iTAP Methods, Processes and Tools

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www.sercuarc.org
Agenda

• End Vision

• Status

• Phase 4 Plans
  – Task 2: iTAP Methods and Tools Piloting and Refinement
  – Task 3: Next-Generation, Full-Coverage Cost Estimation Model Ensembles
Research Objectives

• Total Ownership Cost (TOC) modeling to enable affordability tradeoffs with integrated software-hardware-human factors

• Current shortfalls for ilities tradespace analysis
  — Models/tools are incomplete wrt/ TOC phases, activities, disciplines, SoS aspects
  — No integration with physical design space analysis tools, system modeling, or each other

• New aspects
  — Integrated costing of systems, software, hardware and human factors across full lifecycle operations
  — Extensions and consolidations for DoD application domains
  — Tool interoperability and tailorability (service-oriented)

• Can improve affordability-related decisions across all joint services
Approach

• Research and development
  — Create new ensemble of cost models with DoD stakeholders for broader coverage.
  — Enable interoperability with other toolsets and researchers (plug and play)

• Piloting and refinement
  — Engaging with DoD organizations to pilot the TOC methods, process and tools (MPTs); then refine them based on the results of the pilot applications
• Extended parametric cost models for breadth of engineering disciplines to include systems engineering, software engineering and hardware.

• Improved TOC capabilities by adding lifecycle maintenance models.

• Added Monte Carlo risk analysis for subset of cost parameters in integrated SE/SW/HW cost model.

• Initial extensions of general cost models for DoD system types starting with space systems and ships.

• Developed web service for Orthogonal Defect Classification Constructive Quality Model (ODC COQUALMO) supporting tool interoperability (costing in the cloud).

• Successful piloting and follow-on extensions of product line model at NAVAIR.
Extending models and tools to analyze TOC for a family of systems. The value of investing in product-line flexibility using Return-On-Investment (ROI) and TOC is assessed with parametric models adapted from the Constructive Product Line Investment Model (COPLIMO).

Models are implemented in separate tools for 1) System-level product line flexibility investment model and 2) Software product line flexibility investment model. The detailed software model includes schedule time with NPV calculations.
## Example Product Line TOC and ROI

**System Type:**
- Aircraft
- Ground Vehicle
- Missile
- Ship

**System Costs**
- Average Product Development Cost (Burdened $M): 5
- Ownership Time (Years): 3
- Annual Change Cost (% of Development Cost): 4
- 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

**Means**

<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>
<td>$2.7</td>
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<tr>
<td>Ownership Cost ($M)</td>
<td>$0.9</td>
<td>$0.3</td>
<td>$0.3</td>
<td>$0.3</td>
<td>$0.3</td>
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<tr>
<td>Cum. PL Cost ($M)</td>
<td>$8.0</td>
<td>$10.9</td>
<td>$13.9</td>
<td>$16.9</td>
<td>$19.9</td>
<td>$22.9</td>
<td>$25.9</td>
</tr>
<tr>
<td>PL Flexibility Investment ($M)</td>
<td>$2.1</td>
<td>$0.0</td>
<td>$0.0</td>
<td>$0.0</td>
<td>$0.0</td>
<td>$0.0</td>
<td>$0.0</td>
</tr>
<tr>
<td>PL Effort Savings</td>
<td>($2.4)</td>
<td>$0.3</td>
<td>$2.9</td>
<td>$5.5</td>
<td>$8.1</td>
<td>$10.7</td>
<td>$13.3</td>
</tr>
<tr>
<td>Return on Investment</td>
<td>-1.12</td>
<td>0.12</td>
<td>1.36</td>
<td>2.60</td>
<td>3.84</td>
<td>5.08</td>
<td>6.32</td>
</tr>
</tbody>
</table>

**Monte Carlo Results**
- Mean: 6.5
- SD: 1.3

---

**Legend:**
- **ROI:** Return on Investment
- **%:** Percentage
- **Mean:** Average
- **SD:** Standard Deviation
Sensitivity Analysis Example

ROI by Ownership Duration

- 0 Years
- 3 Years
- 6 Years

# of Products

ROI
Product Line Extension

• Multi-mission, multi-platform needs call for extension of the top-level COPLIMO model to handle subsystems. Immediate pilot applications include:
  — NAVAIR avionics software product line modeling
  — USAF/SMC spacecraft and ground systems cost model development

• Each subsystem has respective cost factors and product line characteristics including
  — Fractions of system fully reusable, partially reusable and cost of developing them for reuse
  — Fraction of system variabilities and cost of development
  — System lifetime and rates of change
Extended Product Line Model

For Set of Products:

For each subsystem:

• 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)
Example Single System TOC

