ODASA-CE Software
Growth Research

ICEAA 2013

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Sponsor: Shawn Collins, ODASA-CE
Outline

1. Background & Purpose
   Software Estimating Process at ODASA-CE & Current Limitations

2. Study Set-Up
   Data, Independent & Dependent Variables

3. Study Methodology
   Developing & Selecting Final Best Models

4. Applying the Models
   Best Models to Use & When
1. Background & Purpose
ODASA-CE Software Team - Overview

- Office of the Deputy Assistant Secretary of the Army, Cost & Economics (ODASA-CE) Software Team provides estimating support on the cost of developed software embedded in large weapon systems.

- Software Team’s estimates support the Army Cost Review Board’s (CRB) Army Cost Position
  - This is used to support the funding request that is considered as part of the development of DoD’s budget, the President’s Budget, and ultimately the final budget as approved by Congress.

- CRB considers both the program office’s software estimate and the estimate from ODASA-CE’s Software Team
  - Because program office estimates may be tied to an existing budget or schedule, ODASA-CE’s estimates provide an essential “check” to help ensure Army programs will have the needed resources to succeed.
ODASA-CE Software Estimating Today

• Cost:
  – Estimated using two main components:
    • **Size** – uses SLOC (reported in CARD or SRDR), adjusted to ESLOC*
    • **Productivity** – use DB of completed software development efforts to find analogous programs’ productivity
  – A single “Growth” factor is applied to Size but it does not account for variations in growth across different types of projects (e.g. “Size Effect”)

• Schedule:
  – No consistent methodology for estimating schedule

• **Purpose of this study:** Develop new models and a process that ODASA-CE can use to account for software cost and schedule growth
  – That is based on visible, historical data
  – Incorporates multiple variables for greater precision
  – That can be tailored based on the variables to be estimated

* Using weights developed in the 2010 ODASA-CE study, “Software Cost Data Collection & Software Metrics Database.” Equation shown on the next slide.
ODASA-CE Software Estimation Model

*ESLOC = New SLOC + (.76) Modified SLOC + (0.22) Reused SLOC + (0.045) Carryover SLOC + (0.04) Autogenerated SLOC*
2. Study Set-Up
SW Growth Study Set Up

1. Develop Database of Initial/Final SRDR data points for historical SW development projects

2. Identify Dependent Variables of Interest – What Aspects of Growth to Study?

3. Identify and Define Independent Variables
   1. What data can we use directly from the SRDRs?
   2. What new data can we calculate or derive?
I. SW Growth Study Database

- SRDRs are the best source of SW cost and descriptive data, reported in a consistent format.
- For every Final SRDR (actual data), there is a corresponding Initial SRDR (contractor estimate). Perfect for growth studies!

**Initial Data Set:**
~127 software development efforts (from 2001-2009)

**Data Scrub:**
Remove all Data Elements that do not meet criteria:
- Both Initial & Finals
- Complete SW Development Effort
- Code Counting Categories & Convention
- Reporting consistent in initial and final reports
- All necessary data is reported

**Final Data Set:**
17 software development effort “data points”
2. Identify Dependent Variables

- Scope of study included three main factors that can grow, impacting cost in different ways:

  **EFFORT**
  (Effort Hours)

  Growth in effort hours results in higher costs

  **SIZE**
  (ESLOC)

  Growth in size of the product results in greater effort

  **PRODUCTIVITY**
  (ESLOC/ Hour)

  Growth in size of the product will cause productivity to *shrink* (DoS)

- We also explored a model to help ODASA-CE estimate schedule (calendar months)
2. Identify Dependent Variables

- Also looked at Effort, Size, and Schedule in terms of a growth “factor”
  - More similar to the process used by ODASA-CE today

- EFFORT Growth Factor (Act. Effort / Est. Effort)
  - Can be used to estimate Effort Hours directly

- SIZE Growth Factor (Act. ESLOC / Est. ESLOC)
  - Each can be used to estimate Effort Hours indirectly


- EFFORT (Effort Hours)

- SIZE (ESLOC)

