Responsive Systems Comparison Method: Case Study in Assessing Future Designs in the Presence of Change

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Motivation

• System designers and architects often face changes in…
  – User needs
  – Available technologies
  – Political and technical contexts
• Classical “scenario analysis” can be too opportunistic, qualitative, or sparse
• Structured method needed for collecting information to characterize wide variety of possible futures
• Paper presents the initial work on Responsive Systems Comparison (RSC) Method
RSC Process 1: Value-Driven Design Formulation

### Design-space:
Designer-controlled parameters that define a system concept

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<th>Parametric Design Variable</th>
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### Value-space:
Concept-neutral evaluation criteria specified by decision makers

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<td>Data Latency (tracking), Number Target Boxes, Min. Detectable Target Velocity, Target Acquisition Time, Tracking Life</td>
</tr>
<tr>
<td>Strategic data user (imaging)</td>
<td>Maximum Resolution, Field of regard, Number Targets Observed per Pass, Revisit Frequency, Geo-location Accuracy, Data Latency (imaging)</td>
</tr>
<tr>
<td>Programmatic &quot;user&quot; (schedule and cost)</td>
<td>Baseline Schedule, Actual Schedule (under changing conditions), Baseline Cost, Actual Cost (under changing conditions)</td>
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**Design-Value Mapping (DVM):**
Ensures alignment between Value-space and Design-space

**Design-Value Mapping (DVM) Ensures Design Decisions Drive Value Delivery**
RSC Process 2: Design Tradespace Evaluation

Compares system designs on a common, quantitative basis
- Uses computer-based models to compare thousands of designs
- Avoids limits of local point solutions
- Maps structure of stakeholder value onto design space
- Simulation can be used to account for design uncertainties (i.e., cost, schedule, performance uncertainty bubbles)

Design Tradespaces Provide High-level Insights into System-level Trade-offs. Detailed System-Level Design would follow-on Preferred System Concept Decisions
RSC Process 3: Epoch Development and Enumeration

Definition of Epoch:
Time period with a fixed context and needs; characterized by static constraints, design concepts, available technologies, and articulated attributes (Ross 2006)

Define Epochs
Potential Contexts
Potential Needs

Construct Eras
Epoch Series
Dynamic Strategies

Parameterize Future Contexts for Design of Experiments Sampling of Scenarios
RSC Process 4: Era Construction

**Definition of Era:**
System life with varying contexts and needs, formed as an ordered set of epochs; characterized by varying constraints, design concepts, available technologies, and articulated attributes.

**Discretization of Change Timeline into Short-run and Long-run Enables Analysis.** Allows Evaluation of System Varying Performance over Possible Futures or Scenarios.
Using Eras to Generate System Evolution Strategies

**Technical Goal:** Develop time-based strategy for selecting designs that continue to deliver value to stakeholders across epochs

- Relevant metric: Minimized distance from “Utopia trajectory” of a design’s performance in a given strategy

Trajectories across a system *Era* can be defined:

1. Set of expected Epochs
2. Strategy for selecting designs in each Epoch (e.g. min cost, max utility, etc.)

In RSC: Multiple Eras defined and system selection strategies compared to “Utopia trajectory”
The Combinatorial Problem

For generating a given *epoch*:

- Needs:  
  - +
- Context:  
  - ...

...there are *n* “slots” in a given *era*

\[
N_{epochs1} = N_{contexts} \times N_{needs}
\]

\[
N_{epochs(total)} = (N_{contexts} \times N_{needs}) \times Lera
\]

\[
N_{eras} = (N_{contexts} \times N_{needs})^{Lera}
\]

Example with very small numbers:

If \( N_{contexts} = 4 \), \( N_{needs} = 3 \), \( Lera = 4 \)

\( N_{epochs1} = 12 \), \( N_{epochs(total)} = 48 \), \( N_{eras} = 20736!! \)

Problem-space can grow more quickly than computational capabilities…

Possible solutions: clever enumeration, sampling strategies, leveraging symmetries and (in)dependence; intent of project is to confront this challenge
Satellite Radar System (SRS)

- Case study for developing method
- Used SRS Program Manager as key decision maker

Process*
- Identify key decision maker(s)
- Scope the enterprise boundary
- Determine key context variables
- Interview decision maker(s)
- Determine attributes
- Determine design variables
- Generate system model
- Assess tradespace

*Team used Multi-Attribute Tradespace Exploration (MATE)
SRS Enterprise

Which SRS Architecture?

