[Pl.27s] Value-Driven Tradespace Exploration for System Design

Lecture 13
Policy and Other Non-Technical Influences on the Tradespace

Dr. Donna H. Rhodes
rhodes@mit.edu

Dr. Adam M. Ross
adamross@mit.edu

Massachusetts Institute of Technology
Outline

• Motivation
• Policy impacts on architectures
• Examples for incorporating policy
  – Space systems
    • Influence diagrams
    • Tradespace effects
  – Chicago Airport Express
    • Feedback between technical and political goals
Motivations - Overall

• Policy and related factors can have significant implications for value delivery of a system throughout its lifespan

• Considering possible and anticipated future policy impacts as part of the concept analysis phase can lead to better decisions and understanding of risks
Motivation

• For a system architecture to be robust, it must weather changes over its entire lifecycle

• Instabilities may arise from large number of domains

• While poorly understood, actions taken in political domain have profound effects of space systems
  – Government restrictions on launch vehicles
  – Budget revisions


Understanding the effects of political domain instabilities on systems is the focus of this presentation
Definition of Policy

Policy

“A definite course or method of action selected from among alternatives and in light of given conditions to guide and determine present and future directions.” [Webster’s Third Intl. Dictionary]

• Policy statements have several features associated with them:
  • definite course(s)
  • selected from alternatives
  • true in light of specific conditions
  • to move one in specific (desired) directions
Policy Formulation
(Weigel 2002)

• Policies arise from the political domain
  – Represents voice of customer (e.g., public)
  – Politics is the mechanism through which value judgments are expressed

• Legislative institutions control budget for government systems

• Funding decisions driven by aggregate of local politics:

  Security
  Benefits
  Jobs
  Revenue

  Personal experiences
  Relationships
  Negotiations
  Compromise

But how to translate complex stakeholder interactions into policy goals?
Identifying Key Decision Makers

Definition of Levels
Level 2 – Close connection to System
Level 1 – Distant connection to System
Level 0 – Little or no connection to System

From Ross 2003
Complex Stakeholder Interactions
Influence Policy Goals

Sample decomposition and mapping for NASA exploration
(Cameron 2007)
Example Policy Constraints: US Space Policy Issues

- Budget restrictions
- Space programs as cooperative foreign policy tools
- Export restrictions on space products
- Restrictions on foreign launches
- Space control
- Operational responsiveness
- Balancing national priorities

Written policies captured as constraints in MATE method
Policy Impact on System Architecture: Influence Diagrams

- Understand policy impacts at early (architecture) stages
- Framework shows flowdown to technical domain, (e.g., design variables)

**Generic Flow of Policy Impacts into Technical Domain**

### Discoverer II Example (Weigel 2002)
(Space-based GMTI mission)

- **Policy Direction**
  - International partners
- **Architecture Objectives**
  - data delivery requirements
  - security requirements
  - % earth coverage requirements
- **Technical Parameters**
  - Location of user sites
  - Size of pipes
  - Encryption scheme
  - # of satellites
  - Instrument field of view
  - Orbit

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Policy influence can be traced to technical (design) parameters, often treated as constraints on allowable enumerations in a MATE study. (Weigel 2002)
Policy Impact on System Architecture: MATE Tradespace


Cost Impact of U.S. Launch Policy on “B-TOS” Mission

Weigel and Hastings 2004
Cost-Capping Policy Intervention

- Cost-capping government program expenditures is most frequently reported government policy intervention
  - Annual program budget capped by Congress
  - Capping stretches out program duration and increases total program costs as a result
- Historical examples provide basis for relationship between schedule extension and cost growth

\[
y = 0.2365x + 1.6987 \\
R^2 = 0.5579
\]

Schedule extension and resulting cost change relationship

\[c = 0.24s + 1.7\]
where \(c\) = % cost change, and \(s\) = % schedule change

Cost-Capping: MATE Tradespace

Policy Intervention: $35M annual program budget cap imposed by Congress

Cost Impact of Program Budget Cap on “B-TOS” Mission

Cost-capping policy differentially pushes tradespace Pareto Front to the right

(Weigel 2004b)
**Application of Real Options: B-TOS Cost-Capping**

**Stage 0:**
No Pareto architectures affected

**Transition at:**
\( \frac{c_{\text{max}}}{d_{\text{max}}} > b_i \)

**Stage I:**
Some Pareto architectures affected

**Transition at:**
\( \frac{c_{\text{min}}}{d_{\text{min}}} > b_i \)

**Stage II:**
All Pareto architectures affected

Transition option has no value in Stage 0, because there is no need to transition.

Transition option has value in Stage I

When
\[
\frac{c_{\text{max}}}{d_{\text{max}}} > b_i \\
\text{and} \quad \frac{c_{\text{min}}}{d_{\text{min}}} < b_i
\]

Transition option has no value in Stage II, because there is no architecture in the Pareto set to transition to.
Goal of analysis: Use real options analysis to measure value of designing architecture to accommodate budget policy instability

- **Scenario**
  - Future budget levels are uncertain
  - Pursue initial architecture choice
  - When budget is cut, program manager may want to transition to a new, lower budget architecture

- **What is the value of a transition architecture option, which provides insurance against budget policy instability and makes a program more policy robust?**

- **Real options useful for valuing projects under uncertainty**
How might program managers acquire real options in practice?

