Software Maintenance Cost Estimating Relationships – One Size Does Not Fit All

28th International Forum on COCOMO and Systems/Software Cost Modeling

22–24 October 2013
Purpose

- This presentation presents an overview of an approach to estimating Software Maintenance (SWM) and sustaining engineering cost at different milestones in a product’s acquisition lifecycle, i.e., from concept development through operations support.
  - Early life cycle
    - No observed cost performance data on program
    - Need for a viable approach is important at this stage because it informs such estimates as a product’s total ownership costs.
  - Late life cycle
    - Actual cost data is available from previous releases
    - “Maintenance rhythm” shows that costs for operation support are more than a linear projection of a product’s anticipated annual change.
Topics

- Current Estimation Approaches
- Maintenance Estimation Scope
- Maintenance Rhythm Impact
- Annualized Cost Estimate
- Cost Estimating Relationship Selection
  - Software System Characterization
  - Software Change Classification
- Conclusions
- Next Steps
Key Estimation Issues

- Systemic availability of software maintenance data:
  - Mapped to a consistent cost structure
  - Traceable to activity and product outputs
  - Both planning and execution data
  - Correlated software maintenance cost, technical and profile data

- Current software maintenance estimation methods:
  - Do not align with an individual program’s unique life cycle sustainment profile
  - Do not take into account specific software maintenance products and related activities for a given program (what’s in and what’s out)
  - Do not encompass multiple types of cost relationships
  - Do not address the differences across functional software domains
Topics

- Current Estimation Approaches
- Maintenance Estimation Scope
- Maintenance Rhythm Impact
- Annualized Cost Estimate
- Cost Estimating Relationship Selection
  - Software System Characterization
  - Software Change Classification
- Conclusions
- Next Steps
**Estimation Breadth**

- Breadth is the span of time covered by the estimate, e.g.,
  - Estimate across the life of the program, from Milestone A forward
  - Estimate for the next 5 years, during Operation & Support
- Estimation considerations:
  - Availability and quality of program data
  - Different CERs at different estimation points
  - Accuracy of the estimate
  - Estimation consistency across the life cycle
  - Information related risk/uncertainty
- DoD’s Acquisition Lifecycle phases are shown in the figure
Estimation Depth

*Depth* is the amount of activities covered by the estimate.

SWM Work Breakdown Structure defines the depth of the estimate:

1. **Software Change Product** - products and activities associated with defining, allocating, generating, integrating, and testing software changes for an operational software product or system.

2. **System Project Management** - products and activities associated with system specific software maintenance project and technical management.

3. **Software Licenses** - products and activities associated with the procurement and renewal of software licenses for operational software and facilities.

4. **Certifications and Accreditations** - products and activities associated with verifying a software system against externally defined domain performance criteria.

5. **System Facilities** - products and activities associated with establishing and operating software maintenance related development, integration, and test facilities, and support equipment and tools.

6. **Sustaining Engineering** - products and activities associated with system specific test, delivery, and training support.

7. **Field Support** - products and activities associated with the on-site support of a deployed software product or system in its operational environment.

8. **Support Infrastructure** - products and activities associated with establishing and operating the organizational infrastructure required to implement common software maintenance business and technical processes across multiple software systems.
Software Maintenance WBS

• A WBS is foundational to understanding sources of cost
  - Product based - system and organizational cost elements identified as those required to make changes to an operational software baseline(s)
  - Common structure that includes all potential software maintenance products and activities
  - Superset of program software maintenance cost elements
• Identifies “what’s in” and “what’s out”
  - Data collection
  - Cost estimate
• Applicable to:
  - Software maintenance estimation and planning
  - Tracking software maintenance execution and data collection
• Establishes common software maintenance definitions and terminology
## Estimation Coverage

Both Breadth and Depth are tailored to match the lifecycle and activities of the program under estimation, e.g., O&S with a subset of activities.