<table>
<thead>
<tr>
<th>Systems Engineering</th>
<th>Software</th>
<th>Hardware</th>
</tr>
</thead>
</table>

**Systems Engineering Acquisition**
- Effort = 1767.4 Person-months
- Schedule = 17.7 Months
- Cost = $17.7 M

**Systems Engineering Maintenance (15 Years)**
- Annual Cost = $1.5 M
- Total Cost = $23.1 M

**Software Development (Elaboration and Construction)**
- Effort = 11520.3 Person-months
- Schedule = 80.3 Months
- Cost = $115.2 M

**Software Maintenance (15 Years)**
- Annual Cost = $8.5 M
- Total Cost = $127.7 M

**Hardware Development and Production**
- Cost = $481.6 M

**Totals**
- Acquisition Cost = $614.4 M
- Maintenance Cost = $150.8 M
- Total Cost = $765.2 M

**Total Cost Distribution Function**
- # Iterations

**Cost ($M)**
- 380-499
- 499-618
- 618-736
- 736-855
- 855-974
- 974-1093

**Total Cost Confidence Levels ($M)**
- 10%: 525.38
- 20%: 600.83
- 30%: 661.31
- 40%: 721.87
- 50%: 778.13
- 60%: 827.96
- 70%: 870.80
- 80%: 913.87
- 90%: 959.81
- 100%: 1,093.48
Service-Oriented Tool Interoperability

• The ODC COQUALMO and Product Line TOC models/tools have been enhanced for interoperability and tailorability.

• Adaptations to the web-based tools enable other toolsets to plug-in, so their analyses can be cross-pollinated with cost, schedule and quality dimensions.
  — External applications can automatically send input parameters and/or files and receive results in lieu of manual user sessions.
  — Ability to modify or add internal model parameters for different scenarios (e.g. effort, schedule and quality calibration parameters; phase/activity distributions for effort and schedule; defect type distributions, etc.).
  — APIs demonstrated for multiple languages and platforms.
Phase 4 Plans – Task 2

• Collaboration with AFIT for a joint Intelligence, Surveillance and Reconnaissance (ISR) mission application involving heterogenous teams of autonomous and cooperative agents.

• NPS will provide cost modeling expertise, tools and Monterey Phoenix (MP) modeling support. A focus will be on translations between models/tools in MBSE, specifically mapping architectural elements into cost model inputs.

• Approach
  — Develop a baseline operational and system architecture to capture a set of military scenarios.
  — Transition the baseline architecture to the MP environment.
  — Utilize the executable architecture modeling framework of MP to perform automated assertion checking and find counterexamples of behavior that violate the expected system's correctness.
    o Operational scenarios will be cycled through the MP modeling process, whereby alternate events are captured for each actor in each scenario. This will produce a superset of scenario variants from the behavior models, suitable for input to tradespace analysis and cost models.
  — Design and demonstrate an ISR UAV tradespace.
  — Develop cost model interfaces for components of the architecture in order to evaluate cost effectiveness in an uncertain future environment.
Phase 4 Plans – Task 3

• Continue extending the scope and tradespace interoperability of cost models and tools from previous phases.

• Cost modeling will engage domain experts for Delphi estimates, evolve baseline definitions of cost driver parameters and rating scales for use in data collection, gather empirical data and determine areas needing further research to account for differences between estimated and actual costs.
  — Prototype cost models and tools will be extended accordingly for piloting and refinement.

• For tool interoperability we will integrate cost models in different ways with MBSE architectural modeling approaches and as web services. We will also automate systems and software risk advisors that operate in conjunction with the cost models.

• NPS will provide domain expertise for SysML cost model integration with Georgia Tech and USC to add software cost model formulas and the risk assessment capabilities.
  — This is also allied with Task 2 where we will assess Monterey Phoenix (MP) for automatically providing cost information from architectural models. MP will extract software sizing cost model inputs to compute costs, and we will assess mapping MP architectural elements into systems engineering cost model inputs.
Monterey Phoenix Overview

- Monterey Phoenix (MP) is an approach to formal software and system specification based on behavior models.

- A view on the architecture model as a high-level description of possible behaviors of subsystems and interactions between subsystems.

- The emphasis on specifying the interaction between the system and its environment.

- The behavior composition operations support architecture reuse and refinement toward design and implementation models.

- Executable architecture models provide for system architecture testing and verification with tools.

