A Practitioner View of CMMI Process Performance Models

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March 20, 2008
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Topics

Purpose of this Tutorial
The Proposal Phase
Project Management Planning
  • The Use of S curves
  • Escaped Defect Analysis Modeling
Performance Models in
  • Requirements
  • Design
  • Build
  • System Test
Summary
Purpose of this Tutorial
Purpose

This tutorial is meant to inform practitioners of the:

• Essential Ingredients of CMMI Process Performance Models

• Examples of CMMI Process Performance Models across the lifecycle

• Examples of methods to implement various quantitative models for CMMI Process Performance Models
Essential Ingredients of CMMI Process Performance Models

Statistical, probabilistic or simulation in nature

Predict interim and/or final project outcomes

Use controllable factors tied to sub-processes to conduct the prediction

Model the variation of factors and understand the predicted range or variation of the outcomes

Enable “what-if” analysis for project planning, dynamic re-planning and problem resolution during project execution

Connect “upstream” activity with “downstream” activity

Enable projects to achieve mid-course corrections to ensure project success
All Models (Qualitative and Quantitative)

Quantitative Models (Deterministic, Statistical, Probabilistic)

Statistical or Probabilistic Models

Interim outcomes predicted

Controllable x factors involved

Process Performance Model - With controllable x factors tied to Processes and/or Sub-processes

Anecdotal Biased samples

No uncertainty or variation modeled

Only final outcomes are modeled

Only uncontrollable factors are modeled

Only phases or lifecycles are modeled

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When and Why Do We Need Process Performance Models?

- Software Design
- Requirements Management
- Project Forecasting
- Project Planning
- Requirements Elicitation

Software Coding
Integration Testing
Software Unit Testing

Project Start
Proposal

Project Finish
Customer Acceptance Testing
Seal of Approval

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The Proposal

Often uses higher level PPMs
  • False precision when using lower
  • Better understanding of the risk in a bid

Results may be used for bid/no-bid decisions along with other criteria
Function Points

FP Type          #  Weight  Total
Inputs           5   4      20
Outputs          7   5      35
Inquiries        2   4      8
Logical Files    1   10     10
Interfaces       1   7      7

Total            80
Function Point Estimate

The function point estimate based on the context diagram results in

- 80 function points or 10,240 lines of code

However, two other context diagrams based on the proposal information resulted in estimates of

- 73 function points, or 9,344 lines of code and
- 96 function points or 12,288 lines of code

This variation in the estimates for the proposed system will be used for the process performance model (PPM) based predictions for the proposal and managing the project.
Composition Trade-offs and PPM Factors

Factors
- Complexity
- Size
- Methodology
- Process/Subprocess
- General Experience
- Domain Experience
- Platform Experience
- Training
- etc.

Quality

Functionality

Duration

Effort
Understanding Distributions – Key to Informed Decisions
Distributions Describe Variation

Populations of data are characterized as distributions in most statistical procedures:

- expressed as an assumption for the procedure
- can be represented using an equation

The following are examples of distributions you may come across:
Crystal Ball uses a random number generator to select values for A and B.

Crystal Ball then allows the user to analyze and interpret the final distribution of C!

Crystal Ball causes Excel to recalculate all cells, and then it saves off the different results for C!
Why is Understanding Variation Important?

Customer wants the product in 10 weeks
Historical range is 9-11 weeks
Should the job be accepted?

Probably Not

Probably Should
The shaded cells are where the effects of variation are incorporated using a Monte Carlo simulation.
Evaluate Proposal Risk and Negotiate

Run “what if” exercises holding one or more values constant
See effects of trade-offs between
  • Schedule
  • Effort
  • Defects
  • Staff
  • Functionality
Variation, Trade-offs, and PPMs – Schedule

Forecast: Schedule = Schedule =
Percentile  Forecast values
0%  7.6
10%  9.4
20%  9.7
30%  10.0
40%  10.2
50%  10.4
60%  10.6
70%  10.8
80%  11.1
90%  11.5
100% 14.0
Variation, Trade-offs, and PPMs – Effort

Forecast: Effort (MM) =
Percentile Forecast values
0%  18.9
10%  34.1
20%  37.4
30%  40.0
40%  42.3
50%  44.6
60%  47.1
70%  49.8
80%  53.2
90%  58.4
100% 99.8
Variation, Trade-offs, and PPMs – Defects