- Risk mitigation strategy against uncertainties
  - Insurance policy (e.g., hedge against budget instability)
- “Purchasing” means funding the design of the unique elements of an alternative architecture
  - Assess commonalities and differences between baseline and candidate transition architectures
  - Co-develop unique elements such that alternative architecture is at similar level of maturity if transition is required
- B-TOS example
  - Assume architecture D is initially chosen and architecture A is held as a transition option
  - Unique technical challenge of A is reduction of swarm radius to .18 km
  - Option costs
    - Development of higher precision attitude control
    - Development of thruster plume impingement management strategy
Pathway to Policy-Robust System Architectures

1. Understand the system architecting domain framework, the specific players involved for your project, and their motivations

2. Identify the important current policy issues relevant to your system

3. Construct influence diagrams for each policy issue, at each stage of your architecture creation and system design, to assess which policy issues most greatly impact your system

4. Identify on influence diagrams which policy impact paths can be understood mathematically and which cannot

5. Seek expert opinion to evaluate those policy impact paths that cannot be understood mathematically

6. Quantify the effects of those impact paths that can be understood mathematically, assess the volatility of the policy issues they stem from, and assess the value of designing for changes in those policies

7. Take the necessary action indicated by preceding analyses to ensure a policy robust architecture

*Weigel 2002*
Balancing Technical and Political Goals

**Technical optimality**: Performance/cost of the physical system that is designed to meet a specified goal

**Political feasibility**: Implementation and acceptability concerns

In addition to “designing for policy robustness” one can also consider the matter a balancing of technical with political considerations
Example: Chicago Airport Express

Chicago Airport Express

Cab fare ~ $45
Chicago Airport Express
## Architecture Concept Scoping

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Concepts</th>
<th>Abbreviation</th>
<th>Description</th>
<th>Rejected?</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Base case</td>
<td>Base</td>
<td>Minimal improvement to status quo infrastructure</td>
<td>yes</td>
<td>Requirements specify minimal improvement from status quo</td>
</tr>
<tr>
<td>1</td>
<td>Direct service</td>
<td>Route 1a</td>
<td>Train solution, shared tracks with local train</td>
<td>yes</td>
<td>Violates reliability requirement of 80% on time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Route 1b</td>
<td></td>
<td>yes</td>
<td>Cannot be financed based on willingness to pay information</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>from stakeholder interviews</td>
</tr>
<tr>
<td>2</td>
<td>Express service</td>
<td>Route 2</td>
<td>Train solution, individual right-of-way</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Bus Rapid Transit</td>
<td>BRT1</td>
<td>Rapid buses on Kennedy Expressway, no separate lane</td>
<td>yes</td>
<td>Violates reliability requirement of 80% on time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BRT</td>
<td>Rapid buses on separate lane of Kennedy Expressway</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Blue Line Switch</td>
<td>BLS</td>
<td>Rapid buses on separate lane on Kennedy Expressway replacing local train</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Airport Express on freed-up tracks from base case</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Nickel 2010)

Three architecture concepts meet cost constraint and Minimum reliability requirements -> Further MATE analysis

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Rights-of-way of Architecture Concepts

“Right-of-way”: The strip of land over which is built a public “road” or public utility

(Merriam-Webster online, www.m-w.com, cited 7/22/10)
Rights-of-way of Architecture Concepts

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(Merriam-Webster online, www.m-w.com, cited 7/22/10)
City Tradespace (by concept)

Concept = BRT, Fare = $10
Frequency = 8 min
Travel time = 27 min
Amenities = 1
Span of service = 19 hrs
City Cost Share = 10%
Comp agreements = 5
Freed. to make changes = 4
CTA paym. = 15

Quality of Service:
- Fare level
- Frequency
- Travel time
- Amenities
- Span of service

Red (Route 2) is the only concept planners had initially considered
Private Operator Tradespace (by concept)

Red (Route 2) is the only concept planners had initially considered.
## Political Feasibility Dimension

<table>
<thead>
<tr>
<th>Concept</th>
<th>Implementation concern</th>
<th>New design variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route 2</td>
<td>Financing</td>
<td>-</td>
</tr>
<tr>
<td>BRT</td>
<td>• Image/ Prestige&lt;br&gt;• Visibility of underused dedicated lane&lt;br&gt;• Increased congestion on Kennedy Expressway</td>
<td>• Marketing of service&lt;br&gt;• Lane use policy</td>
</tr>
<tr>
<td>Blue Line Switch Option</td>
<td>Workforce turnover</td>
<td>-</td>
</tr>
</tbody>
</table>

Fuzzy non-technical concerns<br>Make or break a project

Some implementation challenges can be mitigated -> new design variables
Adding Political Feasibility Dimension to MATE

Technical and cost models

(DV₁, DV₂, ..., DVₘ) → (X₁, X₂, ..., Xₙ) → U(X)

Utility models, based on stakeholder interviews

Explore tradespace

1. Present to policymakers/planners
2. Evaluate implementation concerns
3. Generate new design variables
a) Designs **should not be ruled out early** on because of political feasibility concerns **since** those **concerns can sometimes be mitigated.**

b) **Alternating focus** on political feasibility and technical optimality **suggests and explores new design variables** that can mitigate implementation concerns, thereby broadening design space, and possibly helping to make more informed decisions.

**Political feasibility can be addressed through tradespace exploration**
Concluding Remarks

• Policy robustness is critical to sustaining large programs such as government space programs
  – Technical performance is only one of many requirements for a successful program
  – Need political mandate / business case and validated user needs

• System architecture navigates flow of policy to technical system

• Policy impacts may be assessed qualitatively and quantitatively
  – Influence diagrams
  – Cost impact estimating relationships
  – Real options analysis

• Methods may be used prescriptively by MATE analysts

Make policy an active consideration in systems architecting and design
References

- Crawley, E. (2007). ESD.34 lecture notes, graduate MIT course on system architecture.