Managing Unarticulated Value: Changeability in Multi-Attribute Tradespace Exploration (MATE)

Presented By
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INCOSE CSER
April 08, 2006

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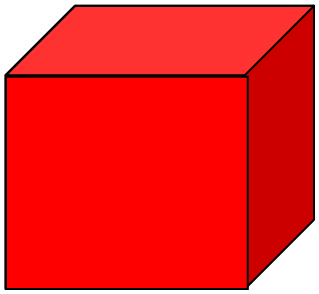
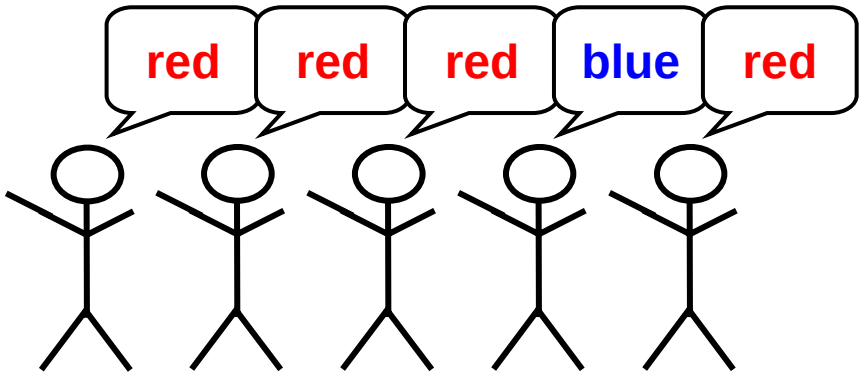
Creating Value





Attributes

What color should the box be?

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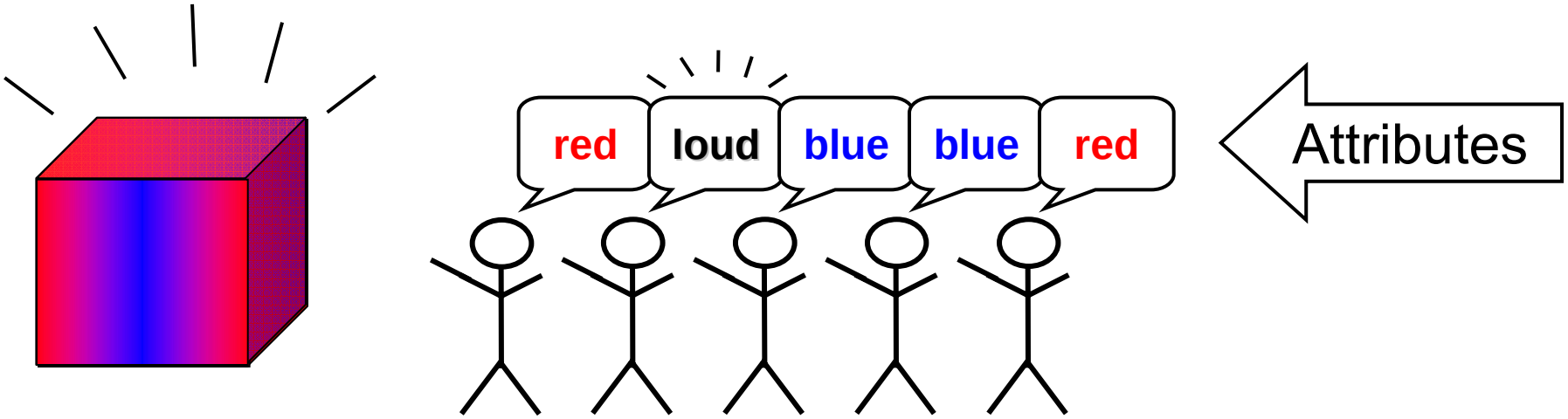
Creating Value



Should box be red or blue?

