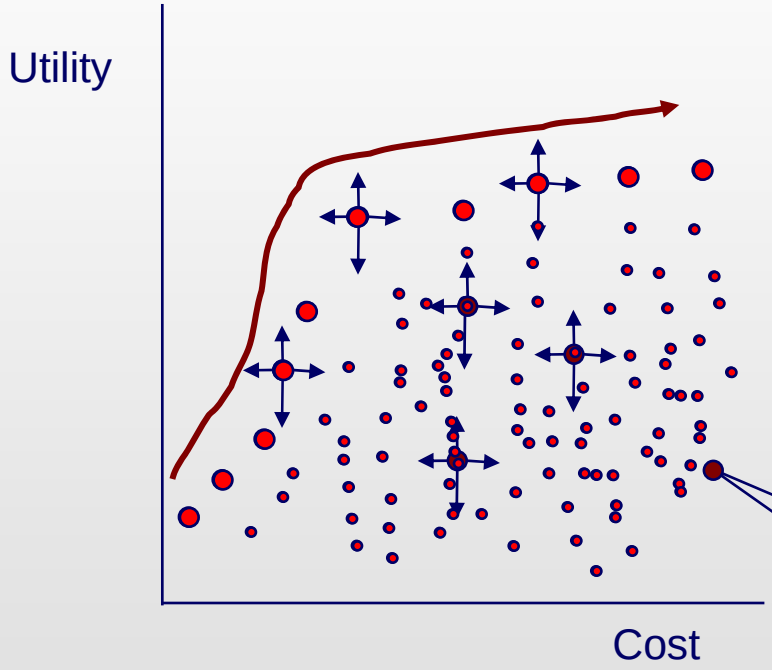


Phases of System/Product Development From Ulrich & Eppinger, *Product Design and Development*, 1995

What is a Tradespace?

An area of evaluation or interest bounded by a prescribed set of boundary constraints that serve to scope the set of candidate alternatives, options, or choices for further trade study investigation and analysis (Wasson, 2006)

Tradespace Exploration Paradigm: Avoiding Point Designs



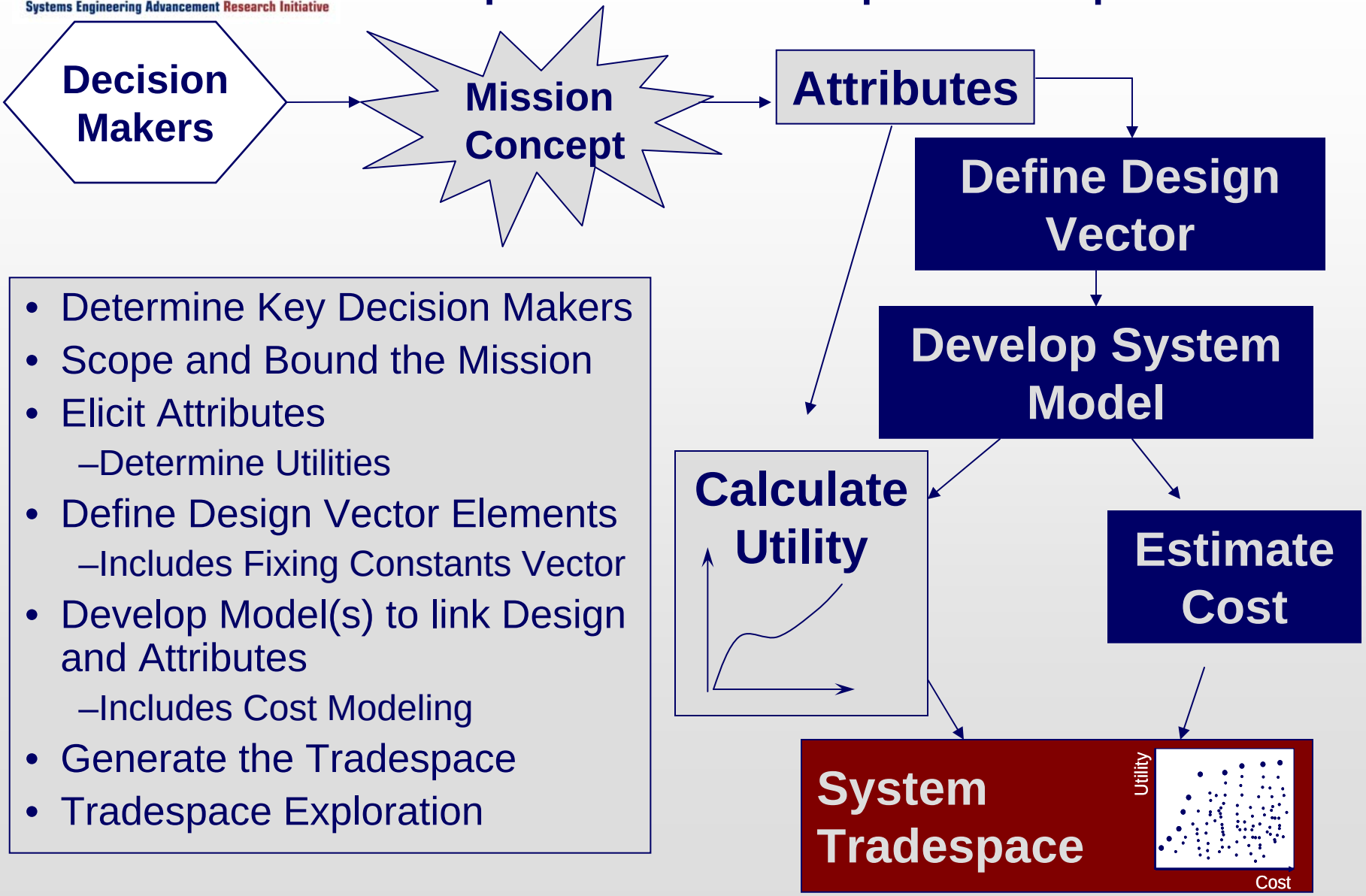
Differing types of "trades"

