Systems Engineering Advancement Research Initiative

Massachusetts Institute of Technology

Quantifying and Valuating Changeability for System Designs in an Uncertain Future

Matthew Fitzgerald, S.M. in Aeronautics and Astronautics (expected in 2012)

Advisors: Dr. Adam Ross, Prof. Daniel Hastings

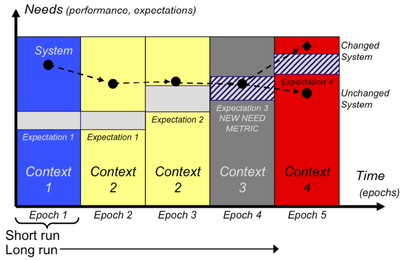
Biography

Matt received a Bachelor of Science in Aeronautics and Astronautics degree from MIT in June 2010, and began pursuing his Masters immediately after. His areas of work include research into passive flow control, compression technology, and tradespace exploration with an emphasis on time-dependent analysis.

mattfitz@mit.edu

Need

- As time progresses, system value, user needs, and expectations change
- System changeability can provide an effective means of maintaining value over "long run" time (system lifetime)



Identifying changeable designs is an important facet of the design process, which is currently in need of improvement to move beyond qualitative analysis!

How can we deal with the effect of changing contexts on the perception of value?

Changeability may be the answer

Source: Ross, A.M., and Rhodes, D.H., "Using Natural Value-Centric Time Scales for Conceptualizing System Timelines through Epoch-Era Analysis," *INCOSE Int'l Symposium 2008*, Utrecht, the Netherlands, June 2008.

Definition / Quantification

Changeability: the ability of a system to undergo architectural or operational changes after being built. Changes are incited by change agents, either internal (adaptability) or external (flexibility), and enacted via change mechanisms, methods by which the system can be altered.

The information needed for quantification is not immediately obvious. What is the best way to measure changeability?

- Number of available end states
- Number of change mechanisms ("rules") / agents
- Potential range of attribute performance

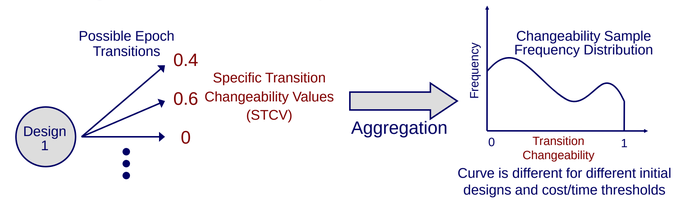
Source: Presentation for Viscito and Ross 2009

With the passage of time so critical to the importance of changeability, how do we quantify a generalized changeability?

- Epochs are defined as fixed sets of contexts and user preferences
- As epochs shift over time, a design's ability to change (and the value of that change) may be altered

Near Term Research

- Create an assumption-minimizing and physically intuitive definition of Specific Transition Changeability Value (e.g. VWFO), potentially based on ARI
- Output of useful summary statistics from frequency distribution to allow for immediate and simple comparison between different designs
- Sensitivity analysis with cost/time thresholds
- Emergent information from tradespace case studies



Curve is different for different initial designs and cost/time thresholds

1. Pick a design
2. Calculate STCV for each potential future epoch
3. Aggregate STCV
4. Analyze frequency distribution to extract changeability information over entire uncertain future

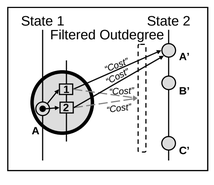
Previous Work

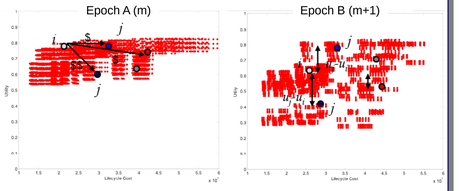
Outdegree and Filtered Outdegree

- Approximates changeability as number of available system changes
- Changes enumerated via pre-defined "change mechanism" transition rules
- Filters the changes using a variable acceptable cost/time threshold

Value Weighted Filtered Outdegree (VWFO)

- Extrapolates from Filtered Outdegree in attempt to value the flexibility
- Weights the changes by their effect on multi-attribute utility
- Requires explicitly defined epoch transitions within an era (pair-wise)





Source: Ross, A.M., Rhodes, D.H., Hastings, D.E., "Defining Changeability: Reconciling Flexibility, Adaptability, Scalability, Modifiability, and Robustness for Maintaining Lifecycle Value," *Systems Engineering*, Vol. 11, No. 3, pp. 246-262, Fall 2008.

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

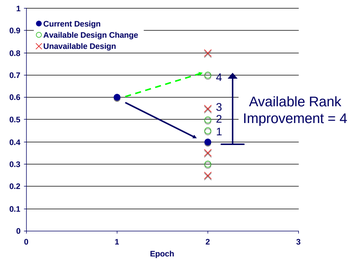
Valuation

Challenge: multi-attribute utility is not a ratio scale and only well-defined within one epoch

- The difference between 0.1 and 0.3 in one epoch is not necessarily the same as 0.5 and 0.7, nor between 0.1 and 0.3 in a different epoch
- Changeability valuation should minimize dependence on utility numbers for methods intended to be generalizable (minimal assumptions)

Utility is a bounded cardinal function, thus relative rank is the soundest comparison between designs

- Available Rank Improvement (ARI) is potentially a source of valuable changeability information independent of specific epoch to epoch transitions, thus reducing assumptions and necessary computations



Research Next Steps

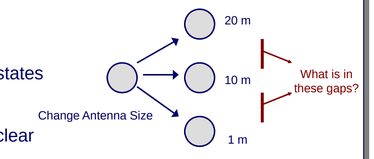
After preliminary metrics are proposed, the following will be considered:

Effects of continuous design variables
- Difficulty dealing with infinite end states

Accounting for fully modular design
- Ability to incorporate unknown/unclear future technology improvements
- Time-dependent change mechanisms

Differentiators between flexibility and adaptability

Alternative aggregation methods
- Effects of weighting Specific Transition Changeability more heavily for epochs with poor original design performance
- Methodology allowing for cost/value tradeoff analysis to be performed between change mechanisms
- Possible attempts to combine changeability with passive robustness to create a new value-over-time metric (value robustness)



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