Value-perception changes over time…

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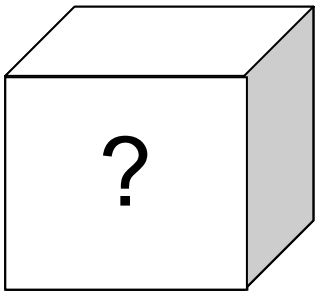
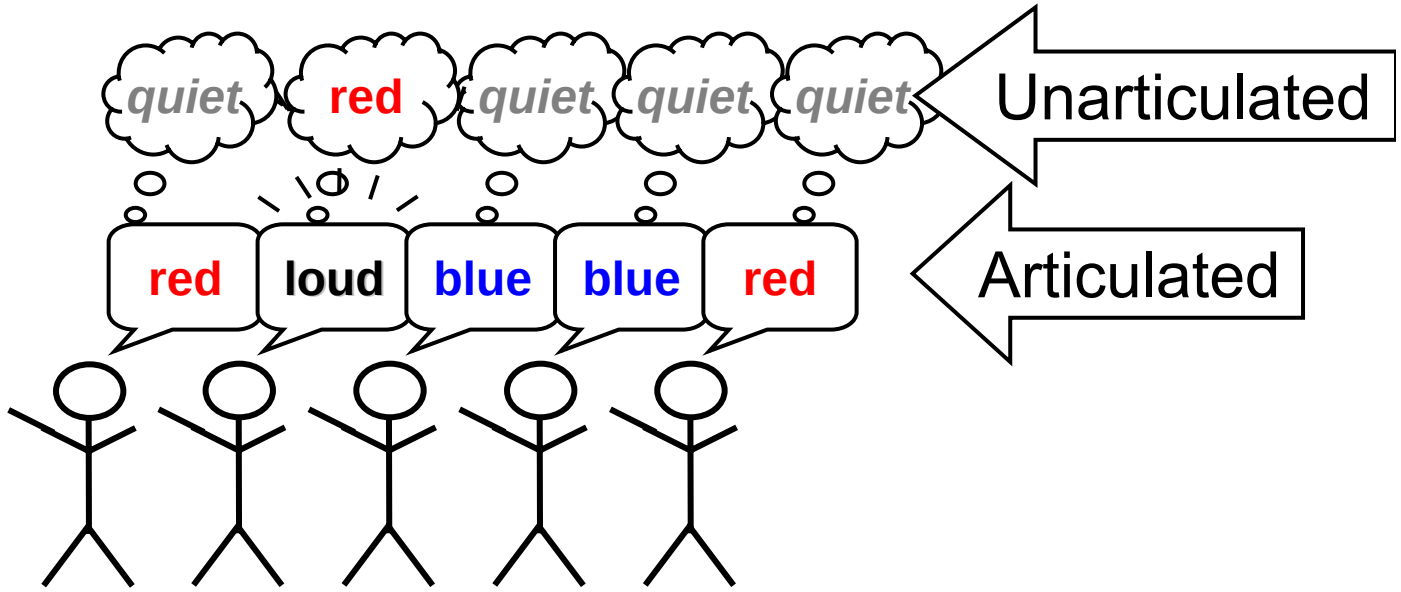
Realizing Unexpressed Needs





Now, what? Should box be red or blue, and **loud** or *quiet*?

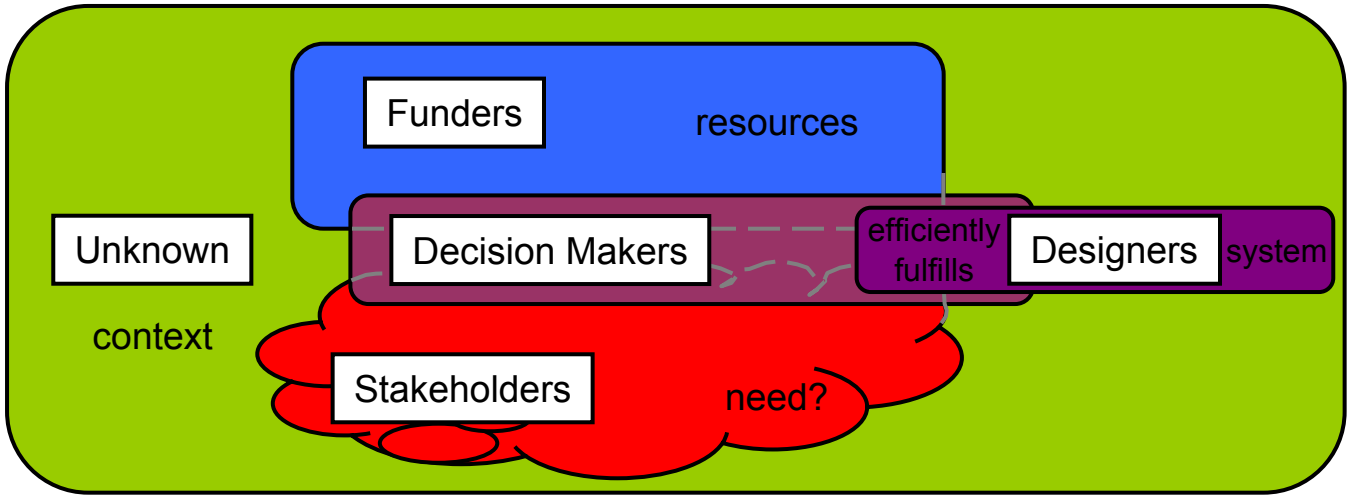
Value-perception changes over time…
And may not be fully "articulated"

Revisiting the Goal of Design

Create a system that fulfills some *need* while efficiently utilizing resources within some context

Question

How can system designers cope with poorly defined *need?*



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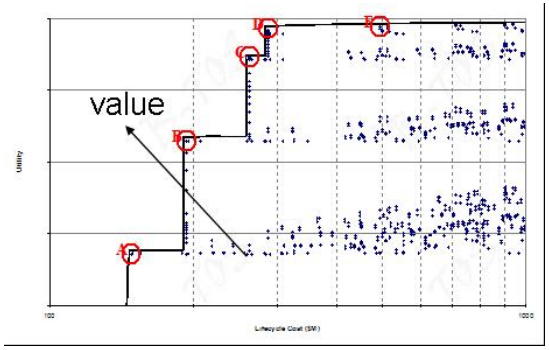
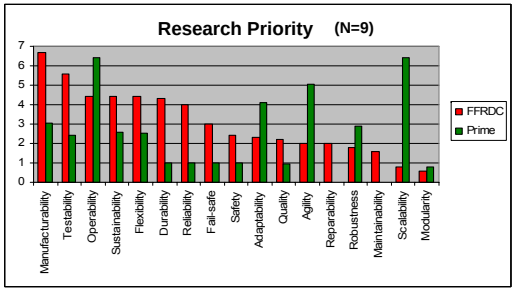
Motivation