- PRODUCTIVITY (ESLOC/Hour)
3. Define Independent Variables

• Studied the data available to us in the SRDR reports to:
  – Identify variables that could be used directly from the Initial SRDR (e.g. estimated effort hours, # of requirements, estimated schedule months)
  – Calculate variables based on SRDR data (e.g. Estimated ESLOC, Estimated ESLOC/Hr, Initial Submission to Start)
  – Develop new variables based on interpretation of data provided – uses rules (e.g. Dummy variables such as Coding Language)

• Independent variables are of two types:
  – “Estimated” data from initial SRDR, or
  – Data elements that do not change from initial to final (e.g. code counting method, Air/Ground)

• Developed data dictionary that contains all descriptions and rules for deriving each data element
3. Define Independent Variables

Independent Variables

- Size
  - Requirements
  - Total SLOC
  - # of COTS
  - ESLOC
  - New SLOC (+%)
  - Modified SLOC (+%)
  - Reused SLOC (+%)
  - Carryover SLOC (+%)
- Duration
  - Schedule Months
- Project Staffing
  - Peak Staff
  - Peak Staff/Hrs
  - Peak Staff/Month
  - Peak Staff/Hrs/Month
  - Peak Staff/Subsystems
- Product Characteristic
  - # of Subsystems
  - Programming Language
  - New / Upgrade
  - Air/Ground
- Development Environment
  - Development Paradigm
- Developer Capability
  - Programming Experience
- Misc
  - Counting Method
  - Year
  - SRDR Submission to Start (Project Maturity)

Dependent Variables that can “Grow”

- EFFORT
  - (Effort Hours)
- SIZE
  - (ESLOC)
- PRODUCTIVITY
  - (ESLOC/Hour)
- SCHEDULE
  - (Calendar Months)

Analyze Characteristics That Have Greatest Impact on Effort, Size, Productivity, & Schedule.
Initial SRDR Date vs. Start Date

- We found there was no consistency in when the Initial SRDR was submitted, relative to the software development effort start date.
- To account for this variability, we added a variable that describes how late the initial SRDR estimate was provided, relative to the actual start date, and expressed as a % of the estimated schedule duration.
- Hypothesis: The later the initial SRDR estimate, the less growth there should be (more information = better estimates).

<table>
<thead>
<tr>
<th>Effort</th>
<th>Initial SRDR Submission</th>
<th>Effort Start Date</th>
<th>Months Delta</th>
<th>As % of Sched.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>June 15, 2005</td>
<td>April-05</td>
<td>2</td>
<td>7%</td>
</tr>
<tr>
<td>2</td>
<td>June 16, 2004</td>
<td>January-04</td>
<td>5</td>
<td>9%</td>
</tr>
<tr>
<td>3</td>
<td>December 20, 2005</td>
<td>January-04</td>
<td>24</td>
<td>57%</td>
</tr>
<tr>
<td>4</td>
<td>July 3, 2001</td>
<td>October 27, 2001</td>
<td>-3</td>
<td>-15%</td>
</tr>
<tr>
<td>5</td>
<td>November 1, 2004</td>
<td>October-02</td>
<td>25</td>
<td>44%</td>
</tr>
<tr>
<td>6</td>
<td>October 1, 2004</td>
<td>October-04</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>7</td>
<td>October 1, 2004</td>
<td>August-04</td>
<td>2</td>
<td>29%</td>
</tr>
<tr>
<td>8</td>
<td>September 29, 2005</td>
<td>October-05</td>
<td>-1</td>
<td>-9%</td>
</tr>
<tr>
<td>9</td>
<td>October 25, 2006</td>
<td>July-03</td>
<td>40</td>
<td>75%</td>
</tr>
<tr>
<td>10</td>
<td>December 29, 2004</td>
<td>February-05</td>
<td>-2</td>
<td>-13%</td>
</tr>
<tr>
<td>11</td>
<td>April 27, 2005</td>
<td>April 18, 2005</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>12</td>
<td>July 20, 2007</td>
<td>July-07</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>13</td>
<td>March 16, 2005</td>
<td>April-05</td>
<td>-1</td>
<td>-8%</td>
</tr>
<tr>
<td>14</td>
<td>September 15, 2005</td>
<td>August-05</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>15</td>
<td>September 12, 2006</td>
<td>June-04</td>
<td>28</td>
<td>64%</td>
</tr>
<tr>
<td>16</td>
<td>September 29, 2006</td>
<td>January-04</td>
<td>33</td>
<td>62%</td>
</tr>
<tr>
<td>17</td>
<td>November 1, 2006</td>
<td>February-06</td>
<td>9</td>
<td>19%</td>
</tr>
</tbody>
</table>

