Distinguishing Attributes for the Operationally Responsive Space Paradigm

Matthew G. Richards
Lauren Viscito
Adam M. Ross
Daniel E. Hastings

Massachusetts Institute of Technology

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Outline

- Introduction
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- Multi-Attribute Tradespace Exploration (MATE)
  - Overview
  - Mission Attributes
  - Responsive Attributes
  - ORS Modeling Architecture
- Conclusions
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Motivation

*ORS is "...**assured** space power focused on **timely** satisfaction of **Joint Force Commanders**' needs…while also maintaining the ability to address other users' needs for improving the responsiveness of space capabilities to meet national security requirements"*
(*The Plan for Operationally Responsive Space, DoD, 2007)*

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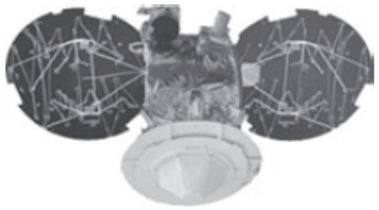	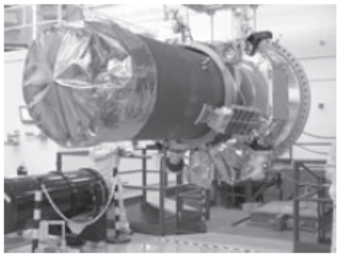		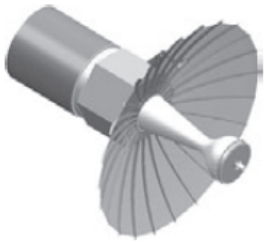

(GAO 2006)

- Goal: reduce time constants associated with space system acquisition, design, and operation *(DoD 2007)*
- Fundamental idea: trade off reliability and performance of "big space" for speed, responsiveness, and customization potentially offered by small tactical spacecraft (TACSATs)
- Problem: uncertain value proposition *(Tomme 2006; Fram 2007)*

"ORS deserves, yet has not received, our analytic due diligence."
(Mr. Gil Klinger, Former Director of Space Policy, U.S. National Security Council, 22 August 2007)

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Distinguishing ORS from "Big Space"

Characteristic	"Big Space"	ORS
Historical Context	Cold War	acquisitions crisis; fragilities inherent in integral, long-life designs
Original Beneficiary	National Command Authority	theater combatant commander
Programmatic Drivers	performance	cost, schedule
Innovation Dynamic	capability-pull	technology-push
Payloads	customized, satisfy multiple missions	off-the-shelf; single-mission focus
Design Life	10+ years	1+ year(s)
Risk Tolerance	risk averse	risk tolerant

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Paradigms: Values vs. Alternatives

	"Big Space"	ORS
Values	Big Space Values – Performance	ORS Values – Timeliness – Control Structure
Alternatives	Big Space Alternatives – Unique – Multi-payload missions	ORS Alternatives – Plug n Play – Fractionated Space – TACSat

