Valuing System Flexibility via Total Ownership Cost Analysis

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Outline

Research Project Context

• Flexibility Definitions and Common Cases
• Total Ownership Cost (TOC) Results to Date
  – Advantages, Challenges, Strategies
  – TOC Analysis for Foreseeable Change
    • For individual systems
    • For families of systems
  – Conclusions and Candidate Extensions
    • Refined and extended model capabilities
    • Integration with alternative valuation models
• Part of SERC Valuing Flexibility Research Task
  – For DDR&E Director of Systems Engineering Steve Welby

• Provide business cases for investing in system flexibility
  – Vs. buying more copies of less flexible systems

• Performed by multi-university team
  – Texas A&M, AFIT, NPS, USC, U. Virginia

• Using multiple analysis approaches
  – Knowledge Value Added, Option Hedging, Portfolio Analysis, Risk Analysis, Total Ownership Cost (TOC) Analysis
Flexibility Definitions and Common Cases

- Working definition of “flexibility”
  - Ability to adapt cost-effectively to sources of change
- Foreseeable sources of change
  - Within single system: encapsulate sources of change
  - Across family of systems: use commonalities and variabilities
- Unforeseeable sources of change
  - Build in analysis of change traffic, adaptability
  - Build in system margins
- Classes of change effects
  - Capabilities, interfaces, levels of service, project constraints, improvement opportunities
Total Ownership Cost (TOC) Approach

• TOC Advantages, Challenges, Strategies
  – Representative examples

• TOC Analysis for Foreseeable Change
  – Model and tool for individual systems
    • Calibrated to TRW software data (3 systems)
    • Exploring calibration to NPS SHIPMAIN hardware data
  – Model and tool for families of systems
    • Calibrated to COCOMO II software data (161 projects)
    • Exploring calibration to AFIT modular munitions hardware data

• Candidate Extensions
  – Refined and extended model capabilities
    • Particular domains, tradeoff analyses, enterprise analysis
    • Effects of adaptation to unforeseeable change
  – Integration with alternative valuation models
• **TOC Advantages**
  – Increasingly required (DoDI 5000.02, WSARA 2009)
  – Easy to understand across specialty domains
  – Clear cause-effect relationships, straightforward calibration

• **TOC Challenges**
  – Defining flexibility investment costs, resulting cost reductions
    • Rework and change-adaptation cost reductions a proxy for benefits
  – Predicting uncertain futures

• **TOC Approach Strategies**
  – Tailor analysis approaches to common situations
    • DoDI 5000.02 milestone reviews, make-or-buy decisions
  – Explicitly emphasize need to define evolution requirements
    • Not just snapshot capability, interface, KPP, project requirements
  – Start with simple models and tools, refine and extend as needed
• Research Project Context
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Point-Solution Architectures Cause Major Rework
Contracts: Nominal-case requirements; 90 days to PDR

% of Cost to Fix SPR’s

TRW Project B
1005 SPR’s

TRW Project A
373 SPR’s

% of Software Problem Reports (SPR’s)

Major Rework Sources:
Off-Nominal Architecture-Breakers
A - Network Failover
B - Extra-Long Messages

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### Projects A and B Major Rework Sources

- Change processing over 1 person-month = 152 person-hours

<table>
<thead>
<tr>
<th>Category</th>
<th>Project A</th>
<th>Project B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra long messages</td>
<td>3404+626+443+328+244= 5045</td>
<td></td>
</tr>
<tr>
<td>Network failover</td>
<td>2050+470+360+160= 3040</td>
<td></td>
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<tr>
<td>Hardware-software interface</td>
<td>620+200= 820</td>
<td>1629+513+289+232+166= 2832</td>
</tr>
<tr>
<td>Encryption algorithms</td>
<td></td>
<td>1247+368= 1615</td>
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<tr>
<td>Subcontractor interface</td>
<td>1100+760+200= 2060</td>
<td></td>
</tr>
<tr>
<td>GUI revision</td>
<td>980+730+420+240+180 =2550</td>
<td></td>
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<tr>
<td>Data compression algorithm</td>
<td></td>
<td>910</td>
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<tr>
<td>External applications interface</td>
<td>770+330+200+160= 1460</td>
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<tr>
<td>COTS upgrades</td>
<td>540+380+190= 1110</td>
<td>741+302+221+197= 1461</td>
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<tr>
<td>Database restructure</td>
<td>690+480+310+210+170= 1860</td>
<td></td>
</tr>
<tr>
<td>Routing algorithms</td>
<td></td>
<td>494+198= 692</td>
</tr>
<tr>
<td>Diagnostic aids</td>
<td>360</td>
<td>477+318+184= 979</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>13620</strong></td>
<td><strong>13531</strong></td>
</tr>
</tbody>
</table>
When investments made in architecture, average time for change order becomes relatively stable over time…

# Single-System TOC Model Example

<table>
<thead>
<tr>
<th>Input Parameters</th>
<th>System</th>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Software Size (KSLOC)</td>
<td>100</td>
<td>100</td>
<td>355</td>
</tr>
<tr>
<td># Change Requests/Release</td>
<td>373</td>
<td>1005</td>
<td>1600</td>
</tr>
<tr>
<td># Change Requests (I&amp;T only)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># I&amp;T Change Requests/Release/ &gt; 1 PM</td>
<td>27</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td># Total Change Requests/Release/ &gt; 1 PM</td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>Change Request Fix Time (See assumption #2)</td>
<td>261</td>
<td>356</td>
<td>263</td>
</tr>
<tr>
<td>Total Effort (Person Months)</td>
<td>731</td>
<td>865</td>
<td>1900</td>
</tr>
<tr>
<td>% Arch, RESL</td>
<td>5%</td>
<td>5%</td>
<td>25%</td>
</tr>
<tr>
<td>% Rework, RVOL</td>
<td>35.70%</td>
<td>41.16%</td>
<td>13.85%</td>
</tr>
</tbody>
</table>