Forecast: Latent Defects

Percentile Forecast values

0% 5.63
10% 8.64
20% 9.69
30% 10.50
40% 11.20
50% 11.92
60% 12.67
70% 13.51
80% 14.52
90% 15.88
100% 21.99
Variation, Trade-offs, and PPMs – Staff

Forecast: Staff =
Percentile Forecast values
0% 2.5
10% 3.6
20% 3.8
30% 4.0
40% 4.2
50% 4.3
60% 4.4
70% 4.6
80% 4.8
90% 5.1
100% 7.2
Proposal CAR/OID to Mitigate Risk

Seeing if there are new technologies that if employed will reduce risk

May build/modify PPM to evaluate impact and ROI
  • May involve a brief pilot
  • May involve industry data
  • May involve professional
  • Each brings their own level of uncertainty to the prediction

Typically involves detailed project planning PPMs
  • Results at micro-
  • Extrapolate to macro
Proposal CAR/OID

New technology will increase coding productivity by 10%
  • May want to verify with
    – pilot
    – in-depth testing
  • Measured results

Adjust proposal model with results
Re-predict and evaluate resulting risks
Plan Project

Like proposal

• More detail
• Interim as well as end state

Compose a PDP and construct an initial PPM to ensure it will meet our goals and aid us managing the project
### Initial PPM

Note: the greenish shaded cells on this and succeeding slides are where variations will be accounted for using a Monte Carlo simulation.

<table>
<thead>
<tr>
<th>Phase</th>
<th>UoM</th>
<th>Size</th>
<th>Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposal/Early Planning</td>
<td>Function Points</td>
<td>80</td>
<td>154</td>
</tr>
<tr>
<td>Elicit Requirements</td>
<td>User Requirements</td>
<td>110</td>
<td>723</td>
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<td>URD Review</td>
<td>Defects</td>
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<tr>
<td>Analyze Requirements</td>
<td>Requirements</td>
<td>176</td>
<td>1809</td>
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<td>SRS Review</td>
<td>Defects</td>
<td></td>
<td>98</td>
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<tr>
<td>Design</td>
<td>Components</td>
<td>124</td>
<td>2236</td>
</tr>
<tr>
<td>Design Review</td>
<td>Defects</td>
<td></td>
<td>72</td>
</tr>
<tr>
<td>Code</td>
<td>Components</td>
<td>110</td>
<td>2950</td>
</tr>
<tr>
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<td>Defects</td>
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<td>65</td>
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<tr>
<td>Test</td>
<td>Test Cases</td>
<td>229</td>
<td>2633</td>
</tr>
<tr>
<td>Deliver</td>
<td>Defects</td>
<td></td>
<td>10806</td>
</tr>
</tbody>
</table>
Initial PPM

Size and Effort are predicted functions:

\[ S_{\text{size}} = \int (U_{\text{RD}}_{\text{size}}, \text{method}, \text{review type. Etc.}) \]

\[ \text{Effort} = \int (D_{\text{ocument}}_{\text{size}}, \text{method, experience, etc.}) \]

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Size and Effort are predicted functions:

\[ SRS_{\text{size}} = \int (URD_{\text{size}}, \text{method, review type, etc.}) \]

\[ \text{Effort} = \int (Document_{\text{size}}, \text{method, experience, etc.}) \]

Effort = constant + multiplier * size(method+experience+training)

Experience = \int (domain, customer, platform general)
## Initial PPM

<table>
<thead>
<tr>
<th>Predicted Defects</th>
<th>URD Defects</th>
<th>SRS Defects</th>
<th>DES Defects</th>
<th>Code Defects</th>
<th>Latent Defects</th>
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<td>24</td>
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<td>1</td>
<td>5</td>
<td>7</td>
<td>16</td>
<td>30</td>
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</table>
# Initial PPM

<table>
<thead>
<tr>
<th>URD</th>
<th>SRS</th>
<th>DES</th>
<th>Code</th>
<th>Latent</th>
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<td>174</td>
<td>202</td>
<td>95</td>
<td>471</td>
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<td>7</td>
<td>3</td>
<td>16</td>
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<td>198</td>
<td>231</td>
<td>108</td>
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<td>620</td>
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<td>278</td>
<td>323</td>
<td>151</td>
<td>115</td>
<td>867</td>
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<tr>
<td>357</td>
<td>415</td>
<td>194</td>
<td>148</td>
<td>1115</td>
</tr>
</tbody>
</table>
PDP Risk

Total Effort (Initial PPM)

Latent Defect Rework Estimate

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PDP Risk
An Alternate Example
Process Performance Model (PPM) to support
Escaped Defect Analysis and Monitoring
The Situation during Development

Defects escaping from one development phase to the next are very expensive to find, diagnose and fix. Some industrial studies suggest the increasing cost may be exponential.

