RESEARCH OVERVIEW

Managing Uncertainty in Complex Systems and Enterprises using Real Options

Tsoline Mikaelian, Doctoral Research Assistant
tsoline@mit.edu
October 16, 2007

Committee: D. Hastings (Chair), D. Nightingale, and D. Rhodes
Researcher’s Background
Tsoline Mikaelian

• Education
  – Doctoral student in Aeronautics and Astronautics
  – M.S. Aerospace Engineering (MIT, 2005)
  – B.S. Space and Communication Sciences (York University, 2002)

• Research Interests
  – Decision-making under uncertainty in complex systems and enterprises
  – Flexibility as means to managing uncertainty
  – Automated diagnosis and repair of complex systems

• Professional Experience
  – Model-based Embedded Robotic Systems group at MIT
Motivation

• Complex systems and enterprises are subject to uncertainties that may lead to suboptimal performance or failure if unmanaged.

• **Flexibility** may provide a means to managing uncertainties
  – Ability to reconfigure or adapt to unanticipated conditions, changing objectives
  – Real options approach shown to be promising for uncertainty management in technical system design

• “Think globally, act locally” philosophy to decision making: holistic analysis of factors that influence and will be influenced by decisions/actions
  – Integrating the silo’s
  – multiple dimensions within enterprise, ranging from strategy, organization to product
Project Title: An Engineering Systems Analysis of Systems Architecture Issues with a Swarm of Mini Air Vehicles (MAV)

Sponsor: SINGAPORE DSO

Goal: Development of a new framework for decision making under uncertainty for complex systems (that have many interacting components)

Approach:
• Representation frameworks
  – Capture interactions among various dimensions within an enterprise, including organizational and technical
• Analytical methods
  – Leverage “holistic” representation for better decision making within the enterprise
  – Real options in complex systems and enterprises
Research Goal

Development of new frameworks for decision making under uncertainty for complex systems (that have many interacting components)
⇒ Assess the various options for a UAV development project
Key Challenges

- **Technical:** Modeling and analysis of various technology options in order to enhance the ability to make decisions related to investments on the component technologies.
  - Investments in new technologies
  - Technology make-buy decisions
  - Technology maturity
  - Robustness of system architecture to operational uncertainties

- **Organizational:** What type of organizational structure would be suitable for this type of UAV system and the make up of its components?
  - The inclusion of industrial partners to work on the development of UAV at some phase of the effort.
  - Contribution to strategic objectives of organization
  - Operator training
Representation Frameworks for Socio-Technical Systems

<table>
<thead>
<tr>
<th>Evaluation Criteria for Scope</th>
<th>QFD</th>
<th>UPP</th>
<th>Axiomatic Design</th>
<th>DSM</th>
<th>DSM/MM Framework</th>
<th>DoDAF</th>
<th>CIOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Represents Social Domain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Represents Functional Domain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Represents Technical Domain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Represents Process Domain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Represents Environmental Domain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Represents Interactions within Domains</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Represents Interactions across Domains</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Conducive for Quantitative Analysis</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Captures System Changes Over Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

(Source: J. Bartolomei dissertation, MIT)

Existing frameworks lack an end-to-end representation of a socio-technical system.
Design Structure Matrix (DSM)

Representation of dependencies and flows as a matrix

Example: task-based DSM

http://www.dsmweb.org/
### DSM: Stakeholders

#### Stakeholders:

<table>
<thead>
<tr>
<th>External stakeholders</th>
<th>Internal stakeholders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer: Singapore Army</td>
<td>DSO: UAV development team</td>
</tr>
<tr>
<td>Customer: Civilian Agencies</td>
<td>DSO: finance group</td>
</tr>
<tr>
<td>DRD - Directorate of R&amp;D</td>
<td>DSO: resource planning group</td>
</tr>
<tr>
<td>Joint Plans</td>
<td>DSO: technical risk assessment group</td>
</tr>
<tr>
<td>DSTA - Defense Science and Technology Agency</td>
<td>DSO: Management and Quality Assurance group</td>
</tr>
<tr>
<td>DSO: Technical support group</td>
<td>DSO: procurement group</td>
</tr>
<tr>
<td>DSO: Engineering and Customer Feedback</td>
<td>DSO: other labs within DSO</td>
</tr>
<tr>
<td>DSO: other labs within DSO</td>
<td></td>
</tr>
</tbody>
</table>

