ility Tradespace Analysis: Analysis of the Influence of Requirements Change on a System

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ility Tradespace Analysis

The AFIT of Today is the Air Force of Tomorrow.

• Previous work at AFIT has focused on flexibility
  • Treat program baseline parameters (req’ts, production #’s, etc.) as stochastic variables
  • Use expected value of life cycle cost as a proxy measure for valuing flexibility

• Recent extensions/applications
  • Use epoch-era analysis as a framework for capturing future uncertainty
  • Initial application on Air Force T-X advanced trainer concept
Methodology

- Developed decision tree map out design strategy and era possibilities

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Epoch Variables</th>
<th>Probability of Occurring</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF</td>
<td>AF</td>
<td>10%</td>
</tr>
<tr>
<td>AFN</td>
<td>AF + N</td>
<td>30%</td>
</tr>
<tr>
<td>AFSO</td>
<td>AF + SO</td>
<td>15%</td>
</tr>
<tr>
<td>AFH</td>
<td>AF + H</td>
<td>15%</td>
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<tr>
<td>AFNSO</td>
<td>AF + N + SO</td>
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<tr>
<td>AFNH</td>
<td>AF + N + H</td>
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<tr>
<td>AFSOH</td>
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<tr>
<td>AFNSOH</td>
<td>AF + N + SO + H</td>
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</tbody>
</table>
Analysis

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- Summary of LCC associated with design strategy and epoch realization

<table>
<thead>
<tr>
<th>Epoch</th>
<th>AF</th>
<th>AFN</th>
<th>AFSO</th>
<th>AFH</th>
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<tbody>
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</table>

NOTE: All $ figures BY13 in millions
Analysis

- Decision tree recommended AF design strategy due to lowest expected LCC
- Expected LCC difference compared to AF design strategy
  - Driven by estimated LCC and probability of occurrence

<table>
<thead>
<tr>
<th>Design Strategy</th>
<th>AF</th>
<th>AFN</th>
<th>AFSO</th>
<th>AFH</th>
<th>AFNH</th>
<th>AFNSOH</th>
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<tbody>
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NOTE: All $ figures BY13 in millions
Sensitivity Analysis

- One way AFN → AFN normalized branch probability

Strategy Region of Decision Tree 'Expected LCC'
Expected Value of Node 'AFN Design Strategy' (D22)
With Variation of Branch Probability 'AFN' of Node 'Realization' (E27)
Sensitivity Analysis

- One way N subjective impact

![Strategy Region of Decision Tree 'Expected LCC'](image)

- Expected Value of Node 'Design Strategy' (D22)
- With Variation of N Subjective Impact (B64)
Results

• Flexible Design Strategy favored when…
  • Probability of era occurring
  • Subjective Impact
  • Production and O&S Cost Modifiers
Current Efforts

• How do we improve on “subjective impact” factors relating a requirements change to design/production effort required to accommodate the change
• Product design literature provides some ideas for relating architectural constructs to meaningful impact factors
• Application to a flexible weapons (munitions) concept
Current Research Questions

1. How does a type of requirements change impact a module/component?
2. How is the module/component impacted by a combination of requirement changes?
3. How does a type of requirements change impact the system?
4. How is the system impacted by a combination of requirement changes?
5. What strategy(ies) should be taken to mitigate the impact of change in the system?
Methodology

- Baseline for Methodology: Martin & Ishii [2002], Generational Variety Index (GVI)
- Define system requirements, system/SoS architecture and a time period for input distributions
- Implement uncertainty into all inputs
  - Likelihood of requirement change in peacetime
  - Likelihood of requirement change in wartime
  - Non-homogeneous state transitions
  - Type of component change (scalable or modifiable) [Ross et al. 2008]
  - Impact of component change
- Analyze over multiple time periods (possible system lifecycle lengths)
Gathering Model Inputs

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- Objective and Scope of the System
- System Architecture Development
  - Generate architectural alternatives from physical and functional DSM

Input questions answered by the system architecture

1. What are the types of requirements that the system supports?
2. What system functions support the type of requirement?
3. What modules/components perform each system function?
4. If the type of requirement changed, does it cause a scalable and/or modifiable functional change?
5. For a functional change, which modules/components are likely to be impacted, and do those changes drive changes elsewhere in the system
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Gathering Model Inputs

- Input questions answered by a Subject Matter Expert
  - As a result of a requirements change, what is the impact on the module/component of a scalable or modifiable functional change from each change state?
  - As a result of a requirements change, what is the probability that the module has a scalable or modifiable change from each change state?
  - What is a reasonable time period for a change to occur in the system?
  - What is the probability that a requirement will change in the defined time period from each change state?
Impact Value

- A measure of “level of effort to change”
- Utilize methods similar to Decision Analysis to define component impact range and weights
- To elicit impact values, determine a triangular distribution (min, max, and mode) of percentage of functional change (scalable and modifiable) per component due to a type of requirements change

Determine the Impact Distribution
Model Formulation

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1. Is the system in peacetime or wartime?

2. Does the requirement change?

3. What modules/components are affected by the type of requirement change?

4. Does the type of requirement change cause a scalable or modifiable change in the component?

5. What is the impact of the type of requirement change on the component and system?
Results

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- Random walk (monte carlo) provides information on the cumulative impact (total, scalable, and modifiable) for how:
  - A type of requirements change impacts a module/component
  - The module/component is impacted by a combination of requirement changes
  - A type of requirements change impacts the system
  - The system is impacted by a combination of requirement changes
Status of Research

- Develop preliminary system architecture that describes component functionality and information/resource flow
- Develop model that incorporates uncertainty into all inputs as described
- Determine how each uncertain input influences the Generational Variety Index results
- Incorporate flexible weapons concept as a case study to determine how the different types of requirement changes impact the system
Quantifying Tradespace

- **Challenges**
  - This current research provides relative value for ranking design options, but does not provide absolute resource (i.e., dollar) values suitable for cost analysis and budgeting actions.
  - Also precludes direct comparison to existing/legacy systems.
  - The DoD has no standard approach for developing credible cost estimates for a program “born flexible” – requirements must be fixed and the APB is assumed to be static.
Quantifying Tradespace

**Stochastic Cost Estimating**
- Methodology intended to account for flexibility related to system *design* and mission *execution*
  - Flexibility related to *acquisition* might be possible as well, but not being evaluated by AFIT at this time
- Using AFRL flexible weapons concept as framework to develop estimating methodology
  - Modularized subsystems, standard interfaces, open system arch
  - Dynamic targeting, accuracy, and effects
- Concept
  - Develop range of estimates for each logical module of munition based on historical costs
  - Conduct sensitivity analysis to determine how sensitive the cost of each module is to variation in component types
  - Aggregate module costs and run Monte Carlo simulation
Future Work

- Incorporate direct and indirect component change propagation into changeability analysis
  - Use cumulative result to further aid in performing architectural tradeoffs and resource allocation
- Incorporate the exogenous factors driving requirements change that impact the system
- Use methodology to determine impact of systems change at all levels (i.e. system of system) due to exogenous factors and/or “component” propagation
- Use impact analysis to inform cost estimation models
- Combine with other architecture evaluation/validation methods to close loop around architectural variations, mission effectiveness and cost effectiveness