- See [http://wiki.nps.edu/display/MP](http://wiki.nps.edu/display/MP)
MP Pipe/Filter Architecture Pattern

Example

SCHEMA simple_message_flow
ROOT Task_A: (* send *);
ROOT Task_B: (* receive *);
COORDINATE $x$: send FROM Task_A,
$y$: receive FROM Task_B
DO ADD $x$ PRECEDES $y$ OD;

a) Example of composed event trace
b) An architecture view for the schema
MP Data Items as Behaviors

Data items are represented by actions that may be performed on that data

SCHEMA Data_flow
ROOT Process_1: (* work write *);
ROOT Process_2: (* (read | work) *);
ROOT File: (* write *) (* read *);
Process_1, File SHARE ALL write;
Process_2, File SHARE ALL read;

a) An example of composed event trace
b) An architecture view
Phase 4 References


# Ship RDT&E Point Estimate

## System Cost Model Suite

### Constructive Systems Engineering Cost Model (COSYSMO)

#### System Size

<table>
<thead>
<tr>
<th># Costs</th>
<th>Easy</th>
<th>Nominal</th>
<th>Difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td># of System Requirements</td>
<td>120</td>
<td>185</td>
<td>48</td>
</tr>
<tr>
<td># of System Interfaces</td>
<td>12</td>
<td>67</td>
<td>45</td>
</tr>
<tr>
<td># of Algorithms</td>
<td>19</td>
<td>125</td>
<td>58</td>
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<tr>
<td># of Operational Scenarios</td>
<td>3</td>
<td>14</td>
<td>8</td>
</tr>
</tbody>
</table>

#### System Cost Drivers

- **Requirements Understanding**
  - High
- **Architecture Understanding**
  - High
- **Level of Service Requirements**
  - Very High
- **Migration Complexity**
  - Nominal
- **Technology Risk**
  - Nominal
- **Maintenance**
  - Off
- **Documentation**
  - Nominal
- **# and Diversity of Installations/Platforms**
  - Very High
- **# of Recursive Levels in the Design**
  - Nominal
- **Stakeholder Team Cohesion**
  - Nominal
- **Personnel/Team Capability**
  - Nominal
- **Personnel Experience/Continuity**
  - Nominal
- **Process Capability**
  - Nominal
- **Multisite Coordination**
  - Nominal
- **Tool Support**
  - Nominal

#### System Labor Rates

- **Cost per Person-Month (Dollars)**: 10000

**Calculate**
Ship RDT&E Point Estimate

Results

Systems Engineering
Effort = 1767.9 Person-months
Schedule = 17.7 Months
Cost = $17679187

Total Size = 2650 Equivalent Nominal Requirements

Acquisition Effort Distribution (Person-Months)

<table>
<thead>
<tr>
<th>Phase / Activity</th>
<th>Conceptualize</th>
<th>Develop</th>
<th>Operational Test and Evaluation</th>
<th>Transition to Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition and Supply</td>
<td>34.7</td>
<td>63.1</td>
<td>16.1</td>
<td>9.9</td>
</tr>
<tr>
<td>Technical Management</td>
<td>66.1</td>
<td>114.2</td>
<td>75.1</td>
<td>45.1</td>
</tr>
<tr>
<td>System Design</td>
<td>180.3</td>
<td>212.2</td>
<td>90.2</td>
<td>47.7</td>
</tr>
<tr>
<td>Product Realization</td>
<td>34.5</td>
<td>79.6</td>
<td>84.9</td>
<td>66.3</td>
</tr>
<tr>
<td>Product Evaluation</td>
<td>98.6</td>
<td>148.0</td>
<td>219.2</td>
<td>82.2</td>
</tr>
</tbody>
</table>

Your output file is [http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_07_42_42_618469.txt](http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_07_42_42_618469.txt)
## Ship RDT&E Point Estimate

### Constructive Cost Model (COCOMO II)

<table>
<thead>
<tr>
<th>Software Size</th>
<th>Sizing Method</th>
<th>Source Lines of Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>SLOC</td>
<td>% Design Modified</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Code Modified</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Integration Required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>% Assessment and Assimilation (0% - 8%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Software Understanding (0% - 50%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unfamiliarity (0-1)</td>
</tr>
</tbody>
</table>

- **New:** 850000
- **Reused:** 225000
- **Modified:** 400000

### Software Scale Drivers
- **Precedent:** Nominal
- **Development Flexibility:** Low
- **Architecture / Risk Resolution:** Nominal
- **Team Cohesion:** High
- **Process Maturity:** Nominal

### Software Cost Drivers
- **Product**
- **Required Software Reliability:** Very High
- **Data Base Size:** Nominal
- **Product Complexity:** High
- **Developed for Reusability:** Nominal
- **Documentation Match to Lifecycle Needs:** Nominal
- **Personnel**
- **Analyst Capability:** Nominal
- **Programmer Capability:** Nominal
- **Personnel Continuity:** Nominal
- **Application Experience:** Nominal
- **Platform Experience:** Nominal
- **Language and Toolset Experience:** Nominal

