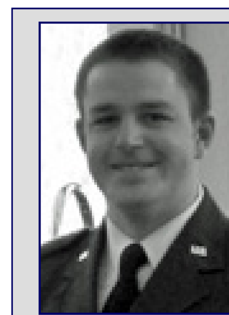
Systems Engineering Advancement Research Initiative

The Epoch Syncopation Framework: Analyzing System Change Options in Cost and Schedule Domains

Dan Fulcoly, S.M. in Aeronautics and Astronautics (expected in 2012)

Advisors: Dr. Adam Ross; Dr. Donna Rhodes; Prof. Daniel Hastings



Biography

Dan Fulcoly is a masters student in the MIT Department of Aeronautics and Astronautics. Prior to attending MIT, he received a B.S. in Physics and a B.S. in Mathematics from the United States Air Force Academy. His prior research experience includes developing methods for non-resolvable space object identification for space situational awareness applications. Dan is a 2nd Lieutenant in the U.S. Air Force and will serve as a physicist after his masters program.

fulcoly@mit.edu

Relevant Publications

Beesemyer, J.C., Fulcoly, D., Rhodes, D.H., and Ross, A.M., “Developing methods to design for evolvability: research approach and preliminary design principles,” *9th Conference on Systems Engineering Research*, Los Angeles, CA, April 2011.

Fulcoly, D., Ross, A.M., and Rhodes, D.H., “Evaluating system change options and timing using the epoch syncopation framework,” *10th Conference on Systems Engineering Research*, St. Louis, MO, March 2012. (submitted)

H. McManus, T. Schuman, “Understanding the Orbital Transfer Vehicle Trade Space,” *AIAA Space 2003*, Long Beach, CA, September 2003.

Motivation

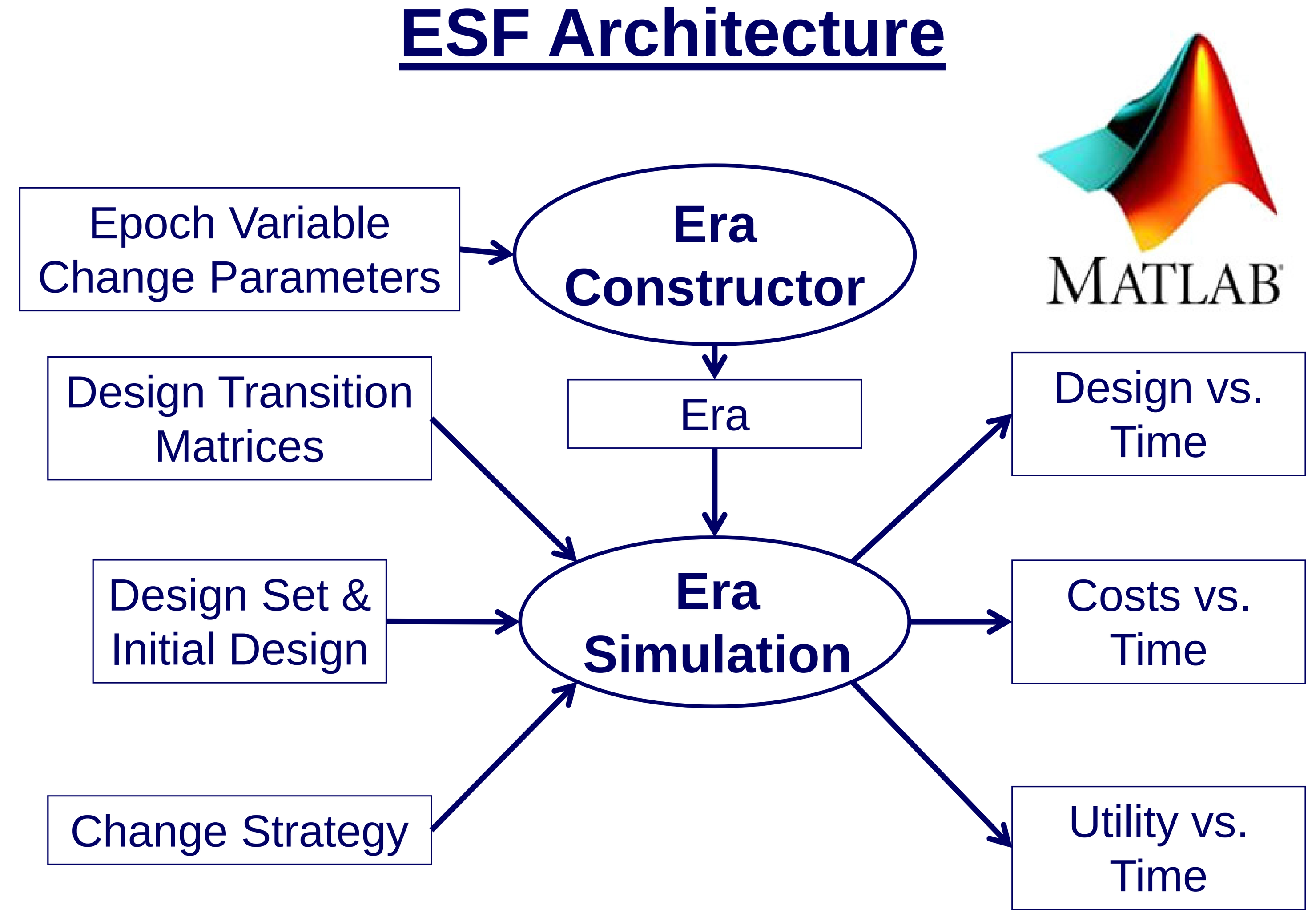
The early phases of tradespace exploration require careful consideration as they will propagate a significant impact to the ultimate success or failure of the system. Planning for uncertainty, both in needs and in context, as early as the tradespace exploration stages allows designers to create a system that provides value in a multitude of epochs at a cost and schedule that meets their constraints.