Values: what we care about; Alternatives: what we do

Can trade alternatives only when values are understood

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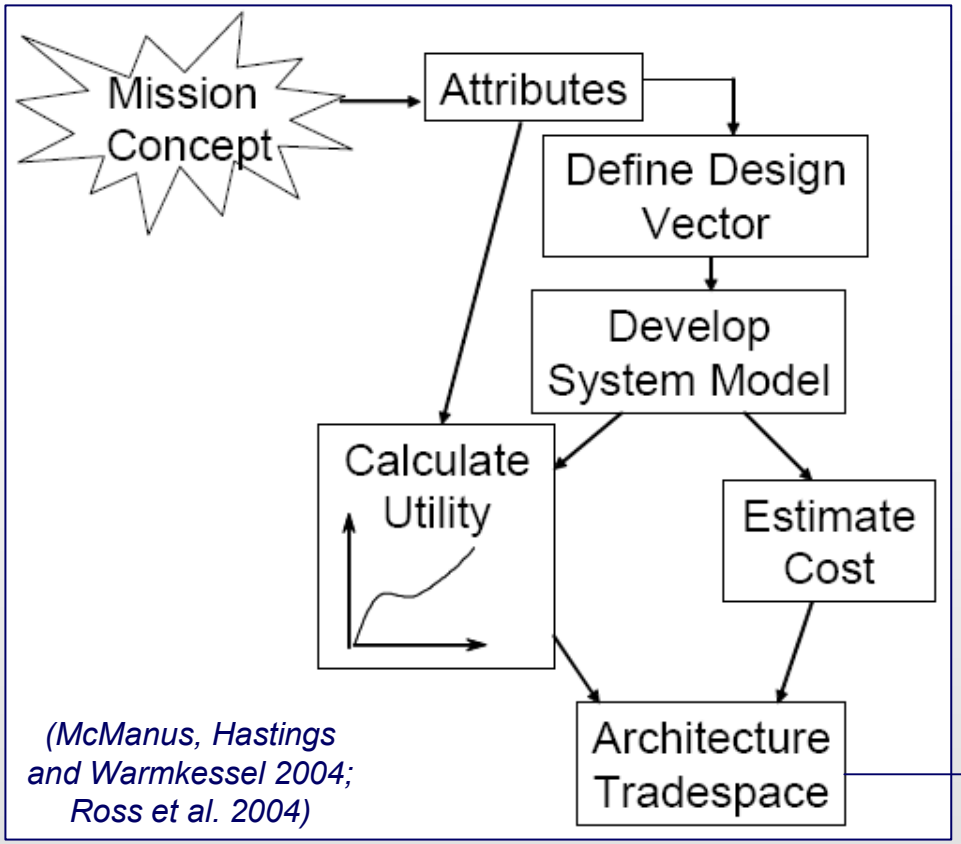
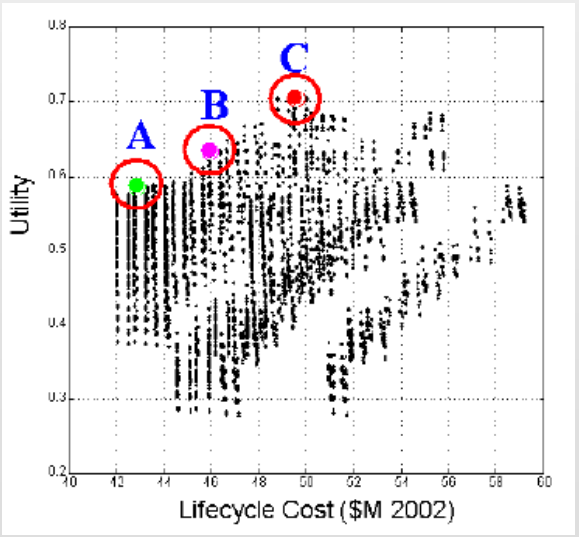
Multi-Attribute Tradespace Exploration



(McManus, Hastings and Warmkessel 2004; Ross et al. 2004)

1. Specify value proposition
   - Interview decision-maker(s)
   - Create a list of attributes
   - Elicit utility curves
2. Enumerate design vector
3. Develop system model
4. Evaluate candidate architectures in tradespace



Application of decision analysis and utility theory to model and simulation-based design

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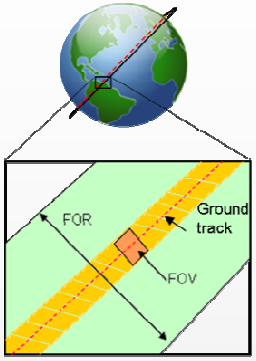
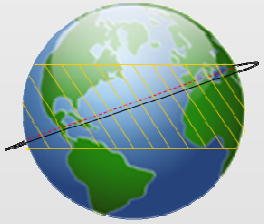
1. Specify Value Proposition: Attribute Interviews



Attribute	Units	Acceptable Range
Signal Coverage	km^2	1,000-10,000
Global Coverage	%	66-100
Resolution	m	0.1-1
Revisit Rate	Days	0.2-2
Sensitivity	Sensor type	Day-Night
Availability	%	95-99
Timeliness	Years	1-10
Control Structure	Structure type	Strategic-Tactical

Mission Attributes

ORS Attributes



Attributes elicited from a proxy stakeholder. MAUT evaluates attributes that are bounded, such that the user derives no utility below the bound and no added utility above the bound.