- **Prior Work (MATE)**
  - Revisiting SM assumptions
  - Follow-on theses (~6 applied MATE SM)
- **ESD Symposium**
  - Defining system properties: what are the “ilities”?
- **LAI/AF Workshop**
  - AF directive for “Systems Engineering for Robustness”
  - Focus on Flexibility, Adaptability, Scalability, Sustainability, Robustness, Upgradability
- **Industry study**
  - Ility survey and interview
  - Focus on Flexibility, Adaptability, Scalability, Agility
  - In general do not effectively explore tradespaces, account for ilities





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Research Questions

- **Principal research questions:**

1. **What are the relationships between *flexibility*, *adaptability*, *robustness*, and *scalability* for *space systems* and how do they relate to *unarticulated value*?**
2. **How can these *ilities* be *quantified* and/or used as *decision metrics* when exploring *tradespaces* during Conceptual Design?**

- **Questions guide exploratory research design**
  - **Inheritance, Theory, Experiments, Case Applications(4)**

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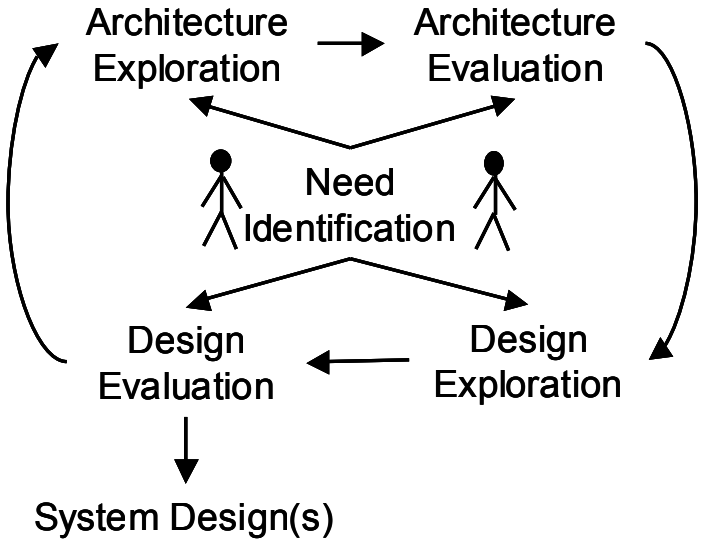
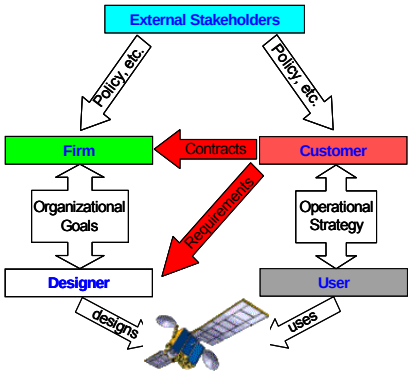
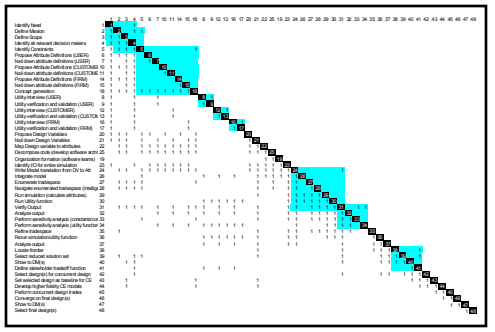
Static Value-centric Design: MATE





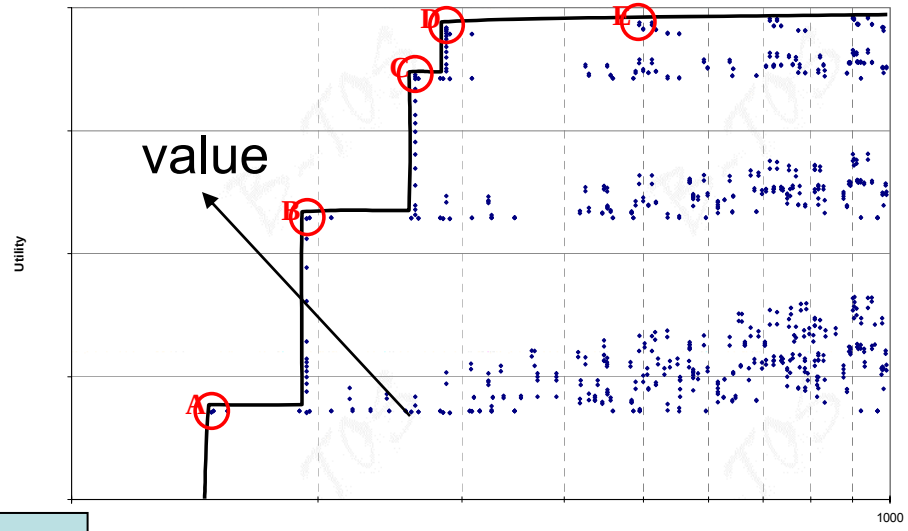


Decision Makers

Formal Framework

MATE-CON is…

- A Decision Maker preference-directed tradespace exploration process
- Robust to changes and concepts
- A formalized framework
- A flexible philosophy



