Combining Attributes for Systems of Systems in Multi-Attribute Tradespace Exploration

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Systems of Systems (SoS) are dynamic higher order systems composed of other independently managed systems that together provide some emergent value.

A system-of-systems is a set of collaboratively integrated systems that possess two additional properties: operational independence of the components and managerial independence of the components. (Maier, 1998)

Coordinating Observatories
Components: HST, Chandra and the Observer/User

Multi Concept Disaster Surveillance System
Components: Aircraft, UAV, Satellite

Motivation

• SoS are different from traditional systems in terms of design issues¹,²
  – Operational independence
  – Managerial independence
  – Emergent behavior
  – Varying composition over time

• SoS engineering requires new methods

• Heuristics and qualitative guidelines in the literature¹
  – Stable intermediate forms
  – Leverage at interfaces, etc.

Need for quantitative method for comparing SoS designs in order to assist decision makers in the conceptual design phase

Research Questions

1. What are the characteristics that distinguish SoS design from traditional system design?
   - local and global stakeholders
   - dynamic composition of system
   - legacy and new components

2. What is a practical framework for SoS tradespace exploration?
   - Step-by-step method utilizing Dynamic Multi-Attribute Tradespace Exploration

3. How can the developed tradespace exploration framework be used to select SoS designs that are value robust through the SoS lifetime?
   - Epoch-era analysis
   - Pareto analysis
SoS - Specific Design Considerations

Local and Global Stakeholder Sets
Legacy and New Systems
Dynamic Composition

Multi-Attribute Tradespace Exploration

1. Determine Stakeholders
2. Specify value proposition
   - Interview stakeholder
   - Determine attribute list
   - Elicit utility curves
3. Enumerate design vector
4. Develop system model linking design variables to attributes
5. Compare candidate architectures on same cost-utility basis in tradespace

Application of decision analysis and utility theory to modeling and simulation based design

SoS Tradespace Exploration

Enhancing Dynamic MATE with SoS-specific considerations
SoS Value Delivery

SoS ‘Value’ \( \approx \) sum of component value

SoS value > Components
- greater functionality in SoS
- SoS value < Components
  - interactions reduce combined capability

Coordinating Observatories, Chandra and HST
SoS Value Delivery

SoS ‘Value’ $\approx$ sum of component value

SoS value> Components greater functionality in SoS

How is SoS value determinedMODELED so that designs can be compared on a tradespace?

Coordinating Observatories, Chandra and HST
System attributes are decision maker perceived metrics that are used to measure the system value delivery. Component system attributes are combined to generate the SoS utility. Attribute combination has an impact on SoS costs.
## Attribute Classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Name</th>
<th>Property of Class</th>
<th>Cost to Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Articulated Value</td>
<td>Exist and assessed</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Free Latent Value</td>
<td>Exist, but not assessed</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Combinatorial Latent Value</td>
<td>Can exist by recombining Class 0 and 1 Attributes</td>
<td>Small</td>
</tr>
<tr>
<td>3</td>
<td>Accessible Value</td>
<td>Can be added through changing the design variable set (scale or modify)</td>
<td>Small -&gt; Large</td>
</tr>
<tr>
<td>4</td>
<td>Inaccessible Value</td>
<td>Cannot be added through changing design variable set (system too rigid)</td>
<td>Large -&gt; Infinite</td>
</tr>
</tbody>
</table>

Component system attributes can be classified based on whether they are articulated by the decision maker, and displayed by the system.

Level of Attribute Combination Complexity

‘Low’ Level Combination

‘Medium’ Level Combination

‘High’ Level Combination
Combining Attributes to Quantify SoS Value Delivery

**SoS Attribute Value**

SoS attribute value = fn(component A attribute value, component B attribute value…)

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**Impact on Cost**

<table>
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<th>Class</th>
<th>Cost Added (% Component Cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,1</td>
<td>Small (10)</td>
</tr>
<tr>
<td>2</td>
<td>Medium (20)</td>
</tr>
<tr>
<td>3</td>
<td>Large (30)</td>
</tr>
</tbody>
</table>

Multiplier (1,2,3) on cost added for level of attribute combination complexity

Steps for Modeling SoS Value Delivery

1. Elicit SoS attributes from stakeholder
2. Generate List of (Legacy or New, or Legacy and New) Components
3. Identify system attributes in each class (0,1,2,3) for each component
4. Estimate participation risk for each component (based on managerial control and influence)

SoS Variables

Levels and Methods of Combination of Attributes

Component A
Class 0  Class 2
------  ------
Class 1  Class 3
------  ------

Component B
Class 0  Class 2
------  ------
Class 1  Class 3
------  ------

Participation Risk

SoS Cost Estimate

Utility

Cost
Qualitative Example of Application

For each SoS attribute, a combination of the component system attributes along with a selected combining method is used to generate the SoS attribute level. Low attribute classes and low level combination have a low impact on cost.
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Higher level of component attribute used in higher level combination has higher impact on cost
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Conclusion

• Component system attribute combination provides a means to quantitatively estimate SoS value delivery
  – As comprehensive lists of attributes for each component system is generated, comparison of these lists may lead to identification of potential undesirable (or desirable) SoS emergent properties

• Modeling SoS value is a key aspect of the quantitative SoS tradespace exploration method that enables the comparison of a large number of designs on the same tradespace
Future Work

• Incorporation of combining attributes and participation risk concepts into the full SoS Tradespace Exploration Method

• Application of full SoS Tradespace Exploration Method to a quantitative case study

• Detailed study of the types of attribute combination methods available within each level of combination complexity
Questions?