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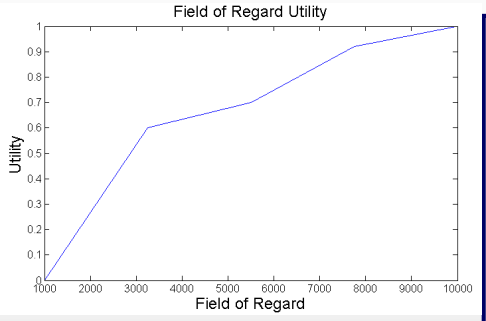
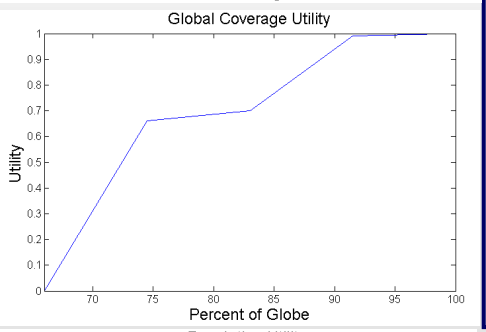
1. Specify Value Proposition: Utility Curve Elicitation

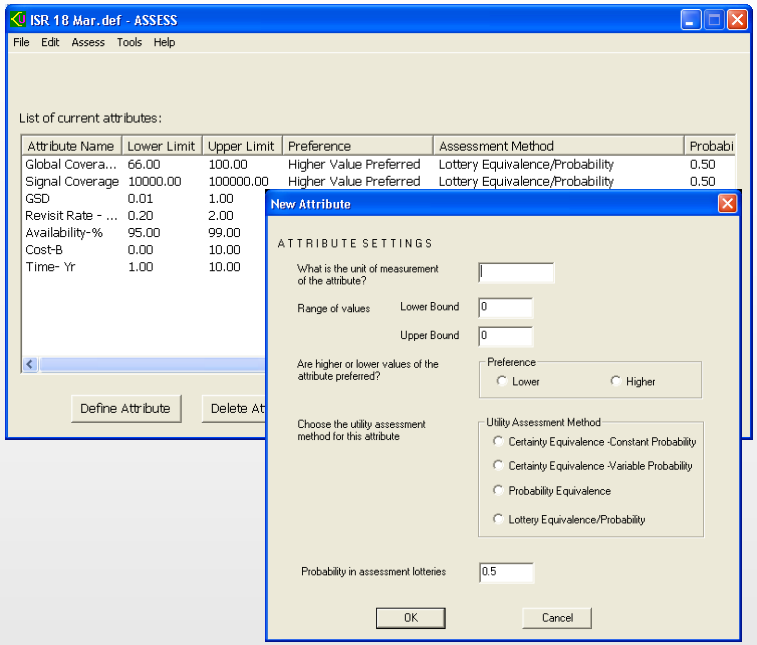
$$KU(x)+1=\prod_{i=1}^{N}[Kk_iU_i(x_i)+1]$$