**Red**=Initial SRDR submitted after effort start date

**Blue**=Initial SRDR submitted before effort start date
3. Study Methodology
Growth Study Methodology

• Approach began with OLS **linear** analysis; cost estimating authoritative guidance* states that in the absence of a known relationship, linear models are a natural starting point & should be checked first

• Several advantages to OLS linear models:
  – Are the best approximations to non-linear models, taking you “least far afield” if you guessed wrong
  – Ability to conduct formal significance testing
  – Allow for formal assumption testing
  – Provide objective measures of uncertainty
  – Provide basis for S-curve analysis (risk analysis)

• Also investigated **log-linear and non-linear** relationships

*ICEAA Cost Estimating Body of Knowledge (CEBok) Module 6: Data Analysis Principles
Methodology – Linear & Log-Linear

• Generated candidate models
  – Principal Component Analysis (PCA) determined that four or five variables are the most efficient number of variables for our models
  – Each dependent variable was regressed on all possible combinations of four and five independent variables (> 1.5 million combinations!)
  – Four variable models with lowest unit-space CVs had variables systematically removed to look for model improvement

• Applied exclusion criteria to candidate models
  – Not significant: F-test p-value > 0.1
  – Multicollinearity: Variance Inflation Factor’s (VIFs) > 4.0
  – Error term non-normality or heteroscedasticity: Error terms not normally distributed or having non-constant variance
  – Counter-intuitive: Does not pass “Common Sense” Test

• Selected remaining candidate model with lowest calibrated unit-space CV
  – Also considered uncalibrated CV and unit-space adjusted $R^2$ (for log-linear models)

• Model forms:
  \[ y = a + b_1 \cdot x_1 + \ldots + b_k \cdot x_k + \varepsilon \]  \hspace{1cm} \text{Linear}

  \[ y = a \cdot x_1^{b_1} \cdot \ldots \cdot x_k^{b_k} \cdot \varepsilon \]  \hspace{1cm} \text{Log-Linear}
Methodology – Non-Linear

- Generated candidate models
  - Started with log-space model (for each dependent variable) with lowest unit-space CV
  - Executed general error regression model (GERM) analysis
    - No assumptions made regarding distribution of error
    - No significance testing
    - Not transferable to log-space
  - Minimize CV subject to the following constraints
    - Unbiased estimate
    - Signs of the coefficients remain the same from the log-linear model
  - Normalized non-dummy variables to allow for comparison of exponents
  - Variables highly correlated with the dependent variable, but not in model, were added and the models retested
  - Variables with low absolute value coefficients were removed and the models retested
  - Performed multiple optimizations to ensure stable predictors
  - Consideration was given to uncalibrated unit-space CV
- Selected remaining candidate model with lowest calibrated unit-space CV
  - Also considered unit-space adjusted R² and engineering judgment

Model form: \( y = a + b_1 \left( \frac{x_1}{\bar{x}_1} \right)^{c_1} \cdot \ldots \cdot \left( \frac{x_k}{\bar{x}_k} \right)^{c_k} \cdot d_1^{(1,0)} \cdot \ldots \cdot d_j^{(1,0)} \cdot \varepsilon \)
Why CV?