Resources (fungible assets)

Congress OMB

Satellite Radar System Program Manager

National Security Strategy/Policy

DNI USD(I)

Extended SRS Enterprise

Radar Product

SRS Enterprise Boundary

SI&E

Comptroller

Nation

Military

R&D

Comm/Grnd

Which SRS Architecture?

Infra-Struct.

Capital (non-fungible assets)

SRS Context

OMB Congress

Which SRS Architecture?
Structuring the Dynamic Context

- Each enterprise influence type has its own timescales for changing in the time period of interest.
- System development itself has programmatic phases, whose duration may vary across system designs in a tradespace.
- Epochs will need to be ordered in an era based on “rules” for allowable context transitions.
- Boundary of analysis will help to encapsulate timescales.
Bounding: Satellite Radar System

Exotic Technologies: Inflatable, Sails

Detailed Mission and Ground Models

Parabolic or AESA Antenna

Schedule

Cost

Time Dynamic Strategies

Limited Horizontal Integration

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**Attributes**

**Attribute**: A decision maker-perceived metric that measures how well a decision maker-defined objective is met.

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These attributes were elicited through semi-structured interviews with various stakeholders.
**Design Variable**: A designer-controlled quantitative parameter that reflects an aspect of a concept

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These design variables were generated through using the DVM to drive attribute value
Epoch Variables

Enterprise scoping exercise informed the types of “epoch variables” encountered by program.

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<th>Variable Type</th>
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<td>Relative Priority change between different users/missions</td>
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<tr>
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<td>Target Radar Cross-Section</td>
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<tr>
<td></td>
<td>Target Velocity</td>
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<tr>
<td></td>
<td>Box Size</td>
</tr>
<tr>
<td>Available Infrastructure</td>
<td>TSAT communication system available</td>
</tr>
<tr>
<td></td>
<td>Airborne Radar System available as complement</td>
</tr>
<tr>
<td>Technology Available</td>
<td>Antenna Mass per unit area and/or power</td>
</tr>
<tr>
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<td>Signal Processing Capability</td>
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<tr>
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<td>Efficiency of Spacecraft Subsystems (power in particular)</td>
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<td>Funding</td>
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Epoch variables allow for parameterization of some “context” drivers for system value.
Overall Model Architecture

1. STATIC MATE
   - Mission
   - Attributes
   - Design Vector
   - Full Factorial
   - Model
   - Utility
   - Cost
   - Tradespace
   - Tradespace Network
   - Epoch Data

2. EPOCH ENUMERATION
   - Epoch Variables
     - Context (Epoch Vector)
     - DV Transition Rules
     - 10% sample

3. CHANGEABILITY ANALYSIS
   - Survivability
   - Flexibility
   - Value Robustness

4. ERA ANALYSIS
   - Epoch Transition Rules
   - Eras

5. PATH ANALYSIS
   - Path Selection Rules
   - Path Calculator
   - Cost-Utility Trajectories

What we’ve seen is just this piece
Anticipated Analytic Capabilities

Project continues through summer and coming fall, with tradespace modeling and dynamic analysis

**Many Designs**
- Identify inconsistent expectations across stakeholders
- Identify distribution of costs and benefits implications of designs
- Identify cost and benefit tradeoffs across heterogeneous concepts

**Changing Contexts**
- New technology
- New concepts
- Shifts in available SoS assets
- Shifts in resource constraints
- Shifts in policy
- Disturbance threats

**Changing Needs**
- New mission applications
- New desired capabilities
- Shifts in desired performance levels
- Shifts in priorities of expectations
- Shifts in stakeholders involved
- New desire for “ilities”

**Dynamic Strategies**
- Technology investment
- System evolution
- Dynamic SoS composition
- Design for Changeability
- Temporal resource allocation
- Motivation for wargaming activities