**OUR NEED:** A PPM used by the software project manager and quality team to analyze escaping defect rates by type to support more informed decisions on where to target dynamic project corrective action, as well as, changes to organizational processes!
Details of the Escaping Defect PPM

The outcome, $Y$, is the amount of escaped defects by type within each phase of development.

The $x$ factors used in this model will be the various injection and detection rates by type of defect across the phases of development.

Not only will this model focus on phase containment of Req’ts, Design, and Code phases, but on the phase screening of defects by type within the different types of testing.
Background Information on the Data

Historical data on escaped defects, by type, across lifecycle phases was recorded.

For each historical project, software size was recorded, as well, to help normalize the defects injected and found, thereby producing injection and detection rates.
A modern spreadsheet for escaped defect analysis before being transformed into a CMMI Process Performance Model.
Let's look at the matrix showing “Phase Injected” vs “Phase Found”
For example, an average of 2000 design defects were found during the design activity.
Let’s look at the “Phase Containment” & “Phase Screening” rates.
<table>
<thead>
<tr>
<th>Phase Found</th>
<th>Regs Activity</th>
<th>Design Activity</th>
<th>Code Activity</th>
<th>Integration Test</th>
<th>System Test</th>
<th>User Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase Containment Rate</td>
<td>500</td>
<td>2080</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase Screening Rate %</td>
<td>60%</td>
<td>46%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Here, 2080 Requirements and Design defects were caught during Design.

Here, 2000 Design defects were caught during Design.

% of all defects entering and injected in Design caught in Design.

% of Design defects caught in Design.
Let's look at the Phase Injection and Escape rates
Here, 4200 Design defects were injected with 2200 of them escaping the Design activity; Additionally, 2450 total defects (injected during Design or inherited from upstream activities) escaped past the Design activity.

<table>
<thead>
<tr>
<th>Phase Injected</th>
<th>All numbers per 1MSLOC</th>
<th>Total Injection Rate by Activity</th>
<th>Escape Rate by Activity</th>
<th>Escape Rate by All Activities</th>
<th>Activity Injection Rate by Total Defects %</th>
<th>Escape Rate by Activity %</th>
<th>Escape Rate by All Activities %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reqs Activity</td>
<td>830</td>
<td>330</td>
<td>330</td>
<td>7</td>
<td>40%</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>Design Activity</td>
<td>4200</td>
<td>2200</td>
<td>2450</td>
<td>36</td>
<td>52%</td>
<td>54%</td>
<td>54%</td>
</tr>
<tr>
<td>Code Activity</td>
<td>6340</td>
<td>2540</td>
<td>4680</td>
<td>54</td>
<td>40%</td>
<td>53%</td>
<td>53%</td>
</tr>
<tr>
<td>Integration Test</td>
<td>355</td>
<td>55</td>
<td>1475</td>
<td>3</td>
<td>15%</td>
<td>29%</td>
<td>29%</td>
</tr>
<tr>
<td>System Test</td>
<td>100</td>
<td>0</td>
<td>275</td>
<td>1</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>User Test</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>
Here, 36% of all defects in a project are expected to be Design defects; 52% of Design defects are expected to escape past Design; and 54% of all types of defects in the Design activity (injected during Design or inherited from upstream activities) are escaping past the Design activity.
Now, let’s transform this spreadsheet model into a valid CMMI process performance model!

Now, let’s transform this spreadsheet model into a valid CMMI process performance model!