<table>
<thead>
<tr>
<th></th>
<th>Concept Refinement</th>
<th>Technology Development</th>
<th>System Development &amp; Demonstration</th>
<th>Production &amp; Deployment</th>
<th>Operation &amp; Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 Software Change Product</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2.0 System Project Management</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3.0 Software Licenses</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4.0 Certifications and Accreditations</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5.0 System Facilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0 Sustaining Engineering</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>7.0 Field Support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.0 Support Infrastructure</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Topics

• Current Estimation Approaches
• Maintenance Estimation Scope
• Maintenance Rhythm Impact
• Annualized Cost Estimate
• Cost Estimating Relationship Selection
  - Software System Characterization
  - Software Change Classification
• Conclusions
• Next Steps
Maintenance Rhythm Impact

- Maintenance costs are driven by repairs, emergency patches, updates, technology refreshes and major upgrades
- Annual release costs are not fixed – must be reflected in estimates
Cost Estimate Timeframes

- SWM WBS costs cover different timeframes
- Release cycles: 6, 12, 18, 24 months
  1.0 Software Change Product
  2.0 System Project Management
- Annual cycle
  3.0 Software Licenses - annual
  4.0 Certifications and Accreditations - annual
  5.0 System Facilities - annual
  6.0 Sustaining Engineering - annual
  7.0 Field Support - annual
  8.0 Support Infrastructure

- The cost estimate has to be normalized to a common timeframe while taking maintenance rhythm into account
Annual Cost Estimates Example

- Estimated release costs for multiple major and minor releases are allocated across the release duration to obtain a “monthly burn rate”
  - Release costs often overlap
- Recurring annual costs are normalized to a monthly burn rate
- Monthly release & annual costs are overlaid
- Monthly costs are rolled-up to a 12-month or annual cost
Topics

• Current Estimation Approaches
• Maintenance Estimation Scope
• Maintenance Rhythm Impact
• Annualized Cost Estimate
• Cost Estimating Relationship Selection
  - Software System Characterization
  - Software Change Classification
• Conclusions
• Next Steps
SWM Cost Estimating Relationships

• The selection of CERs is driven by the program’s life cycle phase
  - Early life cycle
    • No observed cost performance data on program
    • Need for a viable approach is important at this stage because it informs such estimates as a product’s total ownership costs.
  - Late life cycle
    • Actual cost data is available from previous releases
    • “Maintenance rhythm” shows that costs for operation support are more than a linear projection of a product’s anticipated annual change.

• Impact: One CER does not fit all phases

• SWM CER modifiers:
  • phase based data defined CERs
  • software system characterization model

• Multiple CER types:
  • parametric
  • ratios
  • Trend lines
## SWM Phase Driven CERs

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>MS A</th>
<th>MS B</th>
<th>MS C</th>
<th>Post MS C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &amp; 2 - Software Change Produce &amp; Project Management</td>
<td>Analogy for cost</td>
<td>Analogy for size Proxy tables for sizes</td>
<td>Development (baseline) size and build info Formulas for schedule, effort, and cost</td>
<td>MS C information plus actual maintenance data from completed releases</td>
</tr>
<tr>
<td>3 - Software Licenses (Cost of)</td>
<td>Analogy based on type of system and anticipated maintenance depot</td>
<td>Information by system type – used in analogy</td>
<td>List of actual products with costs – license quoted costs</td>
<td>List of actual products with costs – license quoted costs (changes for obsolescence)</td>
</tr>
<tr>
<td>4 - Certifications &amp; Accreditations</td>
<td>Analogy for cost by system domain</td>
<td>Analogy for cost by system domain</td>
<td>List of actual C&amp;As with costs (by release or annual)</td>
<td>List of actual C&amp;As with costs (by release or annual)</td>
</tr>
<tr>
<td>5 - Software Maintenance Facilities</td>
<td>Analogy for cost by maintenance depot</td>
<td>Analogy for cost by depot</td>
<td>Budget cost (percentage) by depot plus extras</td>
<td>Actual cost (percentage) by depot plus extras</td>
</tr>
<tr>
<td>6 - Sustaining Engineering</td>
<td>Analogy for cost by system domain</td>
<td>Analogy for cost by system domain</td>
<td>Analogy for cost by system domain</td>
<td>Actual cost (percentage) by actual maintenance data from completed releases</td>
</tr>
<tr>
<td>7 - Field Software Engineering</td>
<td>Analogy for cost by system domain</td>
<td>Analogy for cost by system domain</td>
<td>Analogy for cost by system domain</td>
<td>Actual cost (percentage) based on sites/users/platforms</td>
</tr>
<tr>
<td>8 – Support Infrastructure</td>
<td>Analogy for cost by maintenance depot</td>
<td>Analogy for cost by maintenance depot</td>
<td>Budget cost (percentage) by maintenance depot plus extras</td>
<td>Actual cost (percentage) by maintenance depot plus extras</td>
</tr>
</tbody>
</table>
Software System Characterization