Tradespace Solution Spaces

Dual-SM
Aero/Astro, TPP 2003

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Articulated Value: Attributes as Decision Metrics

- A decision maker-perceived metric that measures how well a *decision maker-defined* objective is met
- Set of attributes must be*:
  - Complete
  - Operational
  - Decomposable
  - Non-redundant
  - Minimal
  - Perceived Independent**
- "Rule of 7": Human mind limited to roughly 7 (7 ± 2) simultaneous concepts***
- In the limit ranges converge to a point, the attributes become requirements

Attribute Characteristics
• Definition
• Units
• Range (least-most acceptable)

*Keeney, R.L. & Raiffa, H. *Decisions with Multiple Objectives--Preferences and Value Tradeoffs*. 2nd ed. Cambridge: Cambridge University Press, 1993.
**Not strictly necessary, but reduces interview time and complexity.
***Miller, G. A. "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information." *The Psychological Review* 63 (1956): 81-97.

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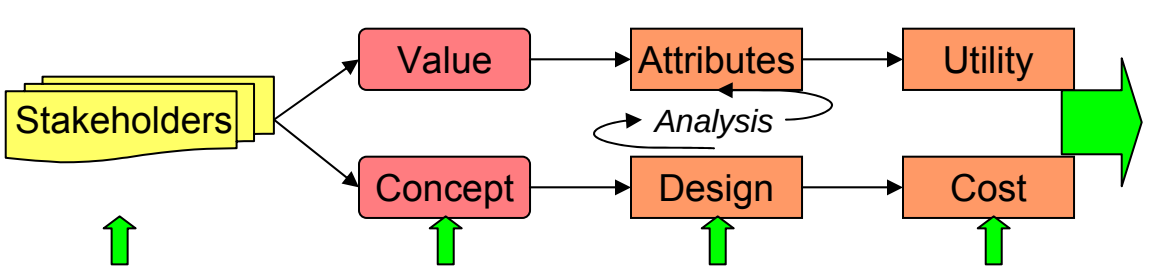
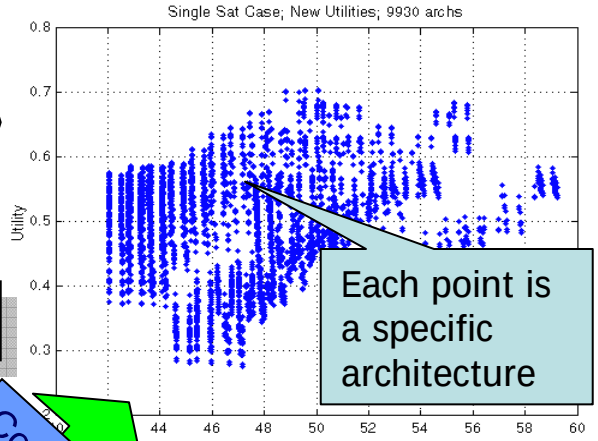
What is an Architecture Tradespace?

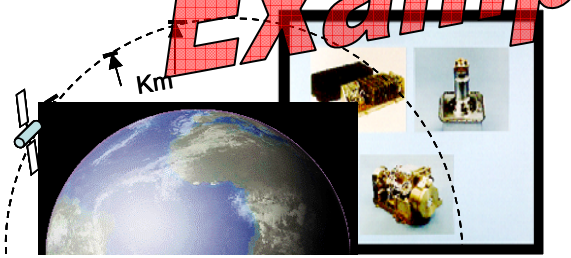


Tradespace: {Design,Attributes} ←→ {Cost,Utility}



X-TOS
Small low-altitude science mission

Example



DESIGN VARIABLES:
Architectural trade parameters

Orbital Parameters
- Apogee Altitude (km)
- Perigee Altitude (km)
- Orbit Inclination (deg)

Spacecraft Parameters
- Antenna Gain
- Communication Architecture
- Propulsion Type
- Power Type
- Total Delta V

ATTRIBUTES:
Architectural decision metrics
- Data Lifespan (yrs)
- Equatorial Time (hrs/day)
- Latency (hrs)
- Latitude Diversity (deg)
- Sample Altitude (km)

Assessment of cost and utility of large space of possible system architectures

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Tradespace Exploration: Avoiding Point Designs

Differing types of trades

1. Local point solution trades
2. Frontier subset solutions
3. Frontier solution set
4. Full tradespace exploration

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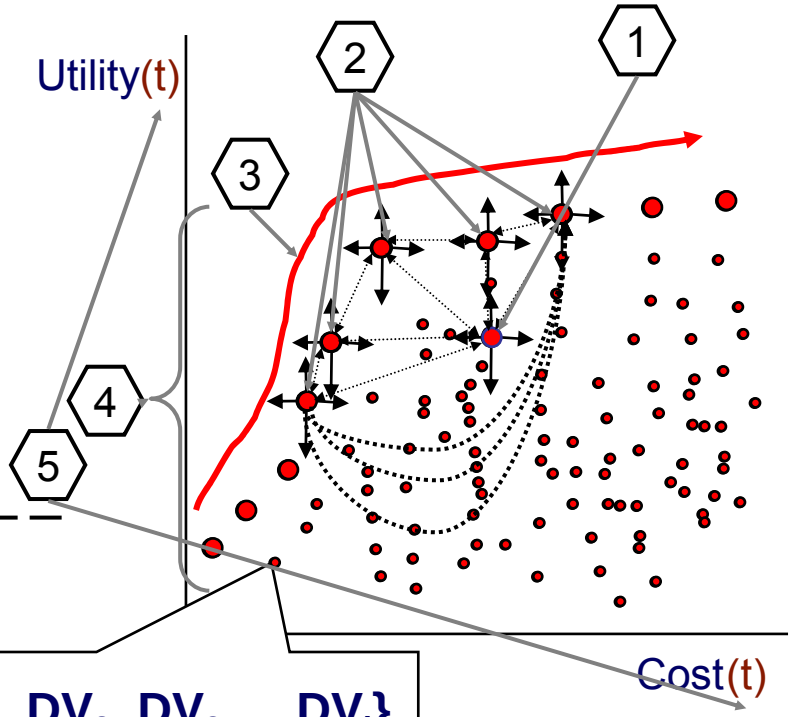
5. Dynamic tradespace relations



$Design_i = \{DV_1, DV_2, DV_3, \ldots, DV_j\}$

Tradespace exploration enables big picture understanding

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Tradespace Exploration Paradigm

- **Tradespace exploration is approach enabling…**
  - **Consideration of diverse and dynamic value functions**
  - **Comparison of a diverse and broad sets of concepts**
  - **Characterization and mitigation of various uncertainties**
  - **Quantification of system properties (e.g., flexibility, robustness)**
- **Applications have included: policy sensitivity analysis, spiral development, cross-proposal evaluation**
- **On-going research seeks to standardize TSE, including theory, method and applications**
- **Dynamic tradespaces to follow…**

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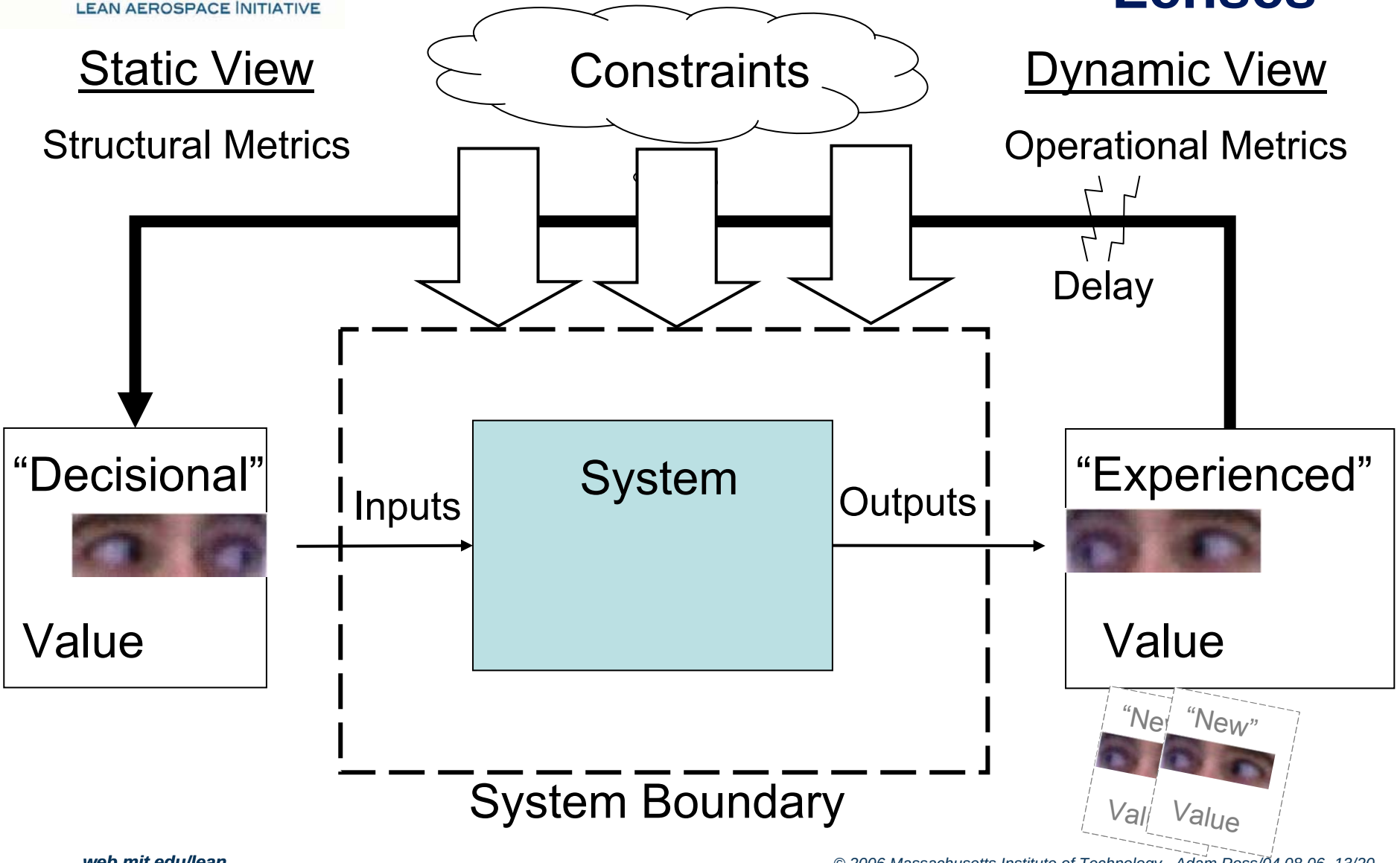
Dynamic System Context: Value Lenses