Now, let’s transform this spreadsheet model into a valid CMMI process performance model!
Each of the green cells have received uncertainty distributions based on historical data.
### Phase Found

#### Define Forecast: Cell D17

- **Name:** `ReqsPC-rate`
- **Units:**
- **LSL:**
- **USL:**
- **Target:**

#### Forecast Window

- **View:** `Frequency`
- **Window:**
  - Show automatically
  - While running simulation
  - When simulation stops

#### Fit distribution

- Fit a continuous probability distribution to the forecast

---

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Rusty Young

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Each of these blue cells were identified as outcomes whose resulting distributions will be studied.
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<table>
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<td>53%</td>
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<tr>
<td>Code Activity</td>
<td></td>
<td>355</td>
<td>55</td>
<td>1475</td>
<td>3%</td>
<td>15%</td>
<td>20%</td>
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<td></td>
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<td>0</td>
<td>275</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
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<td></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0%</td>
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Standard simulation summary results
We are 95% confident that no more than approx. 4,786 Design defects will be injected by a project.
We are 95% confident that no more than 39% of all types of defects will be Design defects.
We are 95% confident that no more than 2,351 Design defects will escape the Design activity.
We are 95% confident that no more than 61% of Design defects will escape the Design activity.
We are 95% confident that no more than 2,607 defects (injected during Design or inherited from upstream activities of Design) will escape the Design activity.
We are 95% confident that no more than 62% of the total defects (injected during Design or inherited from upstream activities of Design) will escape the Design activity.
We are 95% confident that no less than 1,499 total defects (injected during Design or inherited from upstream activities of Design) will be found during the Design activity.
We are 95% confident that no less than 38% of total defects (injected during Design or inherited from upstream activities of Design) will be found during the Design activity.
We are 95% confident that no less than 47 Design defects will be found during the Design activity.
We are 95% confident that no less than 39% of Design defects will be found during the Design activity.
We are 95% confident that no more than 46% of all defects will escape at least one phase.
We are 95% confident that escaping defects will not escape, on average, more than 1.8 phases.
Using Sensitivity Analysis, we can learn more about which factors in our model are most contributing to our outcome.
What Have We Accomplished?

We transformed a model that used only historical averages and substituted uncertainty distributions for each of the injection and found rates

By doing this, we can establish confident conclusions about our outcomes using their resulting distributions:

• Defect Injection rates by Phase
• Phase Containment and Screening Effectiveness

We also used sensitivity analysis to decide which factors to tackle first to improve each outcome
Planning the Requirements Buildup
Generate Plan

Generate schedule based on higher level PPMs which help determine milestones and variation base slack
Generate detailed PPMs to predict performance during this phase

Note: these steps will be repeated periodically (such as at phase or other selected milestones) and on an as needed basis
Elicitation – Requirements Buildup – Predicted

Generalized Logistic (or Richard's)

\[ Y = A + \frac{C}{1 + T e^{-B(x - M)}}^{1/T} \]

- \( x \) = time.
- \( A \) controls the lower asymptote,
- \( C \) controls the upper asymptote,
- \( M \) controls the time of maximum growth,
- \( B \) controls the growth rate, and
- \( T \) controls where maximum growth occurs - nearer the lower or upper asymptote
Elicitation – Requirements Buildup – Predicted

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Calibration of this model for different domains, customers, etc. and the effects of the controllable factors is critical.
Risk in Plan

Use PPMs to judge overall risk in the plan
May use Monte Carlo simulation in the schedule to better understand

- Schedule based sources of risk
- Effects of risks on the schedule
Elicitation – Requirements Buildup – Monitor

- Monitor the buildup
  - Flattening means you are reaching the point of diminishing returns for elicitation
- Significant difference between predicted and actual upper asymptote indicate a potential misunderstanding of the system to be built
- If actuals show significant variation from predicted, re fit curve for new prediction
  - Calculate an appropriate Prediction Interval (PI) to aid in detection of anomalous conditions
The Process is not performing at its' historical Levels. Investigate and calibrate PPM.
The refit curve has extended the predicted buildup time by approximately 20% (31 vs 25)
Elicitation – Requirements Buildup – Notes

Requires a strong consistent requirements elicitation process

• Different standard curves for different elicitation processes such as JAD, prototyping, etc.

• Curve shape parameters can be influenced by context -- re-engineering vs green field, well understood vs non-well understood domain, experience, etc.