0. Choose a solution
1. Local point solution trades
2. Multiple points with trades
3. Frontier solution set
4. Full tradespace exploration

$Design_i = \{X_1, X_2, X_3, \ldots, X_j\}$

Tradespace exploration enables big picture understanding

Steps for Tradespace Exploration



- Determine Key Decision Makers
- Scope and Bound the Mission
- Elicit Attributes
  - –Determine Utilities
- Define Design Vector Elements
  - –Includes Fixing Constants Vector
- Develop Model(s) to link Design and Attributes
  - –Includes Cost Modeling
- Generate the Tradespace
- Tradespace Exploration

Tradespace Exploration

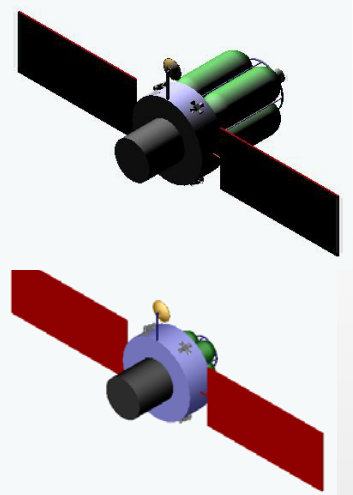
A process for understanding complex solutions to complex problems

- Model-based high-level assessment of system capability
- Ideally, *many* designs assessed
- Avoids optimized *point solutions* that will not support evolution in environment or user needs
- Provides a basis to explore technical and policy *uncertainties*
- Provides a way to assess value of *potential* capabilities

Allows informed “upfront” decisions and planning

Baseline Study: Space Tug

- Existing MATE study* of space tug tradespace
  - Three attributes
    - Delta-V
    - Capability
    - Response time
  - Three design variables