- SWM cost relationships vary based on the technical characteristics of the software system, i.e. one size does not fit all
  - Premise – SWM productivity is different between groups of software with different characteristics and similar within a group
  - Grouping uses both a *taxonomic* and *topologic* characterization approach

- Software product characterization is part of the estimation process
  - Selection criteria to identify other analogous programs
  - Targeted CERs calibrated to the characteristics of that particular group
System Characterization Using Super Domains

<table>
<thead>
<tr>
<th>Super Domain</th>
<th>Software Application Domains</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Real-Time (RT)</strong></td>
<td>Sensor Control and Signal Processing</td>
</tr>
<tr>
<td></td>
<td>Vehicle Control</td>
</tr>
<tr>
<td></td>
<td>Vehicle Payload</td>
</tr>
<tr>
<td></td>
<td>Real Time Embedded-Other</td>
</tr>
<tr>
<td><strong>Engineering (ENG)</strong></td>
<td>Mission Processing</td>
</tr>
<tr>
<td></td>
<td>Executive</td>
</tr>
<tr>
<td></td>
<td>Automation and Process Control</td>
</tr>
<tr>
<td></td>
<td>Scientific Systems</td>
</tr>
<tr>
<td></td>
<td>Telecommunications</td>
</tr>
<tr>
<td><strong>Mission Support (MS)</strong></td>
<td>Planning Systems</td>
</tr>
<tr>
<td></td>
<td>Training</td>
</tr>
<tr>
<td></td>
<td>Software Tools</td>
</tr>
<tr>
<td></td>
<td>Test Software</td>
</tr>
<tr>
<td><strong>Automated Information System (AIS)</strong></td>
<td>Intelligence and Information Systems</td>
</tr>
<tr>
<td></td>
<td>Software Services</td>
</tr>
<tr>
<td></td>
<td>Software Applications</td>
</tr>
</tbody>
</table>
Characterization Using Software System Attributes

**Software System Attributes**

1. **Number of External Interfaces**
   - Interoperability with other systems
   - Change in the number of system interfaces
   - Degree of external interfaces coupling, e.g., waiting problem
   - Integrated functionality (versus stand-alone, maybe implied by # interfaces)
   - Impact of eternal interface volatility
   - Implications:
     - What is indirectly affected by the number of interfaces

2. **Execution Timing Constraints**
   - Event driven
   - Time driven (hard real-time)
   - Non-stop operation

3. **COTS Product Incorporation**
   - Number of COTS products
   - Are new products being incorporated?

4. **Critical Technology**
   - Algorithmic complexity
   - Maturity
   - HMI
   - Display complexity
   - Failure impact
   - Data fusion
   - Info Assurance
   - Pre-programmed reactions
   - Communication complexity
     - Encryption
     - Anti-Jam
     - Frequency hopping
   - Security complexity
     - Multi-level
     - Access partitioning
   - Data bandwidth requirements
   - Real-time data capture
   - Data reduction volume
   - Storage constraints
Estimation at MS-A&B: WBS All Elements

Method #1

- Top-down approach
- Obtain SWM annual cost using analogous programs
- Distribute annual cost across WBS percentage table using software domains:
  - Real-Time (RT)
  - Engineering (ENG)
  - Mission Support (MS)
  - Automated Information Systems (AIS)
- Check for realism of cost in the different WBS elements
- Unrealistic values may indicated analogous system is too dissimilar

<table>
<thead>
<tr>
<th>WBS Elements</th>
<th>Software Domains</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT</td>
</tr>
<tr>
<td>1.0 Software Change Product</td>
<td>45%</td>
</tr>
<tr>
<td>2.0 Project Management</td>
<td>20%</td>
</tr>
<tr>
<td>3.0 Software Licenses</td>
<td>1%</td>
</tr>
<tr>
<td>4.0 Certifications &amp; Accreditation</td>
<td>4%</td>
</tr>
<tr>
<td>5.0 System Facilities</td>
<td>5%</td>
</tr>
<tr>
<td>6.0 Sustaining Engineering</td>
<td>10%</td>
</tr>
<tr>
<td>7.0 Field Support</td>
<td>7%</td>
</tr>
<tr>
<td>8.0 Support and Infrastructure</td>
<td>8%</td>
</tr>
</tbody>
</table>