- CV was used as the “measure of merit”
  - Most closely mirrors the error that an analyst might typically expect when using the equation(s)
  - Is expressed as percentage of the actual value being estimated (percentage of the mean of our data set \(\bar{y}\))
- Minimizing percentage error directly would give too much weight to smaller efforts (e.g., a 50% error in estimating a small effort would be treated the same as a 50% error in estimating a larger one, even though the error on the larger project is much more costly)

Interpretation of CV: Standardized error of estimate, normalized by mean of data set

\[
cv = \left( \frac{SEE}{\bar{y}} \right)
\]
Calibrated vs. Uncalibrated CV

Consideration was given to both calibrated and uncalibrated CV

<table>
<thead>
<tr>
<th></th>
<th>Observations Used</th>
<th>Precision</th>
<th>Representative</th>
<th>Evaluated in Unit-Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibrated CV</td>
<td>All observations used to calculate coefficients</td>
<td>More precise</td>
<td>Less representative of work done by analyst</td>
<td>Yes</td>
</tr>
<tr>
<td>Uncalibrated CV</td>
<td>Observation being predicted not used to calculate coefficients</td>
<td>Less precise</td>
<td>More representative of work done by analyst</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Uncalibrated CV Steps

1. Remove first observation from dataset
2. Re-run regression using the remaining (n-1) data points
3. Use the new regression to generate a prediction for the first data point
4. Repeat this process for all n data points, generating n predictions (each one of them based on equations that exclude the data point being predicted)
5. Calculate the CV associated with these new predictions

Illustration:

Observation one has been removed
Coefficients are calculated
Coefficients are calculated for all 17 unique subsets of 16 data points
Overall Best Models

The overall best model for each dependent variable was selected based on comparing the calibrated CV, uncalibrated CV, and adjusted $R^2$ for each of the winning linear, log-linear, and non-linear models.

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Unit-Space Equations</th>
<th>Cal. CV*</th>
<th>Uncal. CV*</th>
<th>Adj. $R^2*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Log - Linear</td>
<td><strong>Effort Hours</strong> = 7.20*(Estimated Effort Hours)$^{0.80}$ *(Estimated External Requirements + 1)$^{0.08}$ <em>1.19</em>(New)</td>
<td>0.23</td>
<td>0.29</td>
<td>0.94</td>
</tr>
<tr>
<td>2 Linear</td>
<td><strong>Effort Hour Growth Factor</strong> = 2.19 + (Estimated Total Requirements)$^{0.0001}$ + (Estimated Schedule)$^{-0.01}$ + (Estimated Peak Staff per Schedule)$^{-0.15}$ + (Development Paradigm)$^{0.10}$ + (Code Language)$^{-0.50}$</td>
<td>0.17</td>
<td>0.24</td>
<td>0.68</td>
</tr>
<tr>
<td>3 Linear</td>
<td><strong>ESLOC</strong> = 55,988.62 + (Estimated Effort Hours)$^{0.69}$ + (Estimated ESLOC)$^{0.57}$ + (Estimated ESLOC per Peak Staff)$^{4.67}$ + (Estimated Percent High Experience)$^{-121,877.75}$</td>
<td>0.12</td>
<td>0.26</td>
<td>0.99</td>
</tr>
<tr>
<td>4 Log - Linear</td>
<td><strong>ESLOC Growth Factor</strong> = 0.13*(Estimated ESLOC)$^{-0.15}$*(Estimated Peak Staff per Effort Hour per Month)$^{0.80}$ *(Estimated Percent High Experience)$^{0.34}$</td>
<td>0.22</td>
<td>0.28</td>
<td>0.78</td>
</tr>
<tr>
<td>5 Non - Linear</td>
<td><strong>ESLOC per Hour</strong> = -0.71 + 4.59*((Estimated ESLOC per Effort Hour)/(Average Estimated ESLOC per Effort Hour))$^{0.61}$*((Estimated New SLOC per Effort Hour)/(Average Estimated New SLOC per Effort Hour))$^{0.08}$<em>1.02</em>(Programming Experience)</td>
<td>0.23</td>
<td>0.37</td>
<td>0.94</td>
</tr>
<tr>
<td>6 Linear</td>
<td><strong>Schedule Months</strong> = 16.23 + 0.50*(Estimated Schedule) – 3.14*(Estimated Peak Staff per Month) + 0.02*(Estimated ESLOC per Requirement)</td>
<td>0.15</td>
<td>0.21</td>
<td>0.93</td>
</tr>
<tr>
<td>7 Linear</td>
<td><strong>Schedule Growth Factor</strong> = 1.38 + 0.31*(Air Platform) + 0.25*(Development Paradigm) + 0.0006*(Estimated ESLOC per Requirement) – 0.11*(Estimated Peak Staff per Month) – 0.02*(Estimated Schedule)</td>
<td>0.12</td>
<td>0.17</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Note: “Estimated” independent variables are the contractor’s estimate provided in the initial SRDR