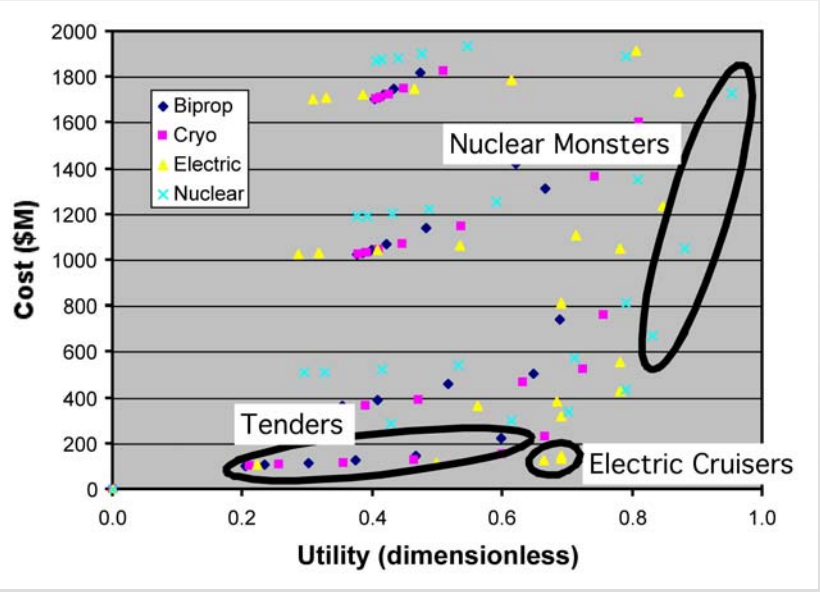


Design Space

>Manipulator Mass
- Low (300kg)
- Medium (1000kg)
- High (3000 kg)
- Extreme (5000 kg)

>Propulsion Type
- Storable bi-prop
- Cryogenic bi-prop
- Electric (NSTAR)
- Nuclear Thermal