Row gives:
- **Green**: Funds to
- **Red**: Product to
- **Blue**: Development Support to
- **Gray**: Information to

Column gives:
- **1**: Co-located
- **2**: Advanced notice
- **3**: Documentation
- **4**: Visits
- **5**: Meetings
- **6**: Correspondence
- **7**: Collaboration
- **8**: Coordination
- **9**: Communication
- **10**: Other

---

*Note: The diagram and table represent stakeholder relationships and interactions in the context of the DSM framework.*
Coupled DSM

System Drivers
Stakeholders
Objectives
Functions
Objects
Activities

End-to-end representation of both inter-domain and intra-domain dependencies within a socio-technical system.

Holistic view useful for change propagation, traceability, and systems analyses.
Activity Clustering

Meta-tasks emerged:

- Equipment Specification and Layout
- Airframe Design
- Equipment Development
- Avionics and Software
- Vehicle Integration
- Testing
Real Options Analysis

“Managing Operational Uncertainties using Real Options”, Conference on Systems Engineering Research (CSER 2007)

• What are operational uncertainties?
  – factors that may change during the operational life of the system, such that they have a potential impact on the requirements, capabilities or performance of the system.
  – directly concern the end user of a system.
    • Eg. Uncertainty in mission duration

• Why manage operational uncertainties?
  – minimize risk and take advantage of opportunities.

• How to manage operational uncertainties?
  – operational option as a real option for managing operational uncertainty by the end user, through the opportunity, but not the obligation, to execute the option during the operational life of the system.
    • Eg. Extra battery is an option that enables extended mission
C-DSM to Real Options

- C-DSM can be used in real options analysis to identify stakeholder preferences, operational uncertainties and technical design levers.
- Real options investments in the technical system may be used to manage operational uncertainties.
Design Valuation

- Consider battery mass budget

<table>
<thead>
<tr>
<th>Design</th>
<th>Battery Mass (gm)</th>
<th>Total Mass (gm)</th>
<th>Endurance (hr)</th>
<th>Cost/MAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed S</td>
<td>88</td>
<td>504</td>
<td>1.005</td>
<td>$1,234.96</td>
</tr>
<tr>
<td>Fixed L</td>
<td>219</td>
<td>635</td>
<td>2.004</td>
<td>$1,271.64</td>
</tr>
<tr>
<td>Flexible</td>
<td>88 + extra 132</td>
<td>639</td>
<td>2.001</td>
<td>$1,281.84</td>
</tr>
</tbody>
</table>

Optimized for:
- Short duration
- Long duration

Option to insert extra battery

Map designs considered to profits per short and long duration flights.

Calculate a Net Present Value (NPV) for each design using probabilistic lattice model of % long duration missions.

Pick the design with highest NPV

In this case: Flexible design
Research Questions

- Can real options be used to manage uncertainties in enterprises? What are the current practices?

- **Type:** What are some examples/kinds of real options that encompass the socio-technical aspects of an enterprise?

- **Identification:** Can the C-DSM or other end-to-end systems representations be used to identify potential real options opportunities within the enterprise?

- **Valuation:** How to quantify the value of real options in enterprises to enable the selection of an options portfolio in enterprise decision making?
Anticipated Contributions

**Expected Outcomes:**
- Extending the real options approach to enterprise decision making
- Case study of UAV swarm project

**Broader Impact:**
- Framework for recommending portfolio of options investments for managing uncertainty
- Applicability to complex systems and enterprises

**Knowledge Deployment:**
- Paper at 2008 Conference on SE Research (CSER)
- Future journal paper on technical effort
