Calibration Approach and Results of the COCOMO II Post-Architecture Model

Sunita Chulani*, Brad Clark, Barry Boehm
(USC-Center for Software Engineering)
Bert Steece
(USC-Marshall School of Business)

ISPA ‘98

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*Email: sdevnani@sunset.usc.edu
Outline

➔ Brief History of COCOMO

◆ COCOMO II.1997
  – Process
  – Prediction Accuracies
  – Comparison with COCOMO ’81

◆ Updates and Plans
  – Plans for Improving Prediction Accuracies
  – COCOMO II Research Aim
  – Effects of Process Maturity on Effort

◆ Acknowledgements and Information Sources
COnstructive COst MOdel (COCOMO)

- COCOMO published since 1981
- Commercial implementations of COCOMO
  - CoCoPro, CB COCOMO, COCOMOID, COSTMODL, GECOMO Plus, SECOMO, etc.
- Other models based on COCOMO
  - REVIC, Gulezian
- COCOMO II
  - Research effort started in 1994 to develop a 1990’s-2000’s software cost model
  - Address new processes and practices
  - COCOMO II.199Y/200Y
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COCOMO II.1997 Calibration Process

- Began with expert-determined a-priori model parameters
  - Iterated with Affiliates (Result => Original Post Architecture Model)
- Collected Data
- Identified and consolidated highly correlated model parameters
- Statistically determined estimates of consolidated model parameters from data
  - Using logarithms to linearize regression
- Used data determined model parameters to adjust a-priori model parameters
  - Experimented with weighting factors
Distribution of Size
Distribution of Effort

![Bar Chart: Distribution of Effort](chart)

- **X-axis**: Person Months
- **Y-axis**: No. of Projects

- Most projects are clustered between 100 and 800 Person Months.
Distribution of Schedule

No. of Projects

Calendar Months
Consolidated Highly Correlated Parameters

<table>
<thead>
<tr>
<th></th>
<th>TIME</th>
<th>STOR</th>
<th>ACAP</th>
<th>PCAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME</td>
<td>1.0000</td>
<td>0.6860</td>
<td>-0.2855</td>
<td>-0.2015</td>
</tr>
<tr>
<td>STOR</td>
<td>0.6860</td>
<td>1.0000</td>
<td>-0.0769</td>
<td>-0.0027</td>
</tr>
<tr>
<td>ACAP</td>
<td>-0.2855</td>
<td>-0.0769</td>
<td>1.0000</td>
<td>0.7339</td>
</tr>
<tr>
<td>PCAP</td>
<td>-0.2015</td>
<td>-0.0027</td>
<td>0.7339</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

- **TIME**, **STOR** to give **RCON** (Resource Constraints)
- **ACAP**, **PCAP** to give **PERS** (Personnel Factors)

Thus, 15 effort multipliers instead of 17 for calibration.
COCOMO II Calibration Model

- Needed linear model for regression:
  \[ Y = B_0 + B_1 X_1 + B_2 X_2 + \Lambda + B_p X_p \]

- COCOMO II Post-Architecture is non-linear
  \[ Y = B_0 X^{B_1} \]

- What did we do?
  - Expanded COCOMO II model
  - Transformed products with logarithms to produce sums
Expanded COCOMO II

◆ Distributed the Scale Factors
◆ Resulted in 21 predictor variables i.e. 15 Effort Multipliers + 5 Scale Factors + (Size)$^{1.01}$

$$PM_{est} = A \cdot (\text{Size}^{1.01} \cdot (\text{Size}^{SF_1} \cdot (\text{Size}^{SF_2} \cdot (EM_1) \times EM_{15})$$

Log Transformed COCOMO:

$$\ln(PM_{est}) - \ln(\text{Size})^{1.01} = \ln(A) + SF_1 \ln(\text{Size}) + EM_1 \times EM_{15}$$

◆ Regression analysis derived the coefficients, $B_i$, for each factor
COCOMO II.1997 Calibration

- 83 projects
- Multiple Linear Regression
  - 10% weighted average between a-priori values and data-determined values

Develop for Reuse (RUSE)
## COCOMO II.1997 Accuracy Results

<table>
<thead>
<tr>
<th>Effort Prediction</th>
<th>Before Stratification By Organization</th>
<th>After Stratification By Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRED(.20)</td>
<td>46%</td>
<td>49%</td>
</tr>
<tr>
<td>PRED(.25)</td>
<td>49%</td>
<td>55%</td>
</tr>
<tr>
<td>PRED(.30)</td>
<td>52%</td>
<td>64%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Schedule Prediction</th>
<th>Before Stratification By Organization</th>
<th>After Stratification By Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRED(.20)</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
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<td>61%</td>
</tr>
<tr>
<td>PRED(.30)</td>
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<td>62%</td>
</tr>
</tbody>
</table>
COCOMO ‘81 & COCOMO II.1997