* In unit-space
## Example: Effort Hours

### Model Type:

| Log-Linear |

### Unit-Space Equation:

\[
\text{Effort Hours} = 7.20 \times (\text{Estimated Effort Hours})^{0.80} \times (\text{Estimated External Requirements} + 1)^{0.08} \times 1.19^{(\text{New})}
\]

<table>
<thead>
<tr>
<th>Cal. CV*:</th>
<th>Uncal. CV*:</th>
<th>Adj. R²*:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.23</td>
<td>0.29</td>
<td>0.94</td>
</tr>
</tbody>
</table>

### Independent Variables

**Definition & Interpretation**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition and Interpretation</th>
</tr>
</thead>
</table>
| Estimated Effort Hours | **Def:** Sum of total estimated effort hours across all activities reported  
 **Int:** We expect the contractor’s initial estimate of effort hours to be a strong predictor of the realized effort hours |
| Estimated External Requirements | **Def:** Total estimated external requirements  
 **Int:** It is reasoned that count of external requirements is a measure of complexity. Therefore, we expect effort hours to increase as the estimated number of external requirements (complexity of the development effort) increases. |
| New | **Def:** Dummy variable; if primary development on the project was considered “new” (no existing system currently performs its function or development completely replaces an existing system - with new requirements, architecture, design, code, etc.), project assigned a “1” value. If project considered an “upgrade”, a “0.” In cases where different subsystems within the same project had different classifications, project was considered “new” if a majority of hours were associated with "new" development.  
 **Int:** Because a new development effort cannot leverage code and lessons learned from a previous increment or build of the system, we expect a new development effort to require more effort hours than an upgrade to an existing development effort |

* In unit-space
4. Applying the Models
Applying the Models - Effort

• Rather than apply a “one size fits all” growth factor to ESLOC for every estimate, we now have a variety of tools for estimating actual drivers of cost, based on historical growth!
  • All five of the models for cost perform better than the contractor’s estimate of each variable
• At the end of the day, ODASA-CE wants to develop the best estimate of Effort Hours possible
  • Using our model to estimate Effort Hours directly greatly outperforms the contractor’s estimate of Effort Hours
  • Our model’s estimate for ESLOC is also very useful for cases when ODASA-CE wants to use an analogous productivity as the basis for an estimate; our model will be more precise than simply applying a single growth factor to ESLOC

<table>
<thead>
<tr>
<th>METHOD</th>
<th>ESLOC</th>
<th>Productivity Factor</th>
<th>Effort Hours</th>
<th>Effort Hour Growth Factor</th>
<th>ESLOC Growth Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct (using our model)</td>
<td>12.4%</td>
<td>23.5%</td>
<td>23.0%</td>
<td>17.5%</td>
<td>21.8%</td>
</tr>
<tr>
<td>Direct (using contractor’s values)</td>
<td>34.0%</td>
<td>104.9%</td>
<td>37.6%</td>
<td>37.5%</td>
<td>54.5%</td>
</tr>
<tr>
<td>Direct (using ODASA-CE growth factor)</td>
<td>79.5%</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>48.3%</td>
</tr>
<tr>
<td>Indirect (our productivity factor, contractor’s ESLOC)</td>
<td>--</td>
<td>--</td>
<td>44.5%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Indirect (contractor’s productivity factor, our ESLOC)</td>
<td>--</td>
<td>--</td>
<td>24.6%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Indirect (our productivity factor, our ESLOC)</td>
<td>--</td>
<td>--</td>
<td>89.7%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Indirect (our effort hour growth factor, contractor’s effort hours)</td>
<td>--</td>
<td>--</td>
<td>23.3%</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Indirect (our ESLOC growth factor, contractor’s ESLOC, contractor’s productivity)</td>
<td>--</td>
<td>--</td>
<td>99.5%</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Applying the Models - Effort

Two recommended models for ODASA-CE to estimate Effort Hours; each one has an advantage depending on the scenario ODASA-CE faces.