### Platform
- **Time Constraint:** High
- **Storage Constraint:** High
- **Platform Volatility:** Nominal

### Project
- **Use of Software Tools:** Nominal
- **Multisite Development:** Nominal
- **Required Development Schedule:** Nominal

### Maintenance
- **Off**

### Software Labor Rates
- **Cost per Person-Month (Dollars):** 10000

[Calculate]
Ship RDT&E Point Estimate

Advanced Missions Cost Model (AMCM)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Weight (lb.)</td>
<td>10000000</td>
</tr>
<tr>
<td>Mission Type</td>
<td>Ship - Amphib Assault</td>
</tr>
<tr>
<td>IOC Year</td>
<td>2013</td>
</tr>
<tr>
<td>Block Number</td>
<td>1</td>
</tr>
<tr>
<td>Difficulty</td>
<td>Average</td>
</tr>
</tbody>
</table>

Results

Hardware Development and Production
Total Cost = $608 M

This is a simple advanced missions cost model (AMCM) for quick turnaround, rough-order-of-magnitude estimating. The model can be used for estimating the development and production cost of spacecraft, space transportation systems, aircraft, missiles, ships, and land vehicles. Initial model provided courtesy of NASA with extensions by NPS.
### Ship RDT&E Point Estimate

<table>
<thead>
<tr>
<th>Systems Engineering</th>
<th>Software</th>
<th>Hardware</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systems Engineering Acquisition</strong></td>
<td>Effort = 1767.9 Person-months</td>
<td>Schedule = 17.7 Months</td>
<td>Cost = $17.7 M</td>
</tr>
<tr>
<td><strong>Software Development (Elaboration and Construction)</strong></td>
<td>Effort = 10344.6 Person-months</td>
<td>Schedule = 77.5 Months</td>
<td>Cost = $103.4 M</td>
</tr>
<tr>
<td><strong>Hardware Development and Production</strong></td>
<td>Cost = $608 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>System Cost = $744.4 M</td>
</tr>
</tbody>
</table>

Your output file is [http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_07_42_42_618469.txt](http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_07_42_42_618469.txt)

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu
Results
Systems Engineering
Effort = 1767.4 Person-months
Schedule = 17.7 Months
Cost = $17673532

Total Size = 2650 Equivalent Nominal Requirements

Acquisition Effort Distribution (Person-Months)

<table>
<thead>
<tr>
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</table>

Monte Carlo Results

Systems Engineering Effort Distribution Function

<table>
<thead>
<tr>
<th># Iterations</th>
<th>48</th>
<th>158</th>
<th>220</th>
<th>260</th>
<th>243</th>
<th>58</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort (PM)</td>
<td>1311-1428</td>
<td>1423-1546</td>
<td>1546-1663</td>
<td>1663-1780</td>
<td>1780-1898</td>
<td>1898-2015</td>
</tr>
</tbody>
</table>

Systems Engineering Effort Confidence Levels

10% 1.480
20% 1.543
30% 1.610
40% 1.650
50% 1.703
60% 1.745
70% 1.785
80% 1.823
90% 1.876
100% 2.015

Your output file is http://diana.nps.edu/~madaytools/data/ccst_model_suiteSeptember_17_2013_07_55_02_565284.txt
Ship RDT&E Monte Carlo Risk Analysis

Advanced Missions Cost Model (AMCM)

- **Quantity**: 1
- **Dry Weight (lb.)**: Distribution Uniform, Min 900000, Max 150000
- **Mission Type**: Ship - Amphib Assault
- **IOC Year**: 2013
- **Block Number**: 1
- **Difficulty**: Average

[Calculate]
# Ship RDT&E Monte Carlo Risk Analysis

**Systems Engineering**

- **Acquisition**
  - Effort = 1767.4 Person-months
  - Schedule = 17.7 Months
  - Cost = $17.7 M

- **Software Development (Elaboration and Construction)**
  - Effort = 10344.6 Person-months
  - Schedule = 77.5 Months
  - Cost = $103.4 M

- **Hardware Development and Production**
  - Cost = $685 M

**Total**

- System Cost = $806.1 M

**Summary**

- **Total Cost Distribution Function**
  - # Iterations:
    - 121
    - 192
    - 188
    - 187
    - 223
    - 87

- **Total Cost Confidence Levels ($M)**
  - 10% = 693.43
  - 20% = 716.06
  - 30% = 739.20
  - 40% = 762.84
  - 50% = 786.89
  - 60% = 815.19
  - 70% = 835.29
  - 80% = 855.01
  - 90% = 875.41
  - 100% = 923.45
### System Maintenance