The values in this table are for illustration purposes and are not real
Estimation at MS-A&B: WBS 1 & 2

Method #2

- Select the anticipated release cycle time and the Maintenance Organization based on analogous programs

<table>
<thead>
<tr>
<th>Maintenance Organization</th>
<th>Release Cycle</th>
<th>Cost ($K) for WBS 1.0 and 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6 months</td>
<td>12 months</td>
</tr>
<tr>
<td>OID: 221</td>
<td>$400 - $600</td>
<td>$800 - $1,000</td>
</tr>
<tr>
<td>OID: 222</td>
<td>$350 - $550</td>
<td>$750 - $950</td>
</tr>
<tr>
<td>OID: 223</td>
<td>$200 - $400</td>
<td>$450 - $650</td>
</tr>
<tr>
<td>OID: 224</td>
<td>$150 - $250</td>
<td>$300 - $500</td>
</tr>
</tbody>
</table>

The values in this table are for illustration purposes and are not real.

- Normalize the release cost to an annual cost, e.g., a release cost, $X, for 18 months would be normalized to an annual (12 month) cost with: $X \times \frac{12}{18}$
Estimation at MS-A&B: WBS 3

• MS-A: Estimate the number of COTS products from analogous programs
  - COTS Solution: these systems depend on one COTS software product
    • Licenses tend to be Enterprise-Wide and a license is more expensive
  - COTS Intensive: these systems depend on a number of COTS software products
    • Licenses vary in coverage (per computer versus enterprise) and cost

• MS-B: Estimate annual cost based on the types of COTS software products anticipated for this program

<table>
<thead>
<tr>
<th>COTS Product Type</th>
<th>Number of COTS Licenses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>COTS Solution/ License</td>
<td>$1,300 - $1,700</td>
</tr>
<tr>
<td>Intensive System/ License</td>
<td>$800 - $900</td>
</tr>
</tbody>
</table>

The values in this table are for illustration purposes and are not real
Estimation at MS-A&B: WBS 4 - 8

• Analogous programs tend to be sustained at the same Maintenance depot
  4.0 C&As: estimate annual cost using average of analogous programs
  5.0 System Facilities: estimate annual cost based on anticipated maintenance depot
  6.0 Sustaining Engineering: estimate annual cost based on analogous programs
  7.0 Field Software Support: estimate annual cost based on analogous programs
  • Number of FSEs may increase if sustainment is supporting a wartime-tempo of operations
  8.0 Support Infrastructure: estimate annual cost based on anticipated maintenance depot
Estimation at MS-C: WBS 1 & 2

- Use historical data from multiple software Development Builds to develop CERs or calibrate estimation models
- Examine build durations for long and short cycles indicating future major and minor release profiles
- Examine build overlaps
- With the CERs, determine a monthly burn rate and normalized to an annual cost for WBS 1 & 2

This data is based on the Real-Time software domain from DoD’s SRDR data
## CER – Project Data

<table>
<thead>
<tr>
<th>Build</th>
<th>Equivalent SLOC</th>
<th>Hours</th>
<th>Start Date</th>
<th>End Date</th>
<th>Months Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>173,447</td>
<td>15,648</td>
<td>01/01/08</td>
<td>07/10/09</td>
<td>18.3</td>
</tr>
<tr>
<td>1a</td>
<td>6,085</td>
<td>1,806</td>
<td>07/01/09</td>
<td>09/15/09</td>
<td>2.5</td>
</tr>
<tr>
<td>1b</td>
<td>6,609</td>
<td>1,441</td>
<td>09/10/09</td>
<td>11/03/09</td>
<td>1.8</td>
</tr>
<tr>
<td>2</td>
<td>108,081</td>
<td>25,153</td>
<td>06/01/09</td>
<td>12/15/10</td>
<td>18.5</td>
</tr>
<tr>
<td>2a</td>
<td>12,436</td>
<td>6,305</td>
<td>12/01/10</td>
<td>05/05/11</td>
<td>5.1</td>
</tr>
<tr>
<td>2b</td>
<td>4,106</td>
<td>1,994</td>
<td>04/01/11</td>
<td>10/15/11</td>
<td>6.5</td>
</tr>
<tr>
<td>3</td>
<td>220,788</td>
<td>40,104</td>
<td>08/20/11</td>
<td>01/09/13</td>
<td>16.7</td>
</tr>
<tr>
<td>3a</td>
<td>19,969</td>
<td>8,785</td>
<td>12/01/12</td>
<td>03/30/13</td>
<td>3.9</td>
</tr>
<tr>
<td>3b</td>
<td>80,575</td>
<td>19,105</td>
<td>02/01/13</td>
<td>09/05/13</td>
<td>7.1</td>
</tr>
</tbody>
</table>