Consider a measurement systems error analysis – perhaps using Gage R&R to ensure consistent buildup counts

Requires a good prediction of size

Can be beneficial with good size prediction and then fitting the curve as you gather data

• It will take time before variation in the buildup time minimizes
Another Example Process Performance Model (PPM) in the Requirements Phase
The Situation in the Requirements Phase

Our products are comprised of 40-60 features

We assign each feature a small development team to develop the feature “cradle to grave”

These feature teams operate in overlapping lifecycles within an overall product incremental waterfall lifecycle model (thus, different features will be added in each new increment)

**OUR NEED:** A PPM that will let each feature team predict the number of requirements defects to be experienced throughout the lifecycle of the feature development
Details of the Requirements Phase PPM

The outcome, Y, is the predicted number of Requirements defects for a given feature team.

The x factors used to predict the Requirements defects are:

- x1: Req’ts Volatility (continuous data)
- x2: Risk of Incomplete Req’ts (nominal data)
- x3: Risk of Ambiguous Req’ts (nominal data)
- x4: Risk of Non-Testable Req’ts (nominal data)
- x5: Risk of Late Req’ts (nominal data)
Background Information on the Data

We collected historical data (of the Y and the x’s) for a large volume of feature teams

For the x2 thru x5 factors, the feature team leader would historically check off as “yes” or “no” depending on whether they felt that the specific risk significantly impacted the feature team cost, schedule or quality

Operational definitions and training were conducted to ensure consistency and repeatability among the feature team leads
### Development of the Req’ts Phase PPM - 1

**Table 1:**

<table>
<thead>
<tr>
<th>Volatility</th>
<th>Risk of Incompleteness</th>
<th>Risk of Ambiguity</th>
<th>Risk of Non-Testability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

**X1: Volatility**

- Shown in decimal form

**All of the risks are rated**

- either 0 or 1, with 0 being the absence of the risk and 1 being the presence of the risk

**The Y outcome**

- Is the Number Of Reqts Defects

**Table 2:**

<table>
<thead>
<tr>
<th>Risk of Late Reqts</th>
<th>Risk of Unsafe Reqts</th>
<th>Number of Reqts Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>
Development of the Req’ts Phase PPM - 2
This will accomplish Dummy Variable Regression to handle X factors that are Continuous and Discrete.
Development of the Req’ts Phase PPM - 4

Summary of Fit
- RSquare: 0.940697
- RSquare Adj: 0.935386
- Root Mean Square Error: 0.28853
- Mean of Response: 13.83784
- Observations (or Sum Wgts): 74

Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>6</td>
<td>88.476347</td>
<td>14.7461</td>
<td>177.1312</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Error</td>
<td>67</td>
<td>5.577707</td>
<td>0.0832</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>73</td>
<td>94.054054</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Sorted Parameter Estimates

<table>
<thead>
<tr>
<th>Term</th>
<th>Estimate</th>
<th>Std Error</th>
<th>t Ratio</th>
<th>Prob&gt;</th>
<th>t</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatility</td>
<td>32.860031</td>
<td>2.9708</td>
<td>11.06</td>
<td>&lt;.0001*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RiskofIncompleteness[0]</td>
<td>-0.240651</td>
<td>0.088552</td>
<td>-2.72</td>
<td>0.0084*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RiskofLateReqts[0]</td>
<td>-0.107577</td>
<td>0.053802</td>
<td>-2.00</td>
<td>0.0496*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RiskofUnsafeReqts[0]</td>
<td>0.1647047</td>
<td>0.095776</td>
<td>1.72</td>
<td>0.0901</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RiskofAmbiguity[0]</td>
<td>-0.031284</td>
<td>0.078746</td>
<td>-0.40</td>
<td>0.6924</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RiskofNonTestability[0]</td>
<td>0.0017969</td>
<td>0.058641</td>
<td>0.03</td>
<td>0.9756</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- * indicates significance at the 0.05 level.
Development of the Req’ts Phase PPM - 6

\[
\text{Prediction Expression} = 7.5937439072846 + 32.8600305113136 \times \text{Volatility} + \begin{cases} 
0 & \Rightarrow -0.2406507338728 \\
1 & \Rightarrow 0.24065073387281 \\
\text{else} & \Rightarrow .
\end{cases}
\]

\[
+ \begin{cases} 
0 & \Rightarrow -0.0312842155195 \\
1 & \Rightarrow 0.03128421551947 \\
\text{else} & \Rightarrow .
\end{cases}
\]