#### Constructive Systems Engineering Cost Model (COSYSMO)

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#### System Cost Drivers

- **Requirements Understanding**: High
- **Architecture Understanding**: High
- **Level of Service Requirements**: Very High
- **Migration Complexity**: Nominal
- **Technology Risk**: Nominal
- **Maintenance**: On
- **Annual Change %**: 10
- **Maintenance Duration (Years)**: 15
- **Personnel Experience/Continuity**: Nominal
- **Process Capability**: Nominal
- **Multisite Coordination**: Nominal
- **Tool Support**: Nominal

**System Labor Rates**

- **Cost per Person-Month (Dollars)**: 10000

[Calculate]
System Maintenance

Results
Systems Engineering
Effort = 1767.9 Person-months
Schedule = 17.7 Months
Cost = $17679187

Total Size = 2650 Equivalent Nominal Requirements

Acquisition Effort Distribution (Person-Months)

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Maintenance
Annual Maintenance Effort = 154.0 Person-Months
Annual Maintenance Cost = $1539792
Total Maintenance Cost = $23096893

Your output file is [http://diana.nps.edu/~madachytools/data/cost_model_suiteSeptember_17_2013_08_06_07_160035.txt](http://diana.nps.edu/~madachytools/data/cost_model_suiteSeptember_17_2013_08_06_07_160035.txt)
## Software Maintenance

### Constructive Cost Model (COCOMO II)

<table>
<thead>
<tr>
<th>Software Size</th>
<th>Sizing Method</th>
<th>Source Lines of Code</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SLLOC</td>
</tr>
<tr>
<td>New</td>
<td>850000</td>
<td></td>
</tr>
<tr>
<td>Reused</td>
<td>225000</td>
<td>0 0 50 4</td>
</tr>
<tr>
<td>Modified</td>
<td>400000</td>
<td>10 15 60 4</td>
</tr>
</tbody>
</table>

### Software Scale Drivers

<table>
<thead>
<tr>
<th>Precededness</th>
<th>Nominal</th>
<th>Architecture / Risk Resolution</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development Flexibility</td>
<td>Low</td>
<td>Team Cohesion</td>
<td>High</td>
</tr>
</tbody>
</table>

### Software Cost Drivers

<table>
<thead>
<tr>
<th>Required Software Reliability</th>
<th>Very High</th>
<th>Personnel</th>
<th>Analyst Capability</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Base Size</td>
<td>Nominal</td>
<td>Programmer Capability</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Product Complexity</td>
<td>High</td>
<td>Personnel Continuity</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Developed for Reusability</td>
<td>Nominal</td>
<td>Application Experience</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td>Documentation Match to Lifecycle Needs</td>
<td>Nominal</td>
<td>Platform Experience</td>
<td>Nominal</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Language and Toolset Experience</td>
<td>Nominal</td>
<td></td>
</tr>
</tbody>
</table>

### Maintenance

<table>
<thead>
<tr>
<th>Annual Change Size (ESLOC)</th>
<th>80000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software Understanding</td>
<td>25</td>
</tr>
<tr>
<td>Unfamiliarity (0-1)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

### Platform

<table>
<thead>
<tr>
<th>Time Constraint</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Constraint</td>
<td>High</td>
</tr>
<tr>
<td>Platform Volatility</td>
<td>Nominal</td>
</tr>
</tbody>
</table>

### Project

<table>
<thead>
<tr>
<th>Use of Software Tools</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multisite Development</td>
<td>Nominal</td>
</tr>
<tr>
<td>Required Development Schedule</td>
<td>Nominal</td>
</tr>
</tbody>
</table>

### Software Labor Rates

<table>
<thead>
<tr>
<th>Cost per Person-Month (Dollars)</th>
<th>10000</th>
</tr>
</thead>
</table>

[Calculate]
## Total Ship Maintenance

<table>
<thead>
<tr>
<th>Systems Engineering</th>
<th>Software</th>
<th>Hardware</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systems Engineering Acquisition</strong></td>
<td>Effort = 1767.9 Person-months</td>
<td>Schedule = 17.7 Months</td>
<td></td>
</tr>
<tr>
<td>Cost = $17.7 M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Systems Engineering Maintenance</strong></td>
<td>Cost = $23.1 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Software Development (Elaboration and Construction)</strong></td>
<td>Effort = 10344.6 Person-months</td>
<td>Schedule = 77.5 Months</td>
<td></td>
</tr>
<tr>
<td>Cost = $103.4 M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Software Maintenance</strong></td>
<td>Cost = $103.8 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hardware Development and Production</strong></td>
<td>Cost = $608 M</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>System Cost = $856.0 M</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Your output file is [http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_08_08_09_196913.txt](http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_08_08_09_196913.txt)
Acquisition and Maintenance
Monte Carlo Risk Results (1/3)