Does ODASA-CE want to use an analogous productivity in their estimate?

- Yes → Use Model to Estimate ESLOC (then apply analogous productivity to estimate Effort Hours)
- No → Use Model to Estimate Effort Hours directly
## Applying the Models - Effort

<table>
<thead>
<tr>
<th>#1: Size (ESLOC)</th>
<th>Reciprocal of Productivity</th>
<th>#2: Effort Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort Hours</td>
<td>Analogous Productivity</td>
<td>Provided by ODASA-CE</td>
</tr>
</tbody>
</table>

**Note:**
- **Green** = Model output
- **White** = Provided by ODASA-CE
## Effort Hours

### Unit-Space Equation:

\[
\text{Effort Hours} = 7.20 \times (\text{Estimated Effort Hours})^{0.80} \times (\text{Estimated External Requirements} + 1)^{0.08} \times 1.19(\text{New})
\]

<table>
<thead>
<tr>
<th>Model Type:</th>
<th>Log-Linear</th>
<th><strong>Definition &amp; Interpretation</strong></th>
<th><strong>Cal. CV</strong>:</th>
<th><strong>Uncal. CV</strong>:</th>
<th><strong>Adj. R²</strong>:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent Variables</strong></td>
<td></td>
<td></td>
<td>0.23</td>
<td>0.29</td>
<td>0.94</td>
</tr>
<tr>
<td><strong>Estimated Effort Hours</strong></td>
<td><strong>Def:</strong> Sum of total estimated effort hours across all activities reported</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positive</strong></td>
<td><strong>Int:</strong> We expect the contractor's initial estimate of effort hours to be a strong predictor of the realized effort hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Estimated External Requirements</strong></td>
<td><strong>Def:</strong> Total estimated external requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positive</strong></td>
<td><strong>Int:</strong> It is reasoned that count of external requirements is a measure of complexity. Therefore, we expect effort hours to increase as the estimated number of external requirements (complexity of the development effort) increases.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>New</strong></td>
<td><strong>Def:</strong> Dummy variable; if primary development on the project was considered &quot;new&quot; (no existing system currently performs its function or development completely replaces an existing system - with new requirements, architecture, design, code, etc.), project assigned a &quot;1&quot; value. If project considered an &quot;upgrade&quot;, a &quot;0.&quot; In cases where different subsystems within the same project had different classifications, project was considered &quot;new&quot; if a majority of hours were associated with &quot;new&quot; development.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Positive</strong></td>
<td><strong>Int:</strong> Because a new development effort cannot leverage code and lessons learned from a previous increment or build of the system, we expect a new development effort to require more effort hours than an upgrade to an existing development effort</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*In unit-space*
Comparison of Performance Based on Uncalibrated CV

Effort Hours

- Predicted Effort Hours (Uncalibrated CV = 29%)
- Actual Effort Hours
- Contractor Estimated Effort Hours (Calibrated CV = 38%)

Software Development Efforts

Presented at the 2013 ICEAA Professional Development & Training Workshop - www.iceaaonline.com
Comparison of Performance Based on Calibrated CV

Effort Hours

- Model Predictions (Calibrated CV = 23%)
- Predicted = Actual
- Contractor Predictions (Calibrated CV = 38%)

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Example – Estimating Effort Hours

• When to use model for Effort Hours
  – No good analogy available; this model provides the ability to estimate Effort Hours directly, no analogous productivity is needed

• Example: Estimate final effort hours for SW Development Effort A.
  Model inputs:
  – New/Upgrade: 1
  – Programming Experience: 0
  – Est. Effort Hours: 29,173

• Effort Hours = -8,651 + (31,174) New/Upgrade + (37,098) Programming Experience + (.745) Est. Effort Hours
  – Effort Hours = -8,651 + (31,174)(1) + (37,098)(0) + (.745) (29,173)
  – Effort Hours = 44,257 (52% Growth Over Initial Estimate)
  – Actual Effort Hours = 46,068
#2 ESLOC