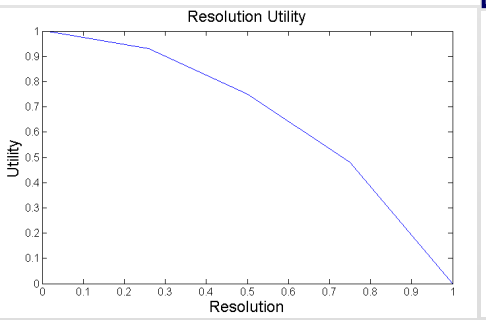


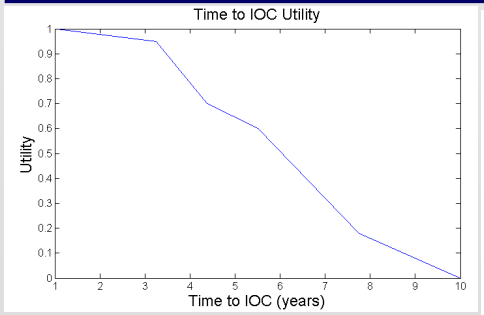
Multi-Attribute Utility Theory

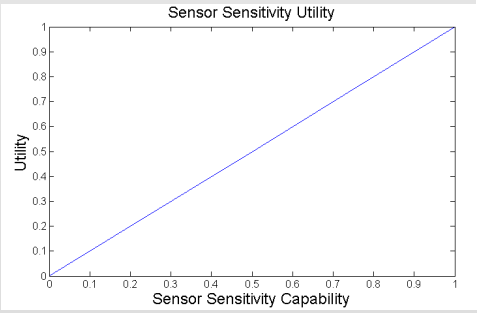
- Lottery elicitation
- Independence of attributes
- Multiplicative function
  - k_i are attribute weights
  - K is normalization constant
- Valid only for DM who gives utility curves

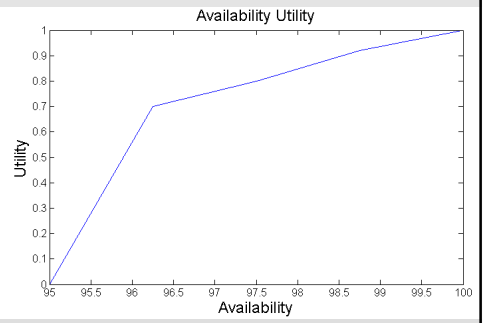


*Assess- Utility Assessment Tool, Philippe Delquie









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2. Enumerate Design Vector: From Attributes to Design Variables

Attributes driven by **orbit selection**

Global Coverage
Over several orbits, how much of the globe is over-flown by the spacecraft

Revisit Rate
Time between target opportunities

Signal Coverage
Field of Regard- the area to either side of nadir that the spacecraft can view

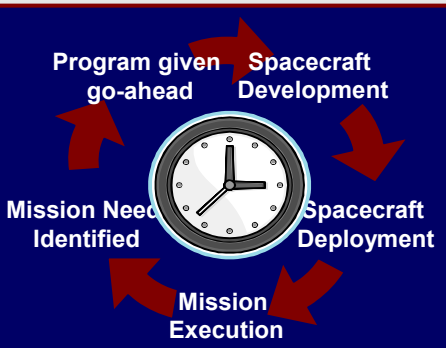
Attributes driven by **spacecraft performance**

Resolution
Ground Sampling Distance

Availability
Scheduled uptime of the spacecraft

Sensitivity
Imaging capability- day, night or both

Timeliness
Length of time from identification of user need to operational capability



Control Structure
Who gets priority in tasking the spacecraft

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2. Enumerate Design Vector: Design Variables

Choose design variables based on first-order impacts. All attributes must be driven.

