COCOMO II: Calibration and Plans

Sunita Devnani-Chulani
USC-CSE

LA SPIN
May 28, 1997
Presentation Outline:

→ COCOMO calibration
  → Calibration process
  Results to date

• Software Tool Status
• Other Ongoing Research and Plans
• Quality Model Extension to COCOMO II
  - Motivation
  - The Software Defect Introduction and Removal Model
  - A-Priori Software Quality Model
  - Plans

• Information Sources
COCOMO II 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
Data Collection:

- Defined the data needed (to completely describe the Post Architecture Model)
- Collected data with a paper form or a computer software tool
- Affiliate Organizations provided majority of data
  - Historical - whole project
- Site visits or phone interviews to record data
- Entered the data into the repository
  - Data is labeled with generic id
  - Stored in locked room
  - Limited access by researchers
- Did Data Consistency checking and conditioning
## Consolidated Highly Correlated Parameters

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- **What do we do?** ⇒ Combine:
  - TIME & STOR to give RCON (Resource Constraints)
  - ACAP & PCAP to give PERS (Personnel Factors)

Thus, 15 effort multipliers instead of 17 for calibration
## Statistical Data Analysis

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Thus, we took log transforms to normalize the response variable. Also, we took log transforms to linearize the parametrized model.
COCOMO Calibration Model:

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

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

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

• Distributed the Scale Factors

• Resulted in 21 predictor variables i.e. 15 Effort Multipliers + 5 Scale Factors + \( (\text{Size})^{1.01} \)

\[
PM_{est} = A \cdot (\text{Size})^{1.01} \cdot (\text{Size})^{SF_1} \cdot (\text{Size})^{SF_2} \cdots EM_1 \cdots EM_{15}
\]

Log Transformed COCOMO:

\[
\ln(PM_{est}) - \ln(\text{Size})^{1.01} = \ln(A) + SF_1 \ln(\text{Size}) + \cdots + \ln(EM_{15})
\]

• Regression analysis derived the coefficients, \( B_i \), for each factor
RUSE Effort Multiplier

- Example of the effect of a negative coefficient
Distribution of RUSE:

![Histogram of RUSE distribution with frequency on the y-axis and RUSE on the x-axis. The histogram shows a peak around RUSE 1.0.](chart10)

Sunita Devnani-Chulani
Evolving Model Values

100% Data Driven

100% Expert Driven

Number of projects used in calibration
## Data Determined Model Parameters

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<tr>
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# Model Parameters with Weighted factors
(Using 10% of data-determined and 90% of a-priori)

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*RCON and PERS - then resolved back into TIME, STOR and ACAP, PCAP respectively*
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• Information Sources
Overview:

- 83 Observations from different Industrial categories including Commercial, Aerospace, FFRDC
- Log transformations of Original Post Architecture Model to achieve linearity for linear regression analysis
- 21 predictor variables i.e. 15 Effort Multipliers +5 Scale Factors + Coefficient A
- Forecast accuracy measured with proportional error:

\[
PE = \begin{cases} 
\left[ PM_{est} \div PM_{act} \right] - 1, & (PM_{est} - PM_{act}) \geq 0 \\
- \left[ PM_{act} \div PM_{est} \right] + 1, & (PM_{est} - PM_{act}) < 0 
\end{cases}
\]
## Accuracy Results:

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<td>PRED(.30)</td>
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Conclusions:

- Regression technique can be used to calibrate COCOMO locally using completed project data
- New cost drivers can be added and calibrated without destroying the structure of the COCOMO model
- COCOMO calibrated to local organization is more accurate than using generic COCOMO II model
- More project data is required to facilitate better calibration of generic COCOMO II model
- 1990’s software data presents more challenges
  - Non-sequential processes: where are end-points?
  - Incremental development: how to separate the increments?
  - COTS, reuse, breakage, mixed language levels: what is size?
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USC COCOMO Software Status:

- There is an initial version available for MS Windows, Sun OS, and Java
  - Has new calibrated values
  - Confidence ranges (optimistic, most likely, pessimistic)
  - User definable Cost Drivers: USR1, USR2
  - Schedule input is now project wide
  - New reference manual
  - New values can be manually input for all cost drivers
  - Version changed to COCOMO II.199Y.X (where Y is the year and X is the version within that year)
USC COCOMO Future Work:

- Entry of actuals for periodic tracking of project and data submission
- Calibration of constant and exponent
- Incremental ratings between Very Low, Low, Nominal, High, Very High, Extra High
- Text entry for SU, AA, UNFM
- New Help file
- Coordination with commercial COCOMO II models
  - COSTAR version currently available
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• Information Sources
Ongoing Research (PhD topics)

- Effects of Process Maturity on Effort (Brad Clark)
- COTS Model (Chris Abts)
- Cost/Quality Tradeoff Model (Sunita Devnani-Chulani)

Future Work:

- Stratify data based on Language Level and Application Type
- Effort distribution based on activities
- Enhancement of COCOMO II database to continuously update the model
Effects Of PMAT On Effort

- Study the effect of Process Maturity (CMM) and individual KPAs on development effort.
- 117 Observations, 55 obs. with KPA data
- Analysis is based on an econometric production function
  - Model form is different than COCOMO II’s form:
    \[ PM = A \cdot B^{B_1} \cdot C^{B_2} \cdot D^{B_3} \]
    - Less general
    - About 10 parameters
- Brad would be happy to present results of his research at a future SPIN meeting.
COTS Model

Formula

\[ ESIZE = UFP \times (1.0 + BRAK / 100) \]

\[ PM = A \times (ESIZE)^B \times \prod_{i=1}^{13} (EM_i) \]

\[ Cost = (PM) \times (\$\$/PM) \]

where:

- A = (as yet unspecified)
- B = 1.0
- EM_i = (5 possible ratings: VL, L, N, H, VH, nominal = 1.0)
- \$\$/PM = average labor rate per person-month
Cost/Quality Tradeoff Model: Extension to COCOMO II

Overall error rate: 60/KDSI

Requirements Errors (5/KDSI)

Design Errors (25/KDSI)

Documentation Errors (15/KDSI)

Code Errors (15/KDSI)

Residual Software Errors

Percent of errors eliminated

Cost, C

Automated requirements aids

Independent requirements V & V activity

Simulation

Design Inspections

Field testing

Cost/Quality Tradeoff Model: Extension to COCOMO II
Presentation Outline:

COCOMO calibration
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    - Motivation
      - The Software Defect Introduction and Removal Model
      - A-Priori Software Quality Model
      - Plans
  - Information Sources
Motivation

• Insight on Determining Ship Time

• Assessment of Quality Investment Payoffs

• Understanding of Quality Strategy Interactions
Presentation Outline:

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‘The S/W Defect Introduction and Removal Model’ (SEE, Barry Boehm) or ‘Tank and Pipe Model’ (Capers Jones)

‘Defects conceptually flow into a holding tank through various defect-source pipes & are drained off through various defect-elimination pipes’.
# Defect Introduction and Removal During Software Development