**Model Type:** Linear

**Unit-Space Equation:**

\[
\text{ESLOC} = 55,988.62 + (\text{Estimated Effort Hours}) \times 0.69 + (\text{Estimated } \text{ESLOC}) \times 0.57 + (\text{Estimated ESLOC per Peak Staff}) \times 4.67 + (\text{Estimated Percent High Experience}) \times -121,877.75
\]

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Definition &amp; Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimated Effort Hours</strong></td>
<td><strong>Positive</strong></td>
</tr>
<tr>
<td><strong>Def:</strong> Sum of total estimated effort hours across all activities reported</td>
<td></td>
</tr>
<tr>
<td><strong>Int:</strong> It is reasoned that both effort hours and ESLOC are measures of the size of a development effort. Therefore, we expect development effort with more effort hours to result in more ESLOC.</td>
<td></td>
</tr>
<tr>
<td><strong>Estimated ESLOC</strong></td>
<td><strong>Positive</strong></td>
</tr>
<tr>
<td><strong>Def:</strong> Total estimated SLOC, adjusted using the adjustment factors currently used by ODASA-CE (developed in 2010) across five categories - New SLOC, Modified SLOC, Reused SLOC, Carryover SLOC, Autogen SLOC.</td>
<td></td>
</tr>
<tr>
<td><strong>Int:</strong> We expect the contractor’s estimate of ESLOC to be a strong predictor of realized ESLOC.</td>
<td></td>
</tr>
<tr>
<td><strong>Estimated ESLOC / Peak Staff</strong></td>
<td><strong>Positive</strong></td>
</tr>
<tr>
<td><strong>Def:</strong> Measure of productivity calculated by dividing total estimated ESLOC (estimated project size) by estimated peak staff size to understand how much work is completed per peak staff member.</td>
<td></td>
</tr>
<tr>
<td><strong>Int:</strong> We expect the contractor’s estimate of ESLOC to be a strong predictor of realized ESLOC. Therefore, we also expect estimated ESLOC normalized by peak staff to be a strong predictor of realized ESLOC.</td>
<td></td>
</tr>
<tr>
<td><strong>Estimated % High Experience</strong></td>
<td><strong>Negative</strong></td>
</tr>
<tr>
<td><strong>Def:</strong> Percent of personnel estimated to be highly experienced in domain, weighted by hours where there are multiple subsystems.</td>
<td></td>
</tr>
<tr>
<td><strong>Int:</strong> It is reasoned that more experienced programmers have more knowledge to draw on. Therefore, we expect that knowledge would allow the programmers to produce the same software capabilities with fewer ESLOC.</td>
<td></td>
</tr>
</tbody>
</table>

* In unit-space
Comparison of Performance Based on Uncalibrated CV

### ESLOC

- **Predicted ESLOC (Uncalibrated CV = 26%)**
- **Actual ESLOC**
- **Contractor Estimated ESLOC w/Growth Factor (Calibrated CV = 80%)**

**Software Development Efforts**
Comparison of Performance Based on Calibrated CV

**ESLOC**

- Model Predictions (Calibrated CV = 12%)
- Predicted = Actual
- Contractor Predictions Applying Growth Factor (Calibrated CV = 80%)

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Example – Estimating ESLOC

- When to use model for ESLOC:
  - Where an excellent analogy is available to estimate productivity, this model provides the ability to estimate size (ESLOC) with more precision than using a single growth factor.

- Example: Estimate final ESLOC for SW Development Effort B.

  **Model inputs:**
  - Est. Peak Staff: 68
  - Est. ESLOC: 826,003
  - Est. Effort Hours: 469,692
  - Est. % High Experience: 75%

  **ESLOC = 55,988.62 + (.69) Est. Effort Hours + (.57) Est. ESLOC + (4.67) Est. ESLOC/Peak Staff - (121,877.75) Est. % High Experience**
  - ESLOC = 55,988.62 + (.69)(469,692) + (.57)(826,003) + (4.67)(12,147) - (121,877.75) (.75)
  - Estimated ESLOC= 816,216 (2% Decay From Initial Estimate)
  - Actual ESLOC = 826,299 (0% Growth Over Initial Estimate)
  - Estimated ESLOC (w/existing Growth Factor) = 1,156,405 (40% Growth Over Initial Estimate)
Applying the Models - Schedule