Goal

The goal of the research team is to create a framework that allows for analysis in both the cost and schedule domains that can identify valuable designs, path enablers, and decision strategies. The ESF will be able to scale to handle new tradespaces, epoch variables, distributions of epoch variables, decision strategies, and the output of new metrics.

Initially, the ESF will be demonstrated on a familiar data set, the orbital transfer vehicle (a.k.a. “Space Tug”). Additional studies will look at applying the ESF to other data sets, including systems of systems (SoS).

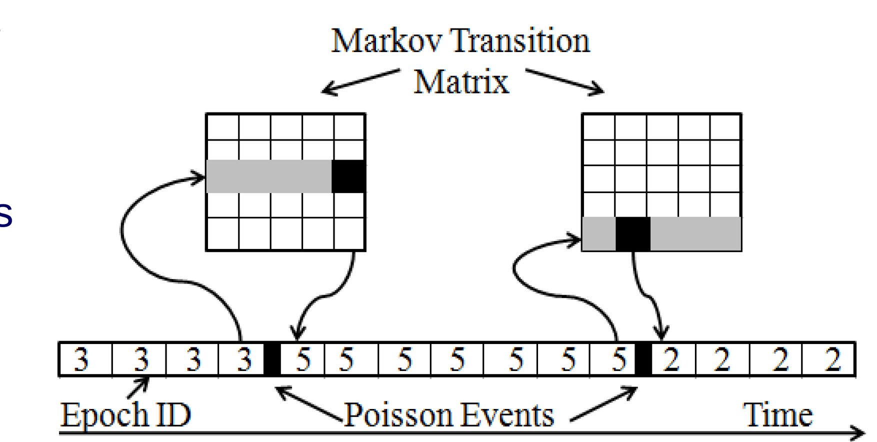
ESF Architecture



Markov Probability Era Constructor

Shifts in epoch variables, including both context variables and preference sets, are treated as independent Poisson events. When shifts occur, a Markov probability matrix is used to determine “to what level” the epoch variable will change.

- Each epoch variable is assigned a mean change time
  - Can be defined as a non-Poisson random variable
- Each epoch variable also has unique Markov transition matrix
- Multiple context variable shifts are allowed in the same time step



Concept Demonstration: Space Tug Case Study

Design Space

Design Variables	Levels
Manipulator Mass (kg)	[300, 1000, 3000, 5000]
Propulsion System	Storable BiPropellant, Cryogenic, Electric, Nuclear
Fuel Mass (kg)	[30, 100, 300, 600, 1200, 3000, 10000, 30000]
DfE (% Mass Penalty)	[0, 20]

Epoch Variables

- Technology Level
  - Future Tech or Present Tech
  - Mean change time: 8 years

Technology Level	To Present	To Future
From Present	0	1
From Future	0	1

- Mission
  - Each mission is a set of preference curves
  - Mean change time: 4 years

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Transition Matrices

- Transition cost is a function of similarity between designs and the inclusion of evolvability design principles (‘DfE’) in current design
- Transition schedule is a function of propulsion system and DfE level in current and target designs
  - The first inclusion of DfE leads to a schedule penalty, but no penalty is accrued for continuation of DfE
  - Redesigns where the current design does not have DfE have longer schedules

Decision Strategies

- Strategy 1: Change to highest utility design at all times
- Strategy 2: Change anytime utility falls below predefined threshold
- Strategy 3: Change only if below threshold at predetermined points in time

Simulation

- Simulated 11 trials, each trial using a single decision strategy for 1000 eras
- Each era simulated once for each starting design
- Strategy 2 simulated at 4 different threshold levels
- Strategy 3 simulated for 2 threshold levels and 3 generation lengths

Results

- Lifecycle cost
  - Decreased as change threshold decreased, decreased as generation length increased
- Time-weighted accumulated utility
  - Increased as change threshold increased, decreased as generation length increased

Next Steps

Expand Scope

- Addition of a budget variable, the size of which determines available (and allowed) transitions
- Develop more decision strategies for analysis
- Output more metrics and indicators concerning performance
- Expand stochastic options in Markov probability era constructor
  - Look at options beyond Poisson arrival
  - Consider having the transition matrix become a function of time elapsed between changes

More Case Studies

- Maritime Security SoS case application
- Satellite Radar System, X-TOS, and other existing data sets

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