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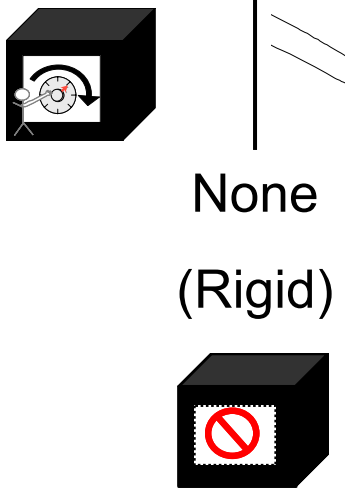
Change Taxonomy

Change is a dynamic event that alters the box from state one to state two

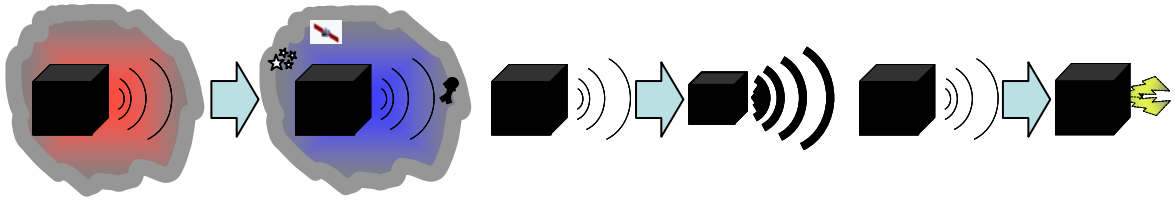
"Real" Box Change

- Internal (Adaptable)
- External (Flexible)
- None (Rigid)



"Perceived" Box Change

- None (Robust)
- Attribute level (Scalable)
- Attribute set (Modifiable)



ΔCost	Perceived Value Spectrum	
	Articulated	Unarticulated
0	Articulated Value	
0	Free Latent Value	
small	Cheap Latent Value	
small	Accessible Value	
large	Inaccessible Value	
∞		

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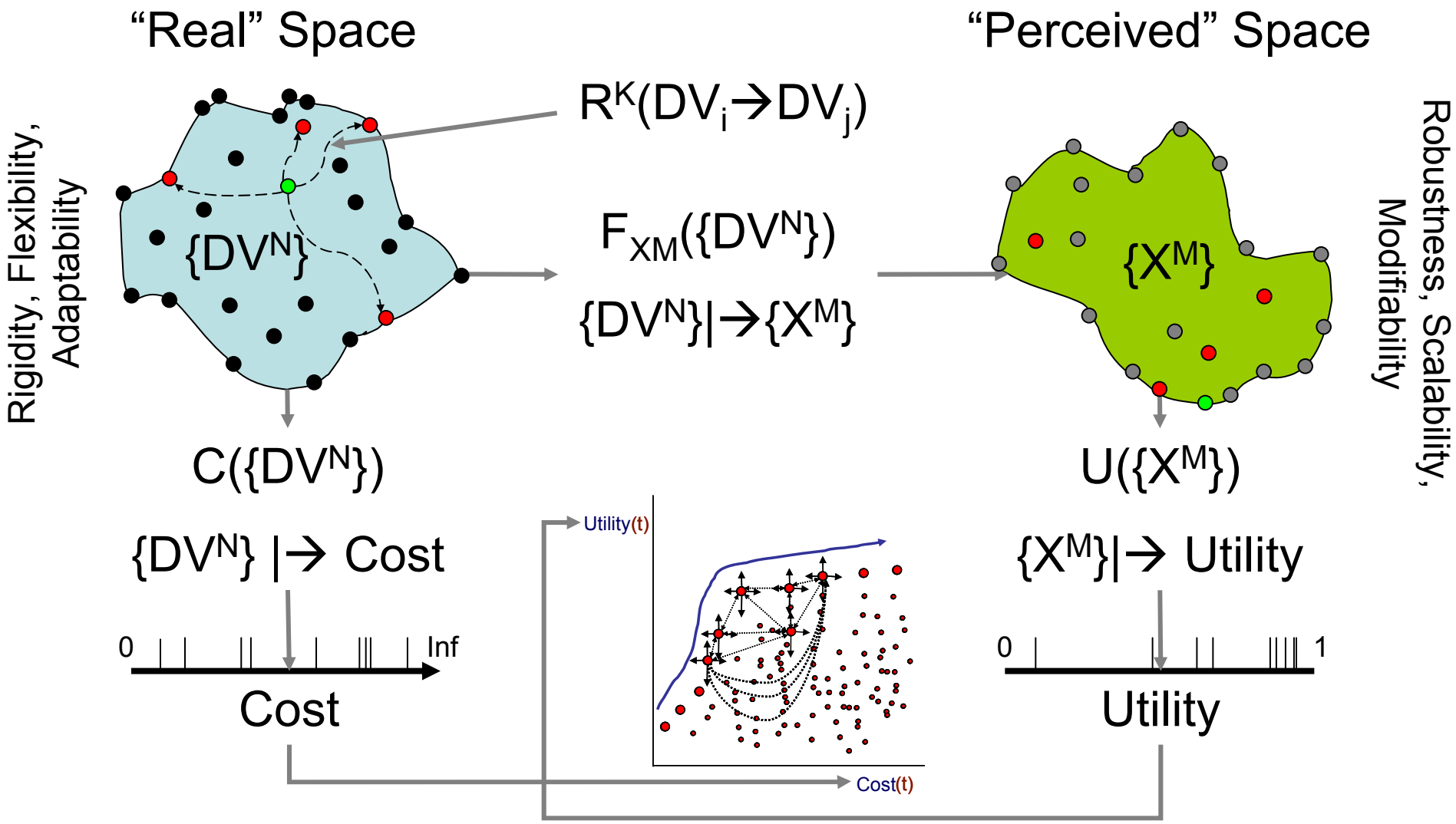
MATE Variable Mappings



