2009 SE Ari Annual Research Summit

Research Report
“An Integrated Real Options Framework for Model-based Identification and Valuation of Options under Uncertainty”

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Cambridge, MA
Massachusetts Institute of Technology
Outline

- Motivation
- Problem Statement
- Background, limitations in relevant areas
- Contribution: Integrated Real Options Framework
- Conclusions

PhD in Aeronautics and Astronautics, June 2009
Thesis Committee:
Dean Daniel Hastings (Chair)
Prof. Deborah Nightingale
Dr. Donna Rhodes
Uncertainty Management for Complex Systems and Enterprises

uncertainty in operations and environment

uncertainty in mission requirements

economic uncertainty, market demands cost of fuel

How to manage uncertainties facing enterprises that develop or operate complex systems?
The Need for Flexibility

Focus on flexibility as a means of managing uncertainties

Flexibility: ability to undergo change with relative ease

- flexibility to repair?
- use alternative vehicle?
- flexibility in UAV design?
- swarm architecture?
- use a satellite?
- flexibility in manufacturing?
- design (hybrid car)?
- business strategy? purchasing?
The Need for Flexibility

flexibility to repair? use alternative vehicle?
flexibility in UAV design? swarm architecture? use a satellite?
flexibility in manufacturing? design (hybrid car)? business strategy? purchasing?

Challenge: holistic identification and valuation of flexibility
Terminology

**Flexibility:**
ability to undergo change with relative ease *

**Real options analysis:**
a means of modeling and valuation of flexibility

**Real option:**
right, but not the obligation, to take an action in the future

**Enterprise:**
defined scope of economic organization or activity, which will return value to the participants through their interaction and contribution *

* MIT Engineering Systems Division definitions
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Research Problem

How can real options be used for holistic decision making within socio-technical enterprises under uncertainty?

Develop a model based, holistic framework to systematically identify and value:

- What type of flexibility, if any, is desirable to manage uncertainty?
- How to enable flexibility?
- Where to enable flexibility in an enterprise?
Outline

• Motivation

• Problem Statement

• Background

• Contribution: Integrated Real Options Framework

• Conclusions
Research Focus

(decision making under uncertainty in enterprise context)

- Enterprise Architecture
- Real Options Theory
- Knowledge Representation using C-DSM

(model based analysis)

(quantifying the value of flexibility)
Research Focus

(decision making under uncertainty in enterprise context)

Enterprise Architecture

Real Options Theory

Knowledge Representation using C-DSM

(quantifying the value of flexibility)

(model based analysis)
## Architecture Frameworks

**What kind of Enterprise Architecture Framework does your organization use?**

<table>
<thead>
<tr>
<th>Framework</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zachman Framework</td>
<td>25%</td>
</tr>
<tr>
<td>FEAF, US Federal Enterprise Architecture Framework</td>
<td>9%</td>
</tr>
<tr>
<td>TOGAF, the Open Group Architecture Framework</td>
<td>11%</td>
</tr>
<tr>
<td>IAF, Capgemini's - Integrated Architecture Framework</td>
<td>3%</td>
</tr>
<tr>
<td>ISO/IEC 14259, Std 1003</td>
<td>11%</td>
</tr>
<tr>
<td>Extended Enterprise Architecture Framework (E2AF)</td>
<td>9%</td>
</tr>
<tr>
<td>TEAF, US Treasury Enterprise Architecture Framework</td>
<td>0%</td>
</tr>
<tr>
<td>TAFIM, US Defense Technical Architecture Framework</td>
<td>11%</td>
</tr>
<tr>
<td>Organization own</td>
<td>22%</td>
</tr>
<tr>
<td>Other</td>
<td>9%</td>
</tr>
<tr>
<td>None</td>
<td>0%</td>
</tr>
</tbody>
</table>

(J. Schekkerman, 2005)