\[
+ \begin{cases} 
0 & \Rightarrow 0.00179694498247 \\
1 & \Rightarrow -0.0017969449825 \\
\text{else} & \Rightarrow .
\end{cases}
\]

\[
+ \begin{cases} 
0 & \Rightarrow -0.107577311748 \\
1 & \Rightarrow 0.10757731174804 \\
\text{else} & \Rightarrow .
\end{cases}
\]

\[
+ \begin{cases} 
0 & \Rightarrow 0.16470472563596 \\
1 & \Rightarrow -0.164704725636 \\
\text{else} & \Rightarrow .
\end{cases}
\]
Intended Use of this Req’ts PPM

Once we decide on the final form of the PPM, we will use it in two primary ways:

1) At the beginning of each feature team kickoff, the team will anticipate the values for the x factors (x1 … x5). They will evaluate the PPM at these values to predict the number of Req’ts defects. If this prediction is unacceptable, they will take immediate action to address one or more of the x factors.

2) During the development, the feature team will periodically re-assess the anticipated values of the x factors and repeat the actions of step 1 above.
Updating this Req’ts PPM

As more feature teams develop features, they will continue to record the data for the x factors and the resulting Y outcome of number of Req’ts Defects.

When a group of feature teams have finished the lifecycle and have recorded their data, the organization may choose to add their data to the existing data set and then repeat the exercise of developing the dummy variable regression equation.

Ultimately, the organization may want to segment the feature teams by type and conduct this analysis for each segment.
An Example Process Performance Model (PPM) during the Design Phase
The Situation in Design

The Design team is faced with modifying legacy software in addition to developing new software.

A major issue that can have disastrous effects on projects is the idea of “brittleness” of software. In a nutshell, software becomes more “brittle” over time as it is changed and experiences a drifting usage model.

**OUR NEED:** A PPM used by each feature team during design to predict how “brittle” software is, and subsequently to make the correct design decisions regarding degree of modification vs rewrite from scratch.
Details of the Software Brittleness PPM

The outcome, \( Y \), is the measure of software brittleness, measured on an arbitrary scale of 0 (low) to 100 (high), which will be treated as continuous data.

The \( x \) factors used in this prediction example are the following:

- Unit path complexity
- Unit data complexity
- Number of times the unit code files have been changed
- Number of unit code changes not represented in Design document updates
Background Information on the Data

We collected historical data from feature teams on their code units. The data, related to the first four x factors, are maintained by the CM system using automated tools tracking this data each time new code file versions are checked in.

- Unit path complexity
- Unit data complexity
- Number of times the unit code files have been changed

We also have access to problem reporting and inspection databases which provide us with a number of issues reported against individual code units. Finally, we have “Brittleness” values for each unit of code that were assigned by a different empirical exercise with domain experts.
## Development of the Brittleness PPM - 1