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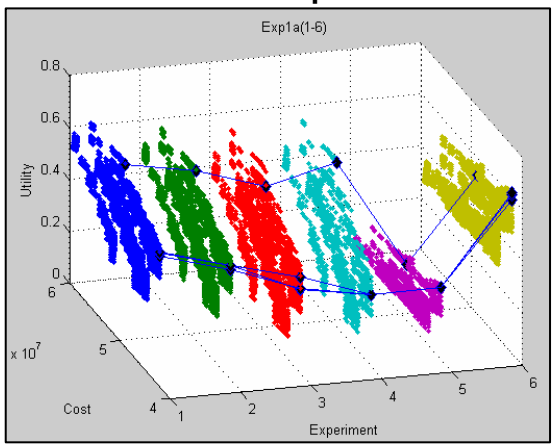
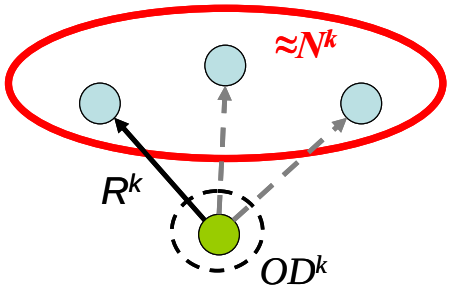
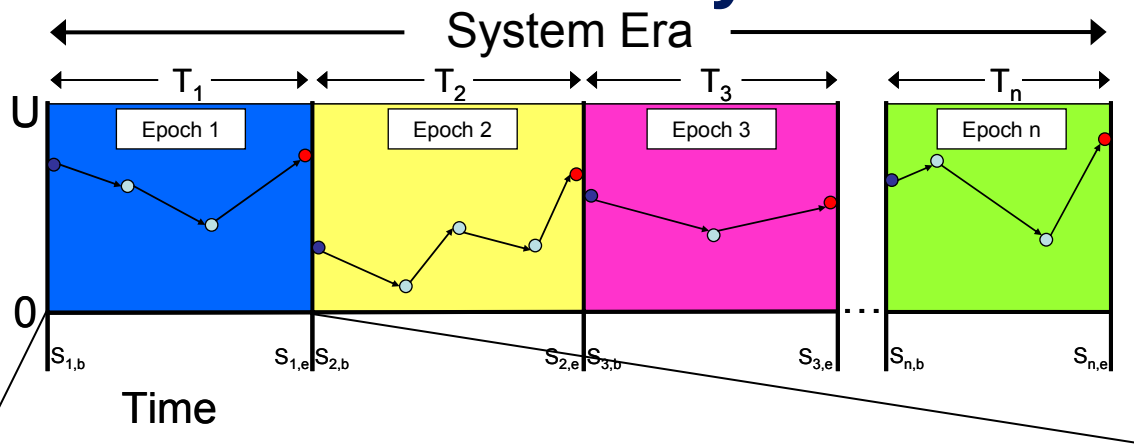
Changeability Network and the System Era