- While both of the schedule models outperform the contractor’s estimate of schedule, we recommend using the Schedule Months model

<table>
<thead>
<tr>
<th>Model</th>
<th>Cal. CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct – Using our model for Schedule Months (Unbiased)</td>
<td>0.15</td>
</tr>
<tr>
<td>Indirect – Using Schedule Growth Factor with Contractor’s estimate of schedule months (Biased)</td>
<td>0.16</td>
</tr>
</tbody>
</table>
# Schedule

**Model Type:** Linear

**Schedule**

\[
\text{Schedule} = 16.23 + 0.50\times(\text{Estimated Schedule}) - 3.14\times(\text{Estimated Peak Staff per Month}) + 0.02\times(\text{Estimated ESLOC per Requirement})
\]

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Definition &amp; Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Estimated Schedule</strong></td>
<td><strong>Def:</strong> Total number of schedule calendar months, including the start month and end month. <strong>Int:</strong> It is expected that estimated schedule is a strong indicator of actual schedule months.</td>
</tr>
<tr>
<td><strong>Estimated Peak Staff per Month</strong></td>
<td><strong>Def:</strong> Measure of project staffing structure; calculated by dividing total estimated peak staff size by estimated schedule months <strong>Int:</strong> By adding resources, Peak Staff normalized by estimated schedule months, it is reasonable to assume a decrease in actual schedule months</td>
</tr>
<tr>
<td><strong>Estimated ESLOC per Requirement</strong></td>
<td><strong>Def:</strong> Measure of complexity calculated by dividing ESLOC (estimated project size) by Total Requirements (excluding external) to measure the amount of coding for each non external requirement of the project. <strong>Int:</strong> It is reasoned that as software developments become more complex, the length of their schedule will increase.</td>
</tr>
</tbody>
</table>
Example – Estimating Schedule

- Estimate actual schedule for SW Development Effort C
- Model Inputs:
  - Est. Schedule: 42
  - Est. Peak Staff per Month: 0.14
  - Est. ESLOC per Requirement: 838.16
- Schedule = 16.23 + 0.50*(Estimated Schedule) – 3.14*(Estimated Peak Staff per Month) + 0.02*(Estimated ESLOC per Requirement)
  - Schedule = 16.23 + 0.50*(42) – 3.14*(0.14) + 0.02*(838.16)
  - Schedule = 53.54 months (27% Growth Over Initial Estimate of 42 months)
  - Actual Schedule = 54 months
Comparison of Performance Based on Uncalibrated CV

Schedule

Predicted Schedule Months (Uncalibrated CV = 21%)
Actual Schedule
Contractor Predicted Schedule Months (Calibrated CV = 22%)

Schedule Months

Software Development Efforts
Comparison of Performance Based on Calibrated CV

Schedule

- Model Predictions (Calibrated CV = 15%)
- Predicted = Actual
- Contractor Predictions (Calibrated CV = 22%)

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Confirmation of Schedule Model Performance

<table>
<thead>
<tr>
<th>Schedule</th>
<th>R²*</th>
<th>Adjusted R²*</th>
<th>Calibrated CV*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our Model</td>
<td>0.94</td>
<td>0.93</td>
<td>0.15</td>
</tr>
<tr>
<td>Contractor’s Estimate</td>
<td>0.86</td>
<td>0.86</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Our model provides more precision (lower CV) and explains more variation (higher R² and Adjusted R²) than the contractor’s estimate.

*In unit space
Next Steps

• Expand Data Set
  • Obtain entire set of SRDR data (post 2009) from DCARC database to enable a more robust analysis

• CARD-Only Analysis
  • Existing Models use Initial SRDR estimates, which may not be available at the time of the analysis
  • Obtain set of more recent CARDs to analyze available data

• Obtain 3-4 “test cases” which we can use to demonstrate the value of the new models:
  • Have a completed estimate using traditional method
  • All actuals are available

• Complete a Software Estimating Workbook
  • Provide ODASA-CE analysts with a user-friendly tool that consolidates models for estimating software development Effort and Schedule with historical program comparison capabilities

• Potential: S-curve risk analysis in order to generate prediction intervals, a range of potential costs, and a confidence level associated with the estimate