>Fuel Load - 8 levels

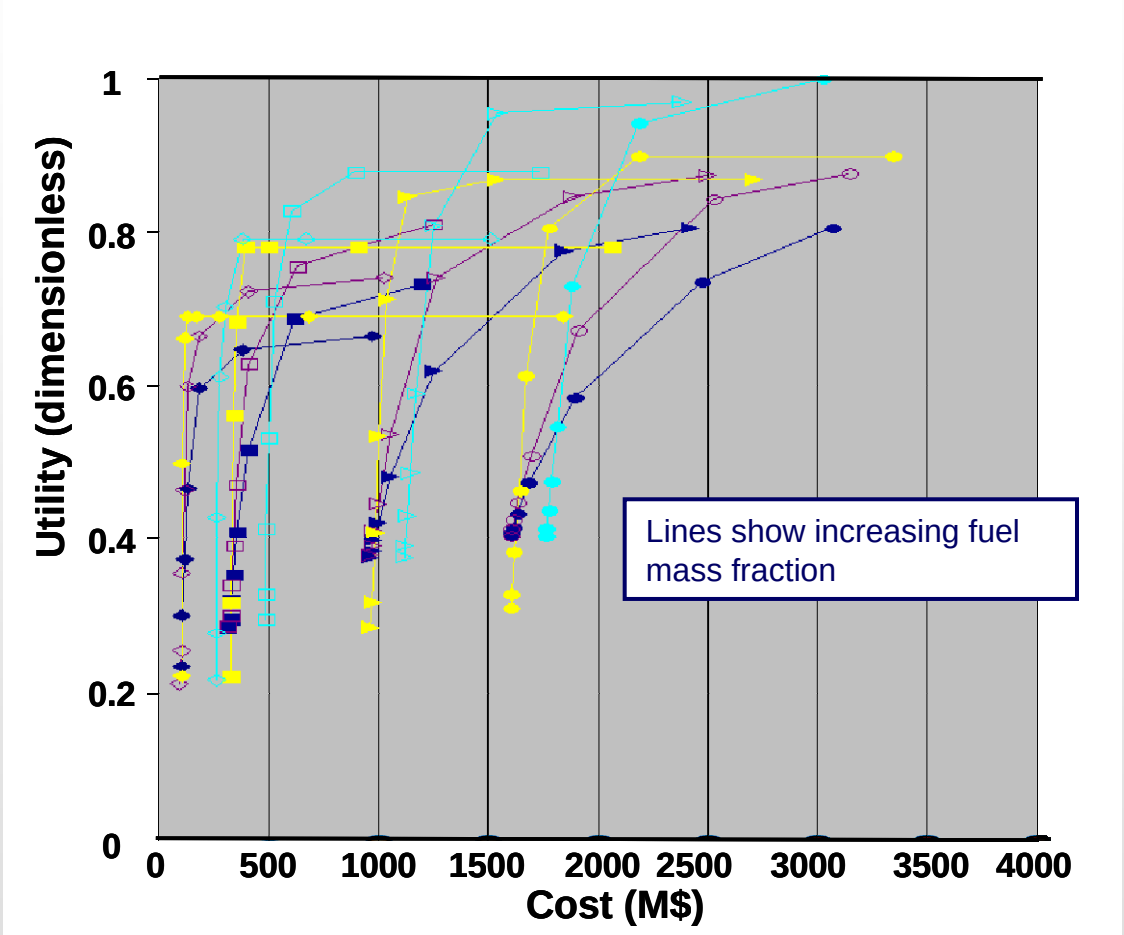


Simple performance model
- Delta-V calculated from rocket equation
- Binary response time (electric propulsion slow)
- Capability solely dependent on manipulator mass
- Cost calculated from vehicle wet and dry mass

* McManus, H., and Schuman, T., "Understanding the Orbital Transfer Vehicle Tradespace," AIAA-2003-6370, Sept. 2003..

Typical Benefits:

Understanding Limiting Physical or Mission constraints

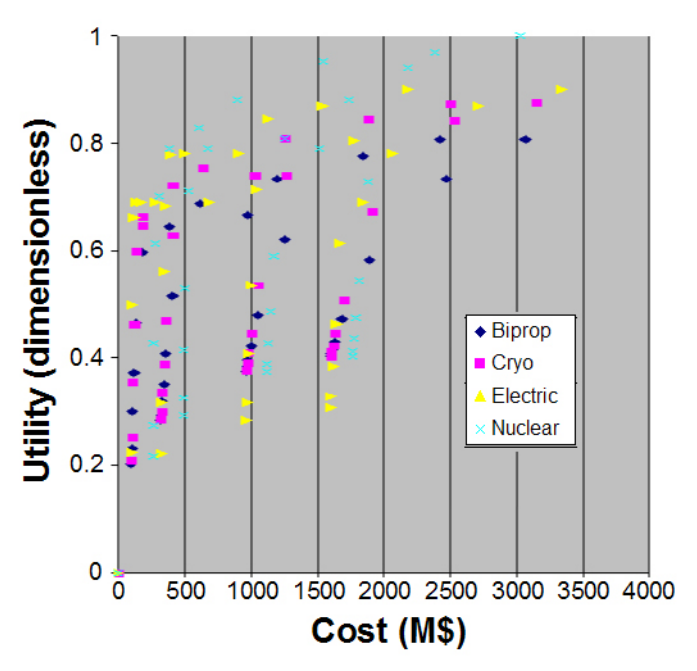


SPACETUG

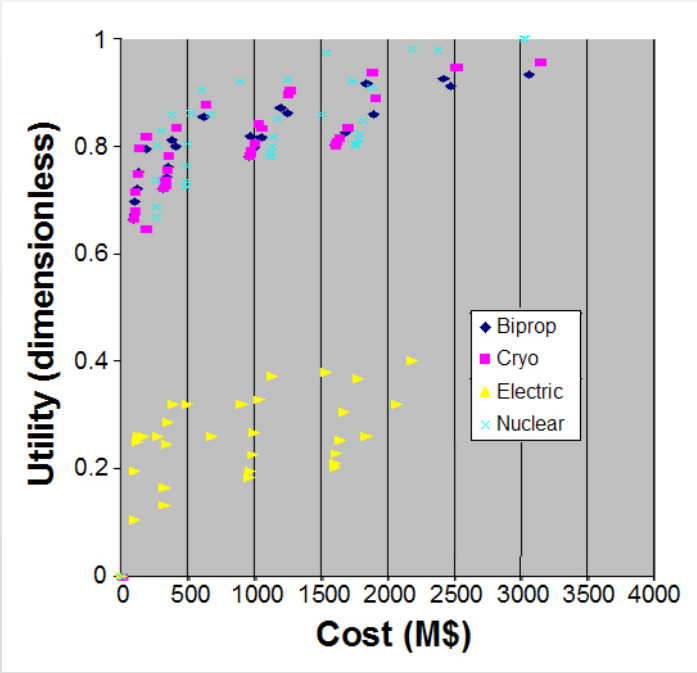
- General purpose orbit transfer vehicles
- Different propulsion systems and grappling/ observation capabilities
- Lines show increasing fuel mass fraction