	Orbit Alt	Orbit Inclination	# S/C	Slew Ability	Power/Duty Cycle	Optic Size	Optic Sensitivity	Software reliability	Tech level	Reuse of Design	Size/Mass	Integration Complexity	Launch	Testing		
Global Coverage	9	9	9	1	3	1										32
Signal Coverage	9			9	1	9										28
Resolution	9			3		9	9		3							33
Revisit rate	9	9	9	3	1											31
Sensitivity	1						9									10
Availability	1	3	9		3			9						3		28
Schedule	1	1	9	3	3	9	9	3	3	9	9	9	9	9		86
Cost	1	3	9	3	3	9	9	3	3	9	9	9	9	3		82
	40	25	45	22	14	37	36	15	9	18	18	18	18	15		

Design Variable	Units	Range
Orbit Altitude	km	200-500
Orbit Inclination	degrees	20-90
# of Spacecraft	integer	1-10
Focal Length	m	0.5-2
Design Reuse	yes/no	0-1
Optic Sensitivity	day and/or night	0-2
Desired Schedule	years	1-10

Design Variables

- Those aspects of a design that the engineer can control
- Typically technical details
- Adding schedule as a design variable
- Tradespace can be populated with a full-factorial of design variables

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3. Develop System Model: Modeling ORS with MATE

N-squared Diagram

Coded Modules	1	2	3	4	5	6	7
(1)Design Variable							
(2)Optics/ Bus	X						
(3)Orbits	X	X					
(4)Launch		X	X				
(5)Schedule	X	x		X			
(6)Utility	x	x	x		x		
(7)Tradespace	x	x	x	x	x	X	

- A tradespace for decision making requires model of system or systems trades
- ORS trades performance and time
  - Spacecraft performance model
    - Standard exercise for most engineers
    - Level of fidelity determined by available time, information and computing power
  - Process and Schedule Model
    - Not yet attempted in any MATE studies
    - Will draw from the Process Development literature

Design modules to reduce feedback loops.
To capture "timeliness," need to include a schedule module.

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Schedule Model Definitions

- Activity- Broad collection of tasks that are required to proceed from user need identification to an operational capability
  - Architect
  - Build
  - Assembly, Integration, Testing (AIT)
  - Launch
  - Mission Prep
- Architecture- complete set of activities
- Baseline Schedule- Length of time an activity nominally takes to be completed
- Schedule Factor- ratio of the desired schedule to the baseline schedule
- Process Readiness Level- Analogous to Technology Readiness Level, describes the extent to which a process is accepted and practiced
- $Risk_{SF}$- determines whether there will be an impact on system performance
- $Risk_{RL}$ – determines the extent of the impact on system performance

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Schedule Model Example

$$Total_Effective_Schedule = \sum_{i=1}^{N} A_i D_i$$

$$Schedule_Factor = \frac{S_i}{S_B}$$

A_i – scaling factor for activity *i*

D_i - nominal duration of activity *i*

S_i – Total Eff. Schedule for activity *i*

S_B – Baseline Schedule

The TRL/PRL is assessed for each activity. To determine $Risk_{SF}$ and $Risk_{RL}$ impact, run Monte Carlo simulation until system performance impact converges.

"Need Identified" "Initial Operating Capability"

Architectures	Activities*						Risk Contributor Components	
	Architect	Build	AIT	Launch	Mission Prep	Total Eff. Sched	SF	TRL/PRL
Baseline (S_B)	1	1	1	1	1	5	1	9
Arch. 1 (S_1)	1	.9	.8	1	1.1	4.8	.96	9
Arch. 2 (S_2)	.9	1	1	.4	.8	4.1	.82	6

*Example assumes all D_i=1

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Future Work and Conclusions

- Model is improved through "spiral development"
  - Starting with small number of design variables
  - Adding fidelity to model
- Explicitly defining value proposition enables objective assessment of ORS *vis-à-vis* "Big Space"
  - ORS suitability may vary across space mission areas
  - Methodological approach: multi-attribute utility theory
- Further analysis on ORS paradigm
  - Asses SSA for volumetric search and UHF Comm missions
  - Identify mission areas and operational contexts where "Big Space" or ORS alternatives (technology and architecture) are most valuable

Value-focused approach allows for explicit and objective comparison of different architectures

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Systems Engineering Advancement Research Initiative

Thank you.

Questions?

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