### CER Data

### Rhythm Data
CER Derivation

Historical Data

\[ y = 3.3388x^{0.7531} \]
\[ R^2 = 0.89827 \]

- Data based on development builds
- Covers WBS 1.0 - 2.0
Cost Projection – WBS 1.0 and 2.0

<table>
<thead>
<tr>
<th>Release</th>
<th>SLOC</th>
<th>Effort (staff hours)</th>
<th>Cost (@ $90/hour)</th>
<th>Duration (months)</th>
<th>Monthly Burn Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>175,000</td>
<td>87,936</td>
<td>$7,914,281</td>
<td>16</td>
<td>$481,707</td>
</tr>
<tr>
<td>4.1</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
<tr>
<td>4.2</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
<tr>
<td>5</td>
<td>200,000</td>
<td>99,431</td>
<td>$8,948,784</td>
<td>18</td>
<td>$510,857</td>
</tr>
<tr>
<td>5.1</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
<tr>
<td>5.2</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
<tr>
<td>6</td>
<td>200,000</td>
<td>99,431</td>
<td>$8,948,784</td>
<td>18</td>
<td>$510,857</td>
</tr>
<tr>
<td>6.1</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
<tr>
<td>6.2</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
<tr>
<td>6.3</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
<tr>
<td>6.4</td>
<td>25,000</td>
<td>14,678</td>
<td>$1,321,056</td>
<td>6</td>
<td>$204,616</td>
</tr>
</tbody>
</table>

Estimate by Release

Cost Estimate by Year

Estimate by Release

Dollars ($K)
Estimation at MS-C: WBS 3 - 8

Mix of observed costs and analogous program costs:

3.0 Software Licenses – use the actual annual cost and adjusted upwards for number of systems to be deployed over time

4.0 C&A – use the actual annual cost incurred during development

5.0 System Facilities: estimate annual cost based on anticipated maintenance depot

6.0 Sustaining Engineering: estimate annual cost based on anticipated maintenance depot

7.0 Field Software Engineering: use the anticipated numbers of FTEs adjusted upwards as systems are deployed over time

8.0 Support Infrastructure: estimate annual cost based on anticipated maintenance depot
Conclusions

• Different estimation approaches are required at different acquisition lifecycle stages

• Estimates require access to program data across the lifecycle, e.g.,
  - Acquisition documents provide descriptive program data that can be used for selecting analogous programs
  - Development data can be useful for developing initial CERs and determining a maintenance rhythm
  - Post Production data provides actual change size, cost and duration

• SWM estimates are driven by release cycle and annual costs
  - “Monthly Burn” rate is a key component to normalizing costs to an annual cycle

• Maintenance Rhythm shows that total cost amortized over the life of a program is inadequate for annual cost planning
Next Steps

- Systemic Army SWM data collection - focus on execution cost data - expanded data store
- WBS cost element CER refinement - quantitative relationships - phase dependent models
- CER calibration based on system software domains and technical characteristics
- Develop historical release profiles based on system domain and technical characteristics
Contact Information

James Judy
U.S. Army Office of the Deputy Assistant Secretary of the Army for Cost & Economics (ODASA-CE)
5701 21st Street
Building 216
Fort Belvoir, VA 22060-5546
(703) 697-1612
james.m.judy.civ@mail.mil

John McGarry
U.S. Army RDECOM – ARDEC Quality Engineering & System Assurance
RDAR-QES-A
Building 62
Picatinny Arsenal, NJ 07806-5000
(973) 724-7007
john.j.mcgarry4.civ@mail.mil

James P. Doswell
U.S. Army Office of the Deputy Assistant Secretary of the Army for Cost & Economics (ODASA-CE)
5701 21st Street
Building 216
Fort Belvoir, VA 22060-5546
(703) 697-1572
James.p.doswell.civ@mail.mil

Cheryl Jones
U.S. Army RDECOM – ARDEC Quality Engineering & System Assurance
RDAR-QES-A
Building 62
Picatinny Arsenal, NJ 07806-5000
(973) 724-2644
cheryl.l.jones128.civ@mail.mil