<table>
<thead>
<tr>
<th></th>
<th>Jones</th>
<th>Thayer &amp; others</th>
<th>Boehm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Defects introduced</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall rate</td>
<td>30-35/KDSI</td>
<td>40-80/KDSI&lt;sup&gt;a&lt;/sup&gt;</td>
<td>65-85/KDSI</td>
</tr>
<tr>
<td><strong>Percentage by component</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requirements</td>
<td>10%</td>
<td>8-10%</td>
<td></td>
</tr>
<tr>
<td>Functional Design</td>
<td>15%</td>
<td>15-20</td>
<td></td>
</tr>
<tr>
<td>Logical Design</td>
<td>20</td>
<td>25-35</td>
<td></td>
</tr>
<tr>
<td>Coding</td>
<td>30</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Documentation</td>
<td>35</td>
<td>17-20</td>
<td></td>
</tr>
<tr>
<td><strong>Defects removed</strong></td>
<td>Function Logic Coding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated requirements aids</td>
<td></td>
<td>63&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Functional specifications review</td>
<td>50</td>
<td></td>
<td>45-60</td>
</tr>
<tr>
<td>Simulation</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Language</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Standards</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logic specifications review</td>
<td>40-50</td>
<td></td>
<td>50-60</td>
</tr>
<tr>
<td>Module logic inspection</td>
<td>60-70</td>
<td></td>
<td>58</td>
</tr>
<tr>
<td>Module code inspection</td>
<td>65-75-70</td>
<td></td>
<td>63</td>
</tr>
<tr>
<td>Code standards auditor</td>
<td>20</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Set/use analyzer</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit test</td>
<td>10 10 25</td>
<td></td>
<td>73</td>
</tr>
<tr>
<td>Function test</td>
<td>20 25 55</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Component test</td>
<td>15 20 65</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>Subsystem test</td>
<td>15 15 55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System test</td>
<td>10 10 40</td>
<td></td>
<td>46 50</td>
</tr>
</tbody>
</table>

<sup>a</sup> Equivalent figure. Reported rate (10-20/KDSI) covered only post-integration test defects discovered.

<sup>b</sup> Bell & Thayer “Software Requirements Are They Really A Problem?” IEEE Proceedings, 2nd Int. Conf. on SE, Oct 1976, pp 61-68
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A-Priori Software Quality Model

- Defect Introduction Model
  - Baseline rates for each type of artifact*</sup>
  - Rates adjusted via COCOMO II cost-drivers + DISC (Disciplined Methods)
  - Initial model ready for review and iteration

- Defect Removal Model
  - Rates for each type of artifact* determined from project’s defect removal activity levels
  - Reviews, inspections, analysis tools, tests
  - Initial Model TBD

- Evolve to a-posteriori model via data collection/analysis

*Types of Artifacts: Requirements, design, code, documentation
A-Priori Defect Introduction Model

- For each type of artifact $j$

  Number of Defects Introduced = $A_j \times (\text{Size})^B \times QAF_j$

  $QAF_j = \text{Quality Adjustment Factor for } j\text{th artifact} = \prod_{i=1}^{N} DRM_{ij}$

  $B = \text{Provisionally set to } 1$

  $DRM_{ij} = \text{Defect Rate Multiplier for each COCOMO cost driver and type of artifact } j$

  $N = 23 \ (17+1+5) \text{ for post-architecture model}$

  $N = 13 \ (7+1+5) \text{ for early-design model}$
Modeling effects of COCOMO cost drivers

<table>
<thead>
<tr>
<th>Defects Inserted/ KDSI or 10FPS</th>
<th>Requirements</th>
<th>Design</th>
<th>Code</th>
<th>Documentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>5</td>
<td>25</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

Now,

If ACAP is VH & RELY is VH

How does baseline change?