### Systems Engineering Acquisition
- Effort: 1767.4 Person-months
- Schedule: 17.7 Months
- Cost: $17.7 M

### Systems Engineering Maintenance (15 Years)
- Annual Cost: $1.5 M
- Total Cost: $23.1 M

### Software Development (Elaboration and Construction)
- Effort: 11520.3 Person-months
- Schedule: 80.3 Months
- Cost: $115.2 M

### Software Maintenance (15 Years)
- Annual Cost: $8.5 M
- Total Cost: $127.7 M

### Hardware Development and Production
- Cost: $481.6 M

### Totals
- Acquisition Cost: $614.4 M
- Maintenance Cost: $150.8 M
- Total Cost: $765.2 M

#### Total Cost Distribution Function

<table>
<thead>
<tr>
<th>Cost ($M)</th>
<th># Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>300-499</td>
<td>66</td>
</tr>
<tr>
<td>500-618</td>
<td>160</td>
</tr>
<tr>
<td>618-736</td>
<td>202</td>
</tr>
<tr>
<td>736-855</td>
<td>233</td>
</tr>
<tr>
<td>855-974</td>
<td>259</td>
</tr>
<tr>
<td>974-1093</td>
<td>78</td>
</tr>
</tbody>
</table>

#### Total Cost Confidence Levels ($M)

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>525.38</td>
</tr>
<tr>
<td>20%</td>
<td>600.83</td>
</tr>
<tr>
<td>30%</td>
<td>661.31</td>
</tr>
<tr>
<td>40%</td>
<td>721.87</td>
</tr>
<tr>
<td>50%</td>
<td>778.13</td>
</tr>
<tr>
<td>60%</td>
<td>827.96</td>
</tr>
<tr>
<td>70%</td>
<td>870.80</td>
</tr>
<tr>
<td>80%</td>
<td>913.87</td>
</tr>
<tr>
<td>90%</td>
<td>959.81</td>
</tr>
<tr>
<td>100%</td>
<td>1,093.48</td>
</tr>
</tbody>
</table>
Acquisition and Maintenance
Monte Carlo Risk Results (2/3)

Acquisition Monte Carlo Results

Systems Engineering Cost Confidence Levels ($M)

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Cost ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>14.80</td>
</tr>
<tr>
<td>20%</td>
<td>15.57</td>
</tr>
<tr>
<td>30%</td>
<td>16.15</td>
</tr>
<tr>
<td>40%</td>
<td>16.59</td>
</tr>
<tr>
<td>50%</td>
<td>17.07</td>
</tr>
<tr>
<td>60%</td>
<td>17.45</td>
</tr>
<tr>
<td>70%</td>
<td>17.78</td>
</tr>
<tr>
<td>80%</td>
<td>18.23</td>
</tr>
<tr>
<td>90%</td>
<td>18.76</td>
</tr>
<tr>
<td>100%</td>
<td>20.16</td>
</tr>
</tbody>
</table>

Software Engineering Cost Confidence Levels ($M)

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Cost ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>88.90</td>
</tr>
<tr>
<td>20%</td>
<td>98.85</td>
</tr>
<tr>
<td>30%</td>
<td>105.11</td>
</tr>
<tr>
<td>40%</td>
<td>110.15</td>
</tr>
<tr>
<td>50%</td>
<td>113.94</td>
</tr>
<tr>
<td>60%</td>
<td>120.28</td>
</tr>
<tr>
<td>70%</td>
<td>125.38</td>
</tr>
<tr>
<td>80%</td>
<td>133.06</td>
</tr>
<tr>
<td>90%</td>
<td>139.49</td>
</tr>
<tr>
<td>100%</td>
<td>178.62</td>
</tr>
</tbody>
</table>

Hardware Cost Confidence Levels ($M)

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>Cost ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>239.39</td>
</tr>
<tr>
<td>20%</td>
<td>319.04</td>
</tr>
<tr>
<td>30%</td>
<td>379.37</td>
</tr>
<tr>
<td>40%</td>
<td>437.89</td>
</tr>
<tr>
<td>50%</td>
<td>490.02</td>
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<tr>
<td>60%</td>
<td>542.82</td>
</tr>
<tr>
<td>70%</td>
<td>592.04</td>
</tr>
<tr>
<td>80%</td>
<td>635.48</td>
</tr>
<tr>
<td>90%</td>
<td>679.27</td>
</tr>
<tr>
<td>100%</td>
<td>721.17</td>
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</table>
Acquisition and Maintenance
Monte Carlo Risk Results (3/3)