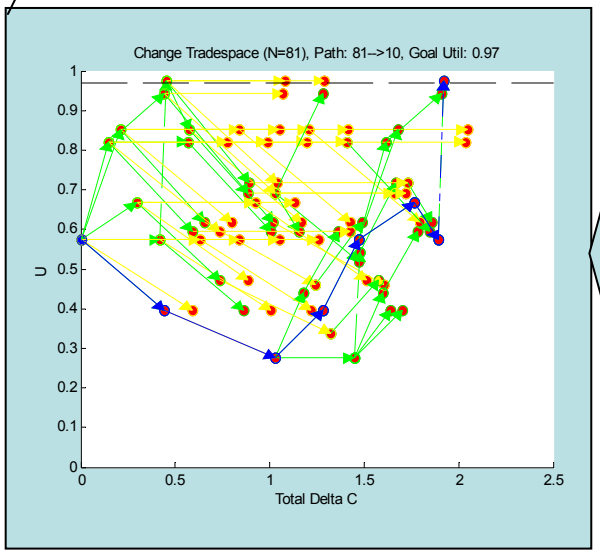
Value "Robustness" Across Epochs

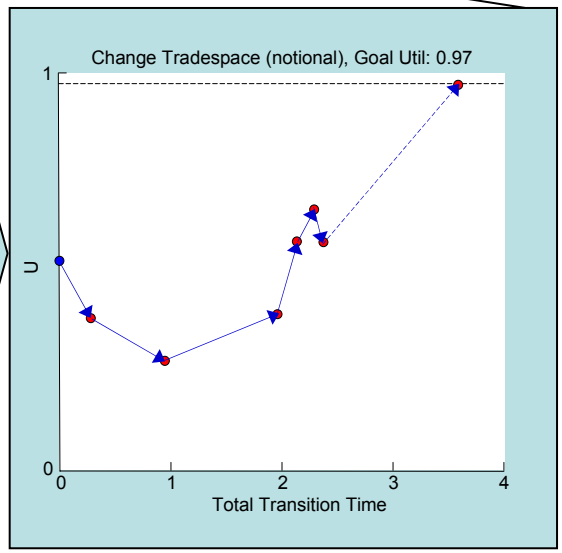


Filtered Outdegree (<C,t) as Quantifiable









Networked tradespace includes heterogeneous transition paths

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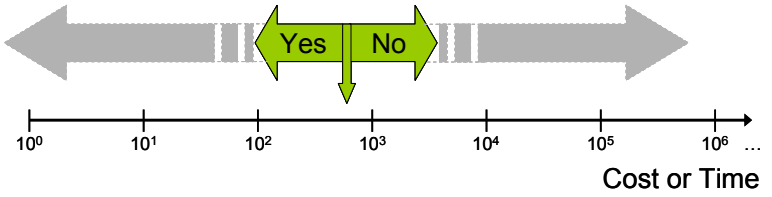
Putting it all Together: Changeability

1. Set the subjective scale
2. Choose the origin of change
3. Ask the perceived change question
   (specifying Era: e.g. during Epoch i, across Epochs i,j)
4. Perform dynamic tradespace analysis



Change instigator: External (Flexible), Internal (Adaptable), None (Rigid)

Desire change

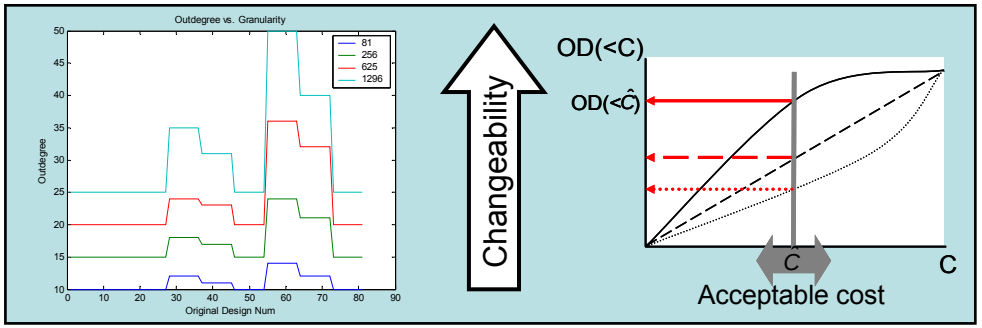
_____ in _____ for _____

"ility"	metric	resource
Scalable	X^i	Cost
Modifiable		Time

Desire no change

_____ in _____ to _____

"ility"	metric	perturb.
Robust	X^i	ΔDV
	Rank (Pareto Efficient)	ΔConstraints
	Cost/Time	ΔConst.
		ΔPreference set



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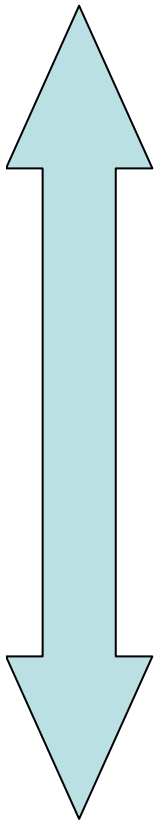
Analysis Method Summary

A Layered Approach



- Construct tradespace
  - Concept formulation (DV)
  - Preference elicitation (Att, Util)
  - Model/Simulations (DV→Att)
  - Preliminary Transition "Rules" (R)
- Determine family of change scenarios (Epochs)
  - Preference (from individual requirement changes to new DMs)
  - Context (policy, market)
  - Technology (new concepts, transitions)
  - New transition "Rules" (R)
- Construct system timeline to define ilities (Era)
  - DV-space: flexibility, adaptability, rigidity
  - Att-space: robustness, scalability, modifiability

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Research Questions Answered

Q1: What are the relationships between *flexibility*, *adaptability*, *robustness*, and *scalability* for aero*space systems* and how do they relate to *unarticulated value*?

A1: Ilities: Changeability of {DV}←→{Att}; Unarticulated value as classes of attributes

Q2: How can these *ilities* be *quantified* and/or used as *decision metrics* when exploring *tradespaces* during Conceptual Design?

A2: Filtered OD(<C,t) coupled with System Timeline tradespace path analysis

Questions guide exploratory research design

Inheritance, Theory, Experiments, Case Applications(4)

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Publications

Ross, Adam M., Nathan P. Diller, Daniel E. Hastings, and Joyce M. Warmkessel. "Multi-Attribute Tradespace Exploration in Space System Design." In *World Space Congress*, 1-14. Houston, TX: IAF, 2002.

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