- COCOMO ‘81: Pred (.20) = 68%
- COCOMO II.1997: Pred (.20) = 46%

Challenges faced in calibrating COCOMO II
- GUI builders, COTS, 4GL’s, reuse, requirements breakage
  - Need to rethink size metrics
- Distributed interactive applications
  - Web-based, object-oriented, event-based
  - Middleware effects
- New process models (evolutionary, incremental, spiral)
  - Phases overlap
  - Where are cost measurement endpoints?
- Lack of good data
  - not enough data (i.e. very little degrees of freedom)
  - lack of dispersion
  - heteroskedasticity
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Plans to Improve Accuracy

- Gather more data
- Bayesian Regression Analysis
- Stratify data based on Language Level and Application Type
- Effort distribution based on activities
- Enhancement of COCOMO II database to continuously update the model
Successive versions of COCOMO II

◆ The 1997 version
  - Multivariate Linear Regression with 10% weighted average of expert-determined and data-determined

◆ The 1998 version
  - Bayesian Regression Analysis
    - Weighted average
    - Separate weights for each parameter based on significance
  - Model more Data-Determined

◆ The 19??/20?? version
  - 100% Data-Determined
Bayes Theorem

\[ g(\beta / y) = \frac{f(y / \beta) g(\beta)}{f(y)} \]

\[ g(\beta / y) \propto l(\beta / y) g(\beta) \]

posterior information $\propto$ sample information $X$ prior information
The Bayesian Approach for COCOMO II

A-posteriori Bayesian update

Productivity Range = Highest Rating / Lowest Rating

Noisy data analysis

A-priori Experts’ Delphi

Literature, behavioral analysis
## Prediction Accuracies*

<table>
<thead>
<tr>
<th>Effort Prediction</th>
<th>Bayesian Approach 159 observations</th>
<th>COCOMO II.1997 83 observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRED(.20)</td>
<td>49%</td>
<td>46%</td>
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<tr>
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</tr>
<tr>
<td>PRED(.30)</td>
<td>64%</td>
<td>52%</td>
</tr>
</tbody>
</table>

* Please note that the COCOMO II.1998 calibration is not yet complete. Hence these results may be different for the COCOMO II.1998 final calibration
COCOMO II Calibration

Approaches

COCOMO II.1997
10% weighted-average approach

Bayesian approach - weight determined by data and prior significance

Productivity Range = Highest Rating / Lowest Rating

Noisy data analysis

A-priori
Expert-determined

A-posteriori Bayesian update

Noisy data analysis

A-priori
Experts’ Delphi

Literature, behavioral analysis

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COCOMO II Research Group’s Aim

100% Data Driven

100

50

10

100% Expert Driven

83 datapoints - COCOMO II.1997 version

~200 datapoints - Bayesian model

Number of projects used in calibration
COCOMO II PMAT Results

- Used COCOMO II Provisional Values
- PMAT is a scale factor in COCOMO II
- PMAT’s influence varies with SIZE: \((\text{Size})^{\text{PMAT}}\)

- Full COCOMO
  - \(b_{\text{PMAT}}: 4.22\) (t-value = 3.05)
  - interval: 1.9 < \(b_{\text{PMAT}}\) < 6.6

- Reduced COCOMO
  - \(b_{\text{PMAT}}: 3.64\) (t-value = 2.19)
  - interval: 1.5 < \(b_{\text{PMAT}}\) < 5.4
Interpreting COCOMO II PMAT Results

For example, let’s say the Scale Factors yield an exponent of 1.10, all Effort Multipliers are 1.0. The effect of PMAT on effort is:

- PMAT unchanged: 
  \[(30)^{1.11}/(30)^{1.10} = 1.035\] change in effort
- PMAT adjusted by 2.0: 1 PMAT increment => \[2(1.035) = 1.07\] change in effort
- PMAT adjusted by 6.0: 1 PMAT increment => \[6(1.035) = 1.21\] change in effort
- Decrease effort 7% for 2.0 adjustment and 21% for 6.0 adjustment
Some Observations on Effects of Process Maturity on Effort

- Process Maturity does effect effort. A one increment change in PMAT (Level 1 Upper to Level 2, Level 2 to Level 3, etc.) results in a 7% to 21% reduction in effort for a 30 KDSI project.
  - Effect is larger for larger products
- Using it as a scale factor appears to provide a stronger influence on effort than as a multiplicative factor.
- Its influence is less than the personnel capability of the team, about the same as product complexity (CPLX), and higher than other COCOMO cost drivers.
- Process Maturity should be in all Software Cost Estimation Models; it is well defined and measurable.
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◆ Website - http://sunset.usc.edu/COCOMOII/Cocomo.html
  - Affiliate Prospectus
  - Model Definition Manual
  - Data Collection Form
  - Java COCOMO
  - Little Expert COCOMO Calculator

◆ Acknowledgements

- AFRL Contract F30602-96-C-0274,
  “KBSA Life Cycle Evaluation”

- COCOMO II Affiliates