As compared to ACAP-VL & RELY-VL

This leads us to “A-Priori Software-Quality Model “

Sunita Devnani-Chulani
## Defect Introduction Rate Sensitivity Example

### ACAP (Analyst Capability)

<table>
<thead>
<tr>
<th>ACAP level</th>
<th>Requirements</th>
<th>Design</th>
<th>Code</th>
<th>Documentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>VH</td>
<td>Fewer Requirements understanding defects</td>
<td>Fewer Requirements traceability defects</td>
<td>Fewer Coding defects due to requirements, design shortfalls</td>
<td>Fewer Documentation defects due to requirements, design shortfalls</td>
</tr>
<tr>
<td></td>
<td>Fewer Requirements Completeness, consistency defects</td>
<td>Fewer Design Completeness, consistency defects</td>
<td>-missing guidelines</td>
<td>-ambiguities</td>
</tr>
<tr>
<td></td>
<td>Fewer defects introduced in fixing defects</td>
<td>Fewer defects introduced in fixing defects</td>
<td>0.75</td>
<td>0.83</td>
</tr>
<tr>
<td>Nominal</td>
<td>Nominal level of defect introduction</td>
<td>0.83</td>
<td>0.90</td>
<td>0.83</td>
</tr>
<tr>
<td>VL</td>
<td>More Requirements understanding defects</td>
<td>More Requirements traceability defects</td>
<td>More Coding defects due to requirements, design shortfalls</td>
<td>More Documentation defects due to requirements, design shortfalls</td>
</tr>
<tr>
<td></td>
<td>More Requirements Completeness, consistency defects</td>
<td>More Design Completeness, consistency defects</td>
<td>-missing guidelines</td>
<td>-ambiguities</td>
</tr>
<tr>
<td></td>
<td>More defects introduced in fixing defects</td>
<td>More defects introduced in fixing defects</td>
<td>1.33</td>
<td>1.20</td>
</tr>
<tr>
<td>Quality Range</td>
<td>1.77</td>
<td>1.40</td>
<td>1.23</td>
<td>1.45</td>
</tr>
<tr>
<td>Your Quality Range Estimate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Quality Range (Reqts Defects)

Quality Range due to Introduction of Requirements Defects

Development Flexibility and Programmer Capability = 1.0

1.02 Required Reusability
1.08 Main Storage Constraint
1.08 Execution Time Constraint
1.15 Data Base Size
1.18 Use of Software Tools
1.18 Language and Tool Experience
1.22 Personnel Experience
1.39 Required Development Schedule
1.45 Personnel Continuity
1.45 Platform Volatility
1.45 Documentation match to Life-Cycle needs
1.45 Multisite Development
1.56 Applications Experience
1.74 Architecture/Risk Resolution
1.74 Team Cohesion
1.75 Process Maturity
1.75 Product Complexity
1.77 Analyst Capability
2.05 Precededness
2.24 Required Software Reliability
2.24 Disciplined Methods

Required Development Schedule
Candidate Defect Removal Activities (Refer to COCOMO II Data Collection Questionnaire)

- Project Reviews
- Artifact Inspections, Peer Reviews
- Prototyping
- Simulation
- Automated Reqs. Aids
- Automated Design Aids
- Design Standards
- Unit Testing
- Coverage Testing
- Integration Testing
- Stress Testing
- System Testing
- Beta Testing
- Cleanroom etc.
# Defect Data Reporting Scheme

<table>
<thead>
<tr>
<th>Activity →</th>
<th>Introduced + Unresolved / Resolved in Activity/Cost To Resolve by Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reqs</td>
</tr>
<tr>
<td>Requirements</td>
<td>50/30/.2</td>
</tr>
<tr>
<td>Design</td>
<td>-</td>
</tr>
<tr>
<td>Coding</td>
<td>-</td>
</tr>
<tr>
<td>Documentation</td>
<td>-</td>
</tr>
</tbody>
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Plans

- Iterating A-Priori Model with Affiliates
  - in Round 2 of Delphi process (10 experts participating)
- Exploratory data collection & analysis
  - Analyzing Data on 3 projects as a starting point
  - Need lots more data
- Calibrate Model
  - Determine Multiplicative Constant for Initial Version
- Integrate to COCOMO II model
Integrated Cost/Quality Model

- Software product size estimate
- Software product, process, computer, and personnel attributes
- Software reuse, maintenance, and increment parameters
- Defect removal activity levels
- Software organization’s project data

COCOMO

Quality Model

- Software development, maintenance cost and schedule estimates
- Cost, schedule distribution by phase, activity, increment
- Software Quality Defects/KDSI or 10FPs

COCOMO recalibrated to organization’s data
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→ • Information Sources
Information Sources:

- Phone: (213) 740-6470
- Email: cocomo-info@sunset.usc.edu
- Web site:
  http://sunset.usc.edu/COCOMOII/Cocomo.html
  - Affiliate Prospectus
  - Model Definition Manual (ver. 1.4)
  - Data Collection Form (ver. 1.6)
  - Java COCOMO
  - Little Expert COCOMO Calculator