Hits "wall" of either physics (can't change!) or utility (can)

Typical Benefits:
Assessing Changing Requirements

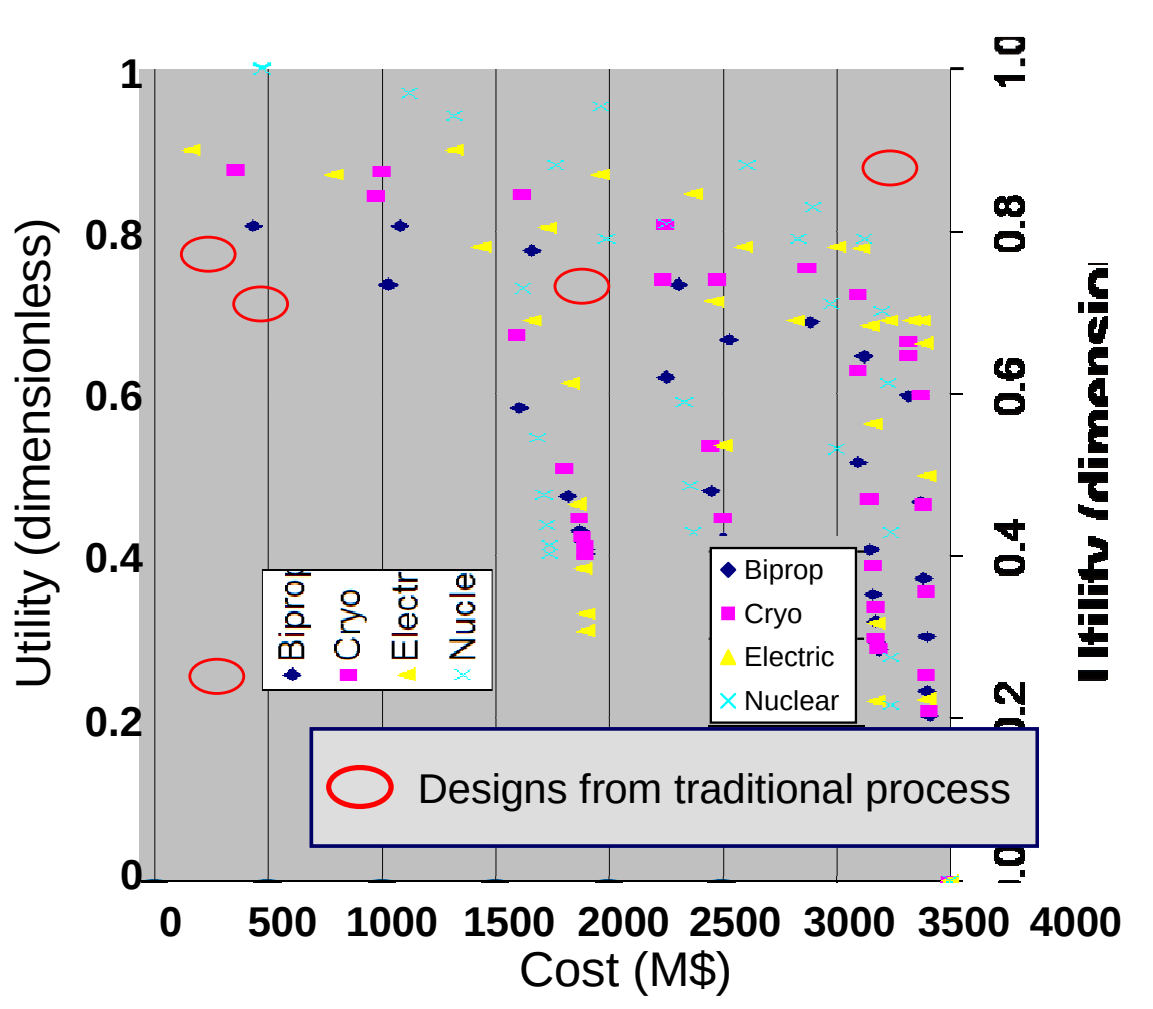


User needs change, so Utilities recalculated



Space Tug example:
added requirement for rapid response drastically lowers utility of electric propulsion designs