Maintenance Monte Carlo Results

<table>
<thead>
<tr>
<th>Systems Engineering Maintenance Cost Confidence Levels ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
</tr>
<tr>
<td>20%</td>
</tr>
<tr>
<td>30%</td>
</tr>
<tr>
<td>40%</td>
</tr>
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<td>50%</td>
</tr>
<tr>
<td>60%</td>
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<tr>
<td>70%</td>
</tr>
<tr>
<td>80%</td>
</tr>
<tr>
<td>90%</td>
</tr>
<tr>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Software Engineering Maintenance Cost Confidence Levels ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
</tr>
<tr>
<td>20%</td>
</tr>
<tr>
<td>30%</td>
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<td>40%</td>
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</tr>
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<td>60%</td>
</tr>
<tr>
<td>70%</td>
</tr>
<tr>
<td>80%</td>
</tr>
<tr>
<td>90%</td>
</tr>
<tr>
<td>100%</td>
</tr>
</tbody>
</table>
# Satellite RDT&E Point Estimate

[![System Cost Model Suite](image)](image)

## System Cost Model Suite

**Project Name:** MiniSat  
**System Type:** Satellite

### Hardware

<table>
<thead>
<tr>
<th>Element</th>
<th>Parameter</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Payload</td>
<td>Aperture diameter (m)</td>
<td>1.0</td>
</tr>
<tr>
<td>1.1 Visible Light Sensor</td>
<td>Structure weight (kg)</td>
<td>245</td>
</tr>
<tr>
<td>2. Spacecraft</td>
<td>Thermal weight (kg)</td>
<td>40</td>
</tr>
<tr>
<td>2.1 Structure</td>
<td>X1 = EPS weight (kg)</td>
<td>420</td>
</tr>
<tr>
<td>2.2 Thermal</td>
<td>X2 = BOL power (wt)</td>
<td>100</td>
</tr>
<tr>
<td>2.3 Electrical Power System</td>
<td>TT&amp;C weight (kg)</td>
<td>50</td>
</tr>
<tr>
<td>2.4 Telemetry, Tracking and Command</td>
<td>ADCS weight (kg)</td>
<td>110</td>
</tr>
</tbody>
</table>

**Calculate**

Your output file is [http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_08_46_43_265739.txt](http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_08_46_43_265739.txt)

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu
Software Cost Estimate Details

**Results**

Software Development (Elaboration and Construction)

- Effort = 169.9 Person-months
- Schedule = 20.0 Months
- Cost = $1698762
- Total Equivalent Size = 40000 SLOC

**Acquisition Phase Distribution**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Effort (Person-months)</th>
<th>Schedule (Months)</th>
<th>Average Staff</th>
<th>Cost (Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inception</td>
<td>10.2</td>
<td>2.5</td>
<td>4.1</td>
<td>$101926</td>
</tr>
<tr>
<td>Elaboration</td>
<td>40.8</td>
<td>7.5</td>
<td>5.4</td>
<td>$407703</td>
</tr>
<tr>
<td>Construction</td>
<td>129.1</td>
<td>12.5</td>
<td>10.3</td>
<td>$1291060</td>
</tr>
<tr>
<td>Transition</td>
<td>20.4</td>
<td>2.5</td>
<td>8.2</td>
<td>$203852</td>
</tr>
</tbody>
</table>

**Staffing Profile**

Month

- People

**Software Activity Distribution (Person-Months)**

<table>
<thead>
<tr>
<th>Phase/Activity</th>
<th>Inception</th>
<th>Elaboration</th>
<th>Construction</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management</td>
<td>1.4</td>
<td>4.9</td>
<td>12.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Environment/CM</td>
<td>1.0</td>
<td>3.3</td>
<td>6.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Requirements</td>
<td>3.9</td>
<td>7.3</td>
<td>10.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Design</td>
<td>1.9</td>
<td>14.7</td>
<td>20.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Implementation</td>
<td>0.8</td>
<td>5.3</td>
<td>43.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Assessment</td>
<td>0.8</td>
<td>4.1</td>
<td>31.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Deployment</td>
<td>0.3</td>
<td>1.2</td>
<td>3.9</td>
<td>6.1</td>
</tr>
</tbody>
</table>

Your output file is [http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_16_2013_11_23_24_410790.txt](http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_16_2013_11_23_24_410790.txt)
• The Advance Missions Cost Model (AMCM) predicts development, recurring and mission operations costs of ground vehicles, ships, aircraft, helicopters, missiles, launch vehicles, spacecraft, and human explorations missions.

• It is a system level cost model appropriate for large scale programs requiring many different systems that will be integrated to perform a complex mission. The model is most useful in the pre-conceptual and conceptual design phases of a program when the actual design of the systems is not known and many factors are being traded off.
The AMCM is a two equation, multi-variable cost estimating relationship. The first equation predicts the development and production cost of the system based on various technical and programmatic factors. The second equation predicts the basic mission operations cost of the system.