**Comparison of frameworks for representing complex engineering systems**

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

(Bartolomei, 2007)
Eight Views of Enterprise Architecture

<table>
<thead>
<tr>
<th>Strategy</th>
<th>The goals, vision and direction of the enterprise, including the business model and competitive environment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy</td>
<td>The external regulatory, political and societal environments in which the enterprise operates, as well as policies internal to the enterprise.</td>
</tr>
<tr>
<td>Organization</td>
<td>The organizational structure as well as the relationships, culture, behaviors, and boundaries between individuals, teams and organizations.</td>
</tr>
<tr>
<td>Process</td>
<td>The core, enabling and leadership processes by which the enterprise creates value for its stakeholders.</td>
</tr>
<tr>
<td>Product</td>
<td>The product architectures of the enterprise. <strong>Traditional system architecture</strong></td>
</tr>
<tr>
<td>Service</td>
<td>The architecture of the services of the enterprise, including service as a primary objective or in support of products.</td>
</tr>
<tr>
<td>Knowledge</td>
<td>The implicit and tacit knowledge, capabilities, intellectual property resident in the enterprise.</td>
</tr>
<tr>
<td>Information Tech.</td>
<td>The information needs of the enterprise including the flows of information as well as the systems and technologies needed to ensure information availability.</td>
</tr>
</tbody>
</table>

(Nightingale and Rhodes, 2007, 2009) **Traditional “enterprise architecture”**
Eight Views of Enterprise Architecture

(Nightingale and Rhodes, 2007, 2009)
Research Focus

(decision making under uncertainty in enterprise context)

- Enterprise Architecture
- Real Options Theory
- Knowledge Representation using C-DSM

(quantifying the value of flexibility)

(model based analysis)
Simple Financial Options

Financial option: right, but not the obligation, to buy or sell an underlying security at a specified price, on or before expiration date of the option

Real option: right, but not the obligation, to take an action in the future

Methods for valuation of financial options: Black-Scholes, binomial pricing, Monte Carlo
Real options analysis is a means of modeling and valuation of flexibility.

Classical ROA Application

$ \quad \text{“Real option” to abandon, expand} \quad \text{time}

Example: invest in new manufacturing plant? real option to abandon plant to manage demand uncertainty
Real Options Analysis (ROA)

Real options analysis is a means of modeling and valuation of flexibility.

Classical ROA Application

$ \rightarrow \text{“Real option” to abandon, expand} \rightarrow \text{time}$

Example: invest in new manufacturing plant? real option to abandon plant to manage demand uncertainty

Application of ROA in design

$\rightarrow \text{“Real option” in design} \rightarrow \text{Flexibility to change design} \rightarrow \text{time}$

Example: modular payload bay in mini air vehicle switch payloads to manage requirements uncertainty
Real Options Analysis (ROA)

Real options analysis is a means of modeling and valuation of flexibility.

Classical ROA Application

$ \quad \text{"Real option" to abandon, expand} \quad \text{time}$

Application of ROA in design

\text{“Real option” in design} \quad \text{Flexibility to change design} \quad \text{time}

1. Isolated Applications of ROA
2. Varying uses of “real option” terminology
Outline

• Motivation

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• Contribution: Integrated Real Options Framework

• Conclusions
Real Options Silos

- Emphasis on sources of flexibility
- Emphasis on future flexibility

- Real Options On Projects (Strategy)
- Real Options In Projects (Product Design)

- Classical ROA Application
- Application of ROA in design

- "Real option" to abandon, expand
- "Real option" in design
- Flexibility to change

- $ uncertainty

Real Options Silos

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1. Real Option Mechanism:
   actions/decisions that enable a real option

2. Real Option Type:
   actions/decisions that may be exercised by the owner of the real option
Real Options: Mechanisms and Types

Real option = right but not obligation to:

 implement mechanism

(at a cost >=0)

Implement Mechanism

Do nothing

Exercise specific Type of action or decision

(at a cost >=0)

Real option enabled

Real option expires

Time, Uncertainty

Examples:

Modular payload bay → Switch payload: to manage uncertainty in mission type

Patenting → License patent: to manage uncertainty in demand for technology
Managing Uncertainty with Options

Without option:

Uncertainty → Value Metric

With option:

Uncertainty → Type of Option → Value Metric

(switch)

Mechanism that enables Option

(enabler)
Integrating the Real Options Silos

Traditional View

Holistic View

Real Option Type

In (Design)          On (Strategy)

MAV design enables a reuse option in future design  MAV design enables future market expansion

Real Option Mechanism

In (Design)          On (Strategy)

MAV development partnership enables option to use new type of technology in design  Investment in MAV project enables option to expand development to swarm in future

→ Explore interactions between “real option silos”

May “classify” the location of both the mechanism and type of real option

MAV = Mini Air Vehicle
Mapping to Enterprise Views

→ Mechanisms, types may exist within any of the enterprise views
Relations among mechanisms and types of options

\[ \text{M = mechanism} \]
\[ \text{T = type} \]
\[ \text{V = enterprise view} \]

\[ M = \{M_i\}, \ i = 1..n \]
\[ T = \{T_j\}, \ j = 1..m \]

\[ (\forall M)(\forall n)(\forall i \in \{1..n\}) : (\exists V | M_i \in V) \]
\[ (\forall T)(\forall m)(\forall j \in \{1..m\}) : (\exists V | T_j \in V) \]
# Types of real options

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Important in:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option to Defer</td>
<td>Management has opportunity to wait to invest, and can see if markets warrant further investment.</td>
<td>Natural resources extraction, real estate, farming, technology.</td>
</tr>
<tr>
<td>Staged Investment</td>
<td>Staging investment creates the option to reevaluate and/or abandon at each stage.</td>
<td>R&amp;D intensive industries, energy generation, start-up ventures.</td>
</tr>
<tr>
<td>Option to alter operating scale</td>
<td>If market conditions change, the firm can expand/contract or temporarily shut down.</td>
<td>Natural resources, fashion, real estate, consumer goods.</td>
</tr>
<tr>
<td>Option to abandon</td>
<td>If market conditions decline, management sells off assets</td>
<td>Capital-intensive industries, new product introductions in uncertain markets.</td>
</tr>
<tr>
<td>Option to switch</td>
<td>If prices or demand change, management can change product mix (product flexibility) or switch inputs (process flexibility)</td>
<td>Companies in volatile markets with shifting preferences, energy companies.</td>
</tr>
<tr>
<td>Growth options</td>
<td>An early investment opens up future growth opportunities in the form of new products or processes, access to markets, or strengthening of core capabilities</td>
<td>High tech; industries with multiple product generations (drug companies, computers, strategic acquisitions).</td>
</tr>
<tr>
<td>Multiple Interacting Options</td>
<td>Projects involve a collection of various options—both put and call types. Values can differ from the sum of separate option values because they interact.</td>
<td>Many of the industries discussed above</td>
</tr>
</tbody>
</table>

(Fig. Source: D. Jenter)
Patterns of mechanisms

Some examples:

<table>
<thead>
<tr>
<th>Mechanism Patterns</th>
<th>Instantiation Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modularity</td>
<td>modular architecture (product)</td>
</tr>
<tr>
<td></td>
<td>task clustering (process)</td>
</tr>
<tr>
<td>Redundancy</td>
<td>multi sourcing (strategy)</td>
</tr>
<tr>
<td></td>
<td>spares (product)</td>
</tr>
<tr>
<td>Buffering</td>
<td>cross-training (knowledge)</td>
</tr>
<tr>
<td></td>
<td>reserve funds (strategy)</td>
</tr>
<tr>
<td>Staging</td>
<td>R&amp;D investment (strategy)</td>
</tr>
<tr>
<td></td>
<td>staged deployment of satellites (process)</td>
</tr>
</tbody>
</table>

→ May be instantiated within one or more enterprise views

→ Support identification and creation of sources of flexibility
Integrated Real Options Framework

1. Enterprise Modeling

- Catalog of potential real options mechanisms and types
  - Patterns, cases

- Model of Uncertainties

- C-DSM Model Of Enterprise Views

- Method of exploring feasible mechanisms and types

- <Mechanism, Type> candidates

- Real Options Valuation

- Baseline candidates (without options)

- Decision
Integrated Real Options Framework

1. Enterprise Modeling
2. Model-based identification of sources and types of flexibility
1. Enterprise Modeling
2. Model-based identification of sources and types of flexibility
3. Is flexibility worthwhile?