Typical Benefits: Comparing Point Designs

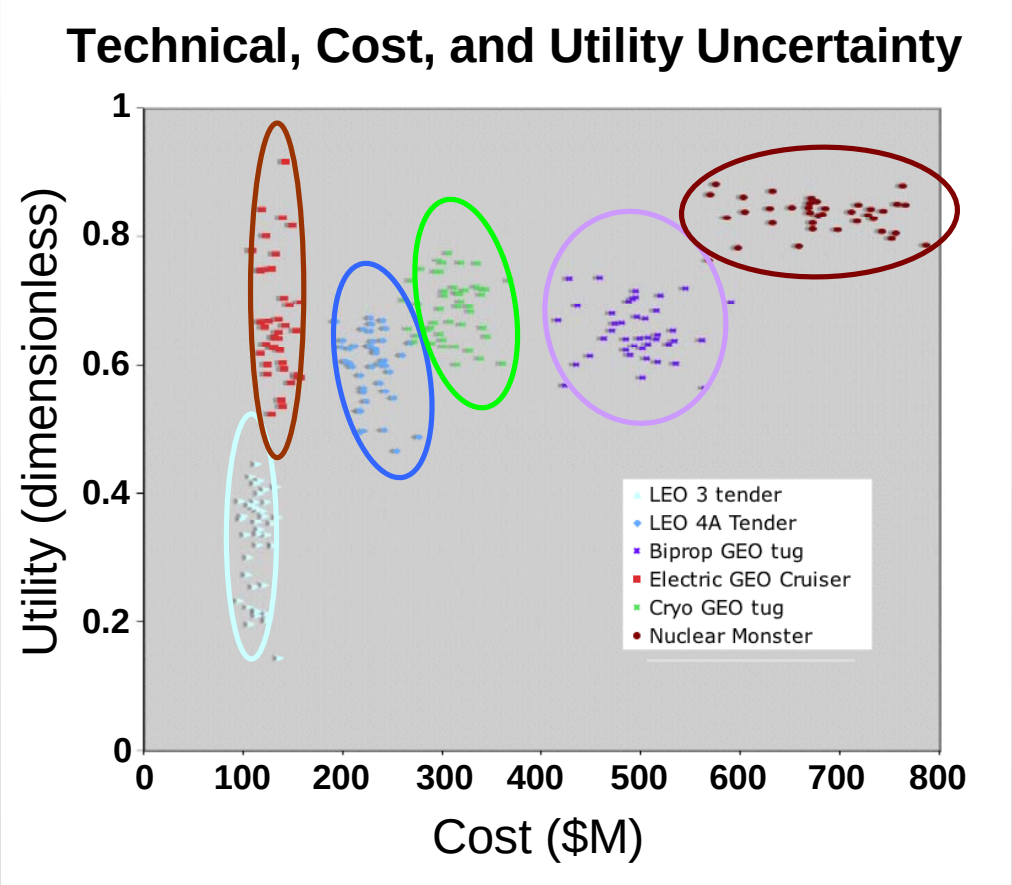


Tradespace helps compare "apples and oranges" concepts

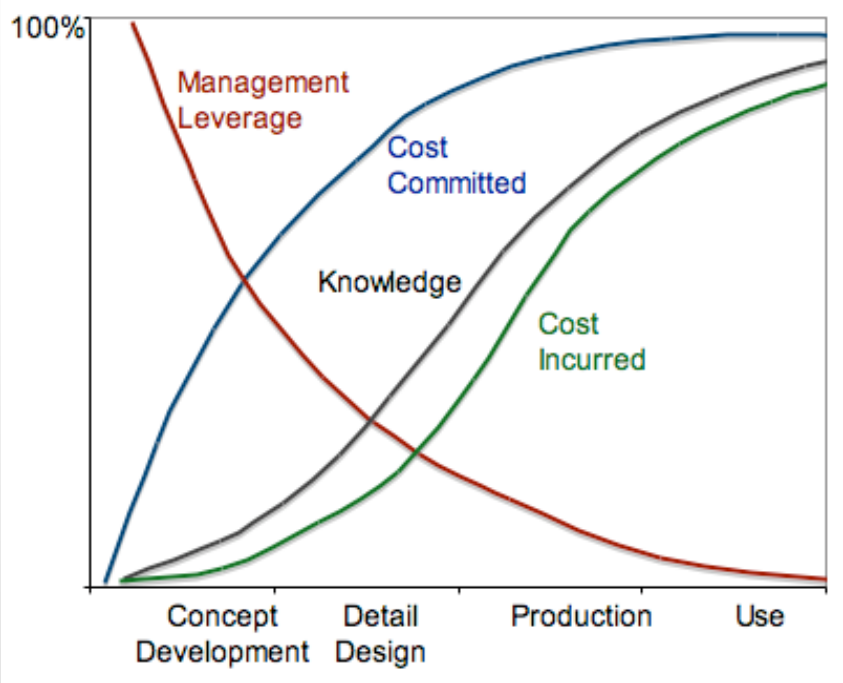
Provides a context for understanding alternatives

Typical Benefits: Understanding Uncertainties

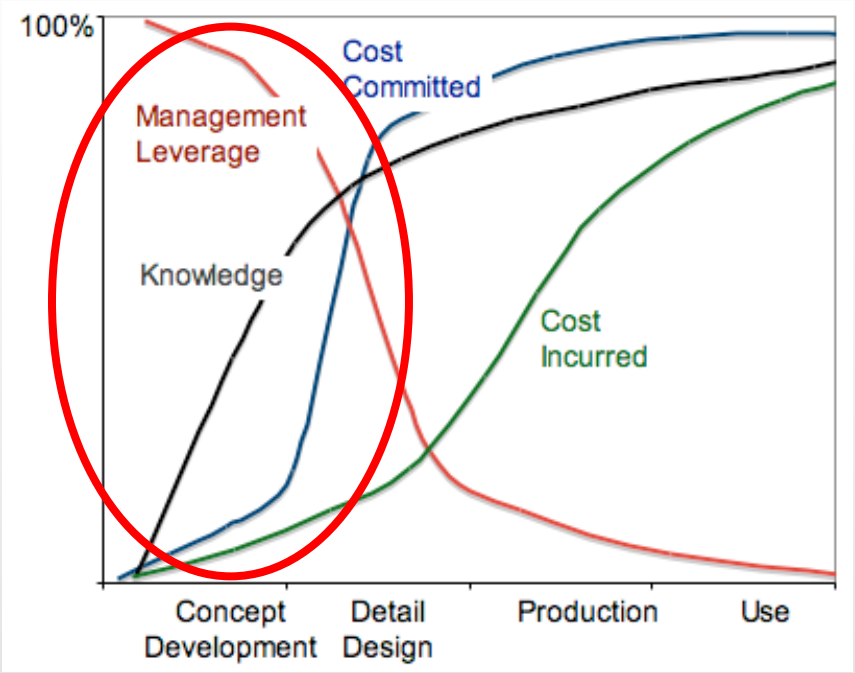
- Often learn a lot by simple examination
- Better: *Explicitly* look at sensitivity of models to uncertainties
  - Clouds are possible locations of a *single* design
- Uncertainties can be market, policy, or technical
- Mitigate with portfolio, real options methods



Changing the Picture



Classic decision impacts



New paradigm decision impacts

Increased knowledge (including understanding of uncertainties) allows better decisions