Both equations are fitted to a large historical database that spans 50 years of systems development. Most of the systems are US Government developed, but some commercial and European systems are included.

- Database of land, water, air and space systems. The data includes 54 spacecraft, 22 space transportation systems, 61 aircraft, 86 missiles, 29 ships, and 18 ground vehicles. All of the data points are from programs that were completed through IOC.
• Cost, schedule and quality are highly correlated factors in software processes

• Thus the COnstructive QUALity MOdel (COQUALMO) was created to predict defects as an extension of the COCOMO II software cost model [Chulani, Boehm 1999]
  — Uses COCOMO II cost estimation inputs with defect removal parameters to predict the numbers of generated, detected and remaining defects for requirements, design and code

• Provides insights into cost/schedule/quality tradeoff analyses, quality investment payoffs, interactions amongst quality strategies, and likely schedule

• Enables what-if analyses that demonstrate the impact of
  — Defect removal techniques for automated analysis, peer reviews, and execution testing on defect types
  — Effects of product, personnel, project, and platform characteristics on software quality

• ODC COQUALMO is a further extension that predicts software defects introduced and removed classifying them with Orthogonal Defect Classification (ODC) defect types
ODC COQUALMO Overview

COQUALMO extensions to COCOMO II in red

ODC additions in blue

Software size

Software product, process, platform and personnel attributes

Defect removal capability levels
- Automated analysis
- Peer reviews
- Execution testing and tools

Defect density per unit of size

Number of residual defects

• Requirements
  - Correctness
  - Completeness
  - Consistency
  - Ambiguity/Testability

• Design
  - Interface
  - Timing
  - Class/Object/Function
  - Method/Logic/Algorithm
  - Data Values/Initialization
  - Checking

• Code (same 6 types as Design)
- ODC COQUALMO decomposes defects using ODC categories [Chillarege et al. 1992]
  - Enables tradeoffs of different detection efficiencies for the removal practices per type of defect

- The ODC taxonomy provides well-defined criteria for the defect types and has been successfully applied on NASA projects and others

- With more granular defect definitions, ODC COQUALMO enables tradeoffs of different detection efficiencies for the removal practices per type of defect.
  - V&V techniques have different detection efficiencies for different types of defects, and may have overlapping capabilities between them

- ODC defect types can be mapped to technical performance parameters for trade analysis
ODC COQUALMO Outputs

Software Effort Distribution for RUP/BEASE (Person-Months)

- Inception: 27.9 months
- Elaboration: 117.7 months
- Construction: 383.6 months
- Transition: 55.8 months

Total Equivalent Size = 100000 SLOC

Software Development (Elaboration and Construction)

- Effort = 565.3 Person-months
- Schedule = 27.9 Months
- Cost = $4052162

Agile Phase Distribution

<table>
<thead>
<tr>
<th>Phase</th>
<th>Effort (Person-months)</th>
<th>Schedule (Months)</th>
<th>Staff</th>
<th>Cost (Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inception</td>
<td>27.9</td>
<td>3.6</td>
<td>8.0</td>
<td>$276159</td>
</tr>
<tr>
<td>Elaboration</td>
<td>117.7</td>
<td>16.4</td>
<td>10.7</td>
<td>$1135757</td>
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<tr>
<td>Construction</td>
<td>383.6</td>
<td>17.4</td>
<td>20.3</td>
<td>$1259396</td>
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<tr>
<td>Transition</td>
<td>55.8</td>
<td>3.5</td>
<td>15.0</td>
<td>$558379</td>
</tr>
</tbody>
</table>

Staffing Profile

- Month 1: 10 people
- Month 2: 12 people
- Month 3: 15 people
- Month 4: 16 people

Requirements Defects

- Introduced: 70
- Removed: 28
- Remaining: 42

- Ambiguity/Testability: 70
- Completeness: 230
- Consistency: 170
- Correctness: 530

Design Defects

- Introduced: 1460
- Removed: 62
- Remaining: 83

- Class/Object/Function: 254
- Data Values/Initialization: 510
- Interface: 510
- Method/Logic/Algorithm: 530
- Timing: 0

Code Defects

- Introduced: 2149
- Removed: 94
- Remaining: 124

- Class/Object/Function: 381
- Data Values/Initialization: 765
- Interface: 765
- Method/Logic/Algorithm: 869
- Timing: 0

Your output file is https://nips.nps.edu/MSc/thesis/OQULMO.pdf

Created by Ray Machedy at the Naval Postgraduate School. For more information contact him at rmachedy@nps.edu
• General cost modeling tool currently available at
  
  http://diana.nps.edu/~madachy/tools/cost_model_suite.php
  http://csse.usc.edu/tools/cost_model_suite.php