Catalog of potential real options mechanisms and types

Model of Uncertainties

C-DSM Model of Enterprise Views

Method of exploring feasible mechanisms and types

<Mechanism, Type> candidates

Real Options Valuation

Decision

Baseline candidates (without options)
## Deployment Scenarios

### Swarm Configurations for LRR and HRR Missions

<table>
<thead>
<tr>
<th>Swarm</th>
<th>Low Revisit Rate</th>
<th>High Revisit Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short range comm.</td>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Long range comm.</td>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>Heterogeneous</td>
<td><img src="image5" alt="Diagram" /></td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
</tbody>
</table>
### Mechanisms, types of options across enterprise views

<table>
<thead>
<tr>
<th>Mechanism that enables real option</th>
<th>Type of real option</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strategy</strong></td>
<td></td>
</tr>
<tr>
<td>Acquisition of UAV Swarm (short range comm.)</td>
<td>Strategy</td>
</tr>
<tr>
<td>Acquisition of UAV Swarm (long range comm.)</td>
<td></td>
</tr>
<tr>
<td>Acquisition of Heterogeneous UAV Swarm</td>
<td></td>
</tr>
<tr>
<td>Acquisition of High Altitude UAV</td>
<td></td>
</tr>
<tr>
<td>Acquisition of Satellites</td>
<td></td>
</tr>
<tr>
<td>Acquisition of Spare Helicopters</td>
<td></td>
</tr>
<tr>
<td><strong>Policy</strong></td>
<td></td>
</tr>
<tr>
<td>Regulations to integrate UAV operations into National Airspace</td>
<td>Policy</td>
</tr>
<tr>
<td><strong>Organization</strong></td>
<td></td>
</tr>
<tr>
<td>Create Satellite Operations Division</td>
<td>Organization</td>
</tr>
<tr>
<td>Partner with peer organizations</td>
<td></td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td></td>
</tr>
<tr>
<td>Training of additional pilots</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td></td>
</tr>
<tr>
<td>Develop UAV with adjustable range comm.</td>
<td>Product</td>
</tr>
<tr>
<td><strong>Service</strong></td>
<td></td>
</tr>
<tr>
<td>Subscribe to satellite imagery provider service</td>
<td>Service</td>
</tr>
<tr>
<td><strong>Knowledge</strong></td>
<td></td>
</tr>
<tr>
<td>License patent for comm. system design</td>
<td>Knowledge</td>
</tr>
<tr>
<td><strong>IT/Resource</strong></td>
<td></td>
</tr>
<tr>
<td>IT system upgrade to acquire real time satellite imagery</td>
<td>IT/Resource</td>
</tr>
</tbody>
</table>

- Deploy sparse swarm
- Deploy dense swarm
- Mobilize helicopter pilots
- Operate high altitude UAV
- Request high rate satellite imagery
- Request low rate satellite imagery
• Flexibility to change swarm density valuable when % high revisit rate missions is initially less than ~ 70%

• Heterogeneous swarm enables less valuable option than LR swarm in this case
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Conclusions

• The integrated real options framework enables holistic identification, synthesis and analysis of mechanisms and types of real options for uncertainty management in an enterprise

• <Mechanism, type> conceptualization should be adopted to emphasize sources of flexibility across the enterprise and support integration of real option silos

• Mapping of mechanisms, types of options and their relations to enterprise views is a generalized classification that encompasses many others and can promote systematic thinking about flexibility