<table>
<thead>
<tr>
<th>C1 Brittleness</th>
<th>C2 Data Complexity</th>
<th>C3 NumChangesNotDocumented</th>
<th>C4 NumOfFileChanges</th>
<th>C5 PathComplexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>69.62</td>
<td>45.68</td>
<td>8.13</td>
<td>10.29</td>
<td>19.98</td>
</tr>
<tr>
<td>67.59</td>
<td>98.09</td>
<td>5.95</td>
<td>11.57</td>
<td>22.88</td>
</tr>
<tr>
<td>64.59</td>
<td>37.02</td>
<td>6.12</td>
<td>16.18</td>
<td>22.52</td>
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<tr>
<td>62.95</td>
<td>36.57</td>
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<td>10.68</td>
<td>20.55</td>
</tr>
<tr>
<td>60.58</td>
<td>24.28</td>
<td>6.32</td>
<td>12.08</td>
<td>20.98</td>
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<tr>
<td>67.44</td>
<td>72.53</td>
<td>7.08</td>
<td>8.68</td>
<td>19.75</td>
</tr>
<tr>
<td>73.75</td>
<td>87.82</td>
<td>7.68</td>
<td>10.90</td>
<td>19.52</td>
</tr>
<tr>
<td>67.00</td>
<td>33.06</td>
<td>6.77</td>
<td>8.97</td>
<td>21.46</td>
</tr>
<tr>
<td>63.06</td>
<td>32.84</td>
<td>5.70</td>
<td>12.81</td>
<td>19.06</td>
</tr>
<tr>
<td>64.15</td>
<td>38.08</td>
<td>6.92</td>
<td>12.90</td>
<td>20.95</td>
</tr>
<tr>
<td>74.27</td>
<td>164.08</td>
<td>6.46</td>
<td>13.85</td>
<td>19.72</td>
</tr>
<tr>
<td>77.70</td>
<td>110.71</td>
<td>7.81</td>
<td>9.33</td>
<td>22.20</td>
</tr>
<tr>
<td>63.63</td>
<td>31.07</td>
<td>6.25</td>
<td>11.05</td>
<td>20.43</td>
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<tr>
<td>61.71</td>
<td>25.43</td>
<td>6.89</td>
<td>11.84</td>
<td>19.76</td>
</tr>
<tr>
<td>73.46</td>
<td>28.92</td>
<td>8.38</td>
<td>12.59</td>
<td>23.18</td>
</tr>
<tr>
<td>73.54</td>
<td>143.56</td>
<td>6.70</td>
<td>9.80</td>
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</tr>
<tr>
<td>61.58</td>
<td>88.74</td>
<td>6.99</td>
<td>5.29</td>
<td>19.38</td>
</tr>
<tr>
<td>66.22</td>
<td>16.32</td>
<td>7.16</td>
<td>11.78</td>
<td>19.75</td>
</tr>
</tbody>
</table>
Development of the Britteness PPM - 2
Development of the Brittleness PPM - 3

Regression

Response:
Brittleness

Predictors:
PathComplexity-NumChangesNotDocumented

Select
Help
Graphs...
Options...
Results...
Storage...
OK
Cancel
## Regression Analysis: Brittleness versus PathComplexity, NumOfFileChanges, ...

The regression equation is:

\[
\text{Brittleness} = 6.62 + 0.793 \text{PathComplexity} + 0.743 \text{NumOfFileChanges} + 5.04 \text{NumChangesNotDocumented}
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6.6168</td>
<td>0.4192</td>
<td>15.78</td>
<td>0.000</td>
</tr>
<tr>
<td>PathComplexity</td>
<td>0.79281</td>
<td>0.01173</td>
<td>67.58</td>
<td>0.000</td>
</tr>
<tr>
<td>NumOfFileChanges</td>
<td>0.74298</td>
<td>0.01197</td>
<td>62.07</td>
<td>0.000</td>
</tr>
<tr>
<td>NumChangesNotDocumented</td>
<td>5.04283</td>
<td>0.04320</td>
<td>116.75</td>
<td>0.000</td>
</tr>
</tbody>
</table>

\[
S = 2.99998 \quad R-Sq = 69.0\% \quad R-Sq(adj) = 69.0\%
\]
### Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>3</td>
<td>200594</td>
<td>66865</td>
<td>7429.50</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual Error</td>
<td>9996</td>
<td>89963</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9999</td>
<td>290557</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PathComplexity</td>
<td>1</td>
<td>41056</td>
</tr>
<tr>
<td>NumOfFileChanges</td>
<td>1</td>
<td>36875</td>
</tr>
<tr>
<td>NumChangesNotDocumented</td>
<td>1</td>
<td>122663</td>
</tr>
</tbody>
</table>
Once we decide on the final form of the PPM, we will use it in two primary ways:

1) As each feature team begins software design, the team will collect the x factor information for the software units to be worked on, and then evaluate the PPM at these values to predict the brittleness of the individual software units. If the brittleness prediction is too high, they will decide whether they should continue with modifying legacy code units or rewrite them from scratch.
Intended Use of this Britteness PPM - 2

Once we decide on the final form of the PPM, we will use it in two primary ways:

2) Ideally, management would have access to this PPM during proposal and planning activities so that predictions of high vs low brittleness may appropriately influence the early estimates.
Updating this Brittleness PPM

As more code units are inspected and tested with corresponding x factor information recorded, the organization will periodically add this new data to the original data set and re-run the regression analysis.

Over time, an analysis relating predicted brittleness of code units to the actual experienced ripple effects of changes to the same code units would be warranted, to ensure the PPM is accurate.
Continuing into the Build Phase
Updating PPM – Post Design PPM

Update PPