Systems Engineering Advancement Research Initiative

Massachusetts Institute of Technology

Metrics for Flexibility in the Operationally Responsive Space Paradigm

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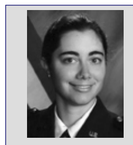


Biography

Lauren Viscito received a B.S. in Astronautical Engineering from the United States Air Force Academy in 2007 and her S.M. in Aeronautics and Astronautics from MIT in 2009. As 2ndLt and an engineer in the USAF, she will be working on complex systems and program management. Viscito hopes that studying flexibility metrics for space systems will help build the business case for more flexible spacecraft in the future.

Related Publications

Viscito, L., and Ross, A.M., "Quantifying Flexibility in Tradespace Exploration: Value-Weighted Filtered Outdegree," AIAA Space 2009, Pasadena, CA, September 2009.

Viscito, L., Chattopadhyay, D., and Ross, A.M., "Combining Pareto Trace with Filtered Outdegree for Identifying Valuably Flexible Systems," 7th Conference on Systems Engineering Research, Loughborough University, UK, April 2009

Viscito, L., Richards, M.G., and Ross, A.M., "Assessing the Value Proposition for Operationally Responsive Space," AIAA Space 2008, San Diego, CA, September 2008.

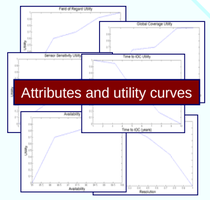
Richards, M.G., Viscito, L., Ross, A.M., and Hastings, D.E., "Distinguishing Attributes for the Operationally Responsive Space Paradigm," Responsive Space 6 Conference, Los Angeles, CA, April 2008.

Mapping User Preferences to Design Choices

Attributes are aspects of a design that a decision maker (DM) desires
- Attributes ultimately reflect whether a DM will determine if a given design alternative is 'good'
- Typically attributes are performance characteristics

Design Variables (DV) are aspects of a design that an engineer or program manager can affect
- The DV define individual designs
- DV are typically parameterized technology or physical choices

For Operationally Responsive Space (ORS), DM cares most about the *time from need identification to on-orbit capability (responsiveness)*
- This requires a new way of thinking about assessing designs
- Must include some process development design variables, and need to model the process by which the solution is obtained



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
Desired Schedule	years	1-10

Beyond Technical Performance

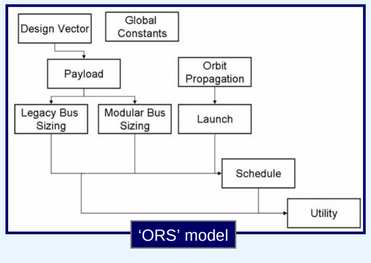
Schedule and Process
- How long does it take to achieve capability given a program?
- What are the risks inherent in the process?
- How much do certain real options cost?

Need to consider aspects not typically looked at in conceptual design
- How to trade design choices that will impact schedule
- Explicitly trade "iron triangle" to manage program risk.

Computer Models

Need to assess alternative spacecraft performance
- Translate levels of Design Variables into performance Attributes
- Physics-based evaluation of design – i.e. best theoretical resolution and field of view calculations

Calculate performance of two architectures under changing stakeholder preferences



Flexibility is a subcategory of MATE changeability, and implies an active change in the system as a response to context shift.

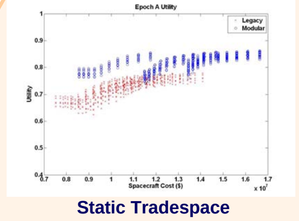
Research Questions:
Does a "valuably flexible" metric exist that allows explicit trades in conceptual design?

Can the metric determine the flexibility in legacy and modular ORS architectures?

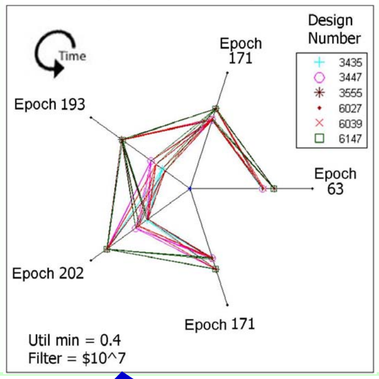
Flavors of Flexibility

Process Flexibility
- Emergent during design and build phases of spacecraft lifetime
- Changes are made to systems before they are fielded
- Pull from process development community
- Changes also extended to subsequent generations of systems
- System may be "optimal" under current contexts, subsequent systems also "optimal"
  -- Requires front end effort for every system

Product Flexibility
- Emergent during operational phase of spacecraft lifecycle
- Changes made to systems after fielding
- Active change- not just margins
- Less than "optimal" design, under current context
  -- Requires "extra" mass/power/cost on system



Static Tradespace



"Valuably Flexible" Metric

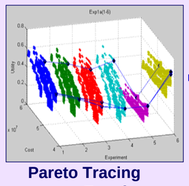
$$VWFO_i^{m,m+1} = \frac{1}{N-1}\sum_{j=1}^{N-1}[sgn(u_j^{m+1} - u_i^{m+1}) * Arc_{i,j}^m]$$

N	= number of designs	m	= current time (context)
i	= origin design	m+1	= future time (context)
j	= destination design	u	= utility of design
Arc	= transition allowed		

Value Weighted Filtered Outdegree captures
- Changeability of design (number of transitions)
- Goodness of transition (utility sign change)
- Epoch context change

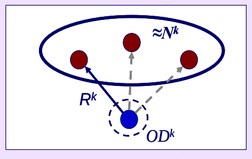
Combined graphically in a spider plot, gives decision maker a 'quick look' at valuably flexible designs

Can be used to quickly screen tradespace for "interesting" designs that can change to higher value across specific context changes

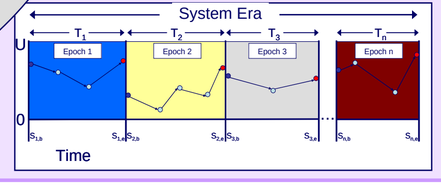


Pareto Tracing across Epochs

Changeability Quantified as Filtered Outdegree



Dynamic Tradespace Sequence



Dynamic Analysis

Epoch-Era Analysis
- Several Epochs are strung together to form an Era
- The changing contexts can cause different designs to become Pareto efficient

Two dynamic tradespace metrics can be used to identify value robust alternatives
- *Pareto Trace* collects all Pareto efficient designs across the epochs (passive value robustness)
- *Filtered Outdegree* indicates how many transitions a given design may follow (changeability)

Dynamic strategies can be developed
- Actively changing designs can create a 'trajectory' of an evolving design across epochs
- Designs that stay high utility are 'value robust'

Tradespace Exploration

- Designs are displayed on a cost-utility axis
- Patterns from design vector enumeration or constraints become apparent in this phase
- Within a static context, able to see which designs perform best or are Pareto Efficient
- Each static tradespace has a unique context, and is called an Epoch

For more information, please visit:
http://seari.mit.edu

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