## Cumulative Total Cost of Ownership

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Project A</th>
<th>Project B</th>
<th>Project C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40.70%</td>
<td>46.16%</td>
<td>38.85%</td>
</tr>
<tr>
<td>2</td>
<td>76.41%</td>
<td>87.31%</td>
<td>52.70%</td>
</tr>
<tr>
<td>3</td>
<td>112.11%</td>
<td>128.47%</td>
<td>66.55%</td>
</tr>
<tr>
<td>4</td>
<td>147.82%</td>
<td>169.62%</td>
<td>80.40%</td>
</tr>
<tr>
<td>5</td>
<td>183.52%</td>
<td>210.78%</td>
<td>94.25%</td>
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</tbody>
</table>
Valuing Flexibility via TOC

Relative* Total Ownership Cost (TOC)

* Cumulative architecting and rework effort relative to initial development effort
USC and NPS collaborating on modeling value of investing in product-line flexibility with Return-On-Investment (ROI) and Total Ownership Cost (TOC) parametric models

- System-level product line flexibility investment model
- Software product line flexibility investment model.
- Net present value (NPV) calculations included

Models adapted from the Constructive Product Line Investment Model (COPLIMO*)

- Special versions also developed for Daimler Chrysler and JPL

Systems Product Line Flexibility Value Model

For Set of Products:
- Average Product Cost
- Annual Change Cost
- Ownership Time
- Percent Mission-Unique, Adapted, Reused
- Relative Cost of Developing for PL Flexibility via Reuse
- Relative Costs of Reuse

As Functions of # Products, # Years in Life Cycle:
- PL Total Ownership Costs
- PL Flexibility Investment
- PL Savings (ROI)
Valuing Flexibility via TOC

## Systems Product Line Flexibility Value Model

Welcome SERC Collaborator

### System Costs

- **Average Product Development Cost (Burdened $M)**: 5
- **Ownership Time (Years)**: 3
- **Annual Change Cost (% of Development Cost)**: 10
- **Interest Rate (Annual %)**: 7

### Product Line Percentages

- **Unique %**: 40
- **Adapted %**: 30
- **Reused %**: 30

### Relative Costs of Reuse (%)

- **Relative Cost of Reuse for Adapted**: 40
- **Relative Cost of Reuse for Reused**: 5

### Investment Cost

- **Relative Cost of Developing for PL Flexibility via Reuse**: 1.7

### Results

<table>
<thead>
<tr>
<th># of Products</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development Cost ($M)</td>
<td>$7.1</td>
<td>$2.7</td>
<td>$2.7</td>
<td>$2.7</td>
<td>$2.7</td>
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<tr>
<td>Ownership Cost ($M)</td>
<td>$2.1</td>
<td>$0.8</td>
<td>$0.8</td>
<td>$0.8</td>
<td>$0.8</td>
<td>$0.8</td>
<td>$0.8</td>
</tr>
<tr>
<td>Cum. PL Cost ($M)</td>
<td>$9.2</td>
<td>$12.7</td>
<td>$16.2</td>
<td>$19.7</td>
<td>$23.1</td>
<td>$26.8</td>
<td>$30.1</td>
</tr>
<tr>
<td>PL Flexibility Investment ($M)</td>
<td>$2.1</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>PL Effort Savings</td>
<td>($2.7)</td>
<td>$0.3</td>
<td>$3.3</td>
<td>$6.3</td>
<td>$9.4</td>
<td>$12.4</td>
<td>$15.4</td>
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<tr>
<td>Return on Investment</td>
<td>-1.30</td>
<td>0.14</td>
<td>1.58</td>
<td>3.02</td>
<td>4.46</td>
<td>5.90</td>
<td>7.34</td>
</tr>
</tbody>
</table>

### Return on Investment

- Return on Investment values for different # of products:
  - Product 1: -1.3
  - Product 2: 0.1
  - Product 3: 1.6
  - Product 4: 3.0
  - Product 5: 4.5
  - Product 6: 5.9
  - Product 7: 7.3

<table>
<thead>
<tr>
<th>Product #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return on Investment</td>
<td>-1.3</td>
<td>0.1</td>
<td>1.6</td>
<td>3.0</td>
<td>4.5</td>
<td>5.9</td>
<td>7.3</td>
</tr>
</tbody>
</table>

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Sensitivity Analysis Example

ROI by Ownership Duration

ROI

# of Products

0 Years
3 Years
6 Years

0 2 3 4 5 6 7

10 8 6 4 2 0
Conclusions and Candidate Extensions

• TOC approach has several advantages
  – Increasingly required (DoDI 5000.02, WSARA 2009)
  – Easy to understand across specialty domains
  – Clear cause-effect relationships, straightforward calibration

• Important to determine evolution requirements

• Basic models available for foreseeable change
  – Individual systems, families of systems
  – Best to have calibration data

• Candidate Extensions
  – Refined and extended model capabilities
    • Particular domains, tradeoff analyses, enterprise analysis
    • Effects of adaptation to unforeseeable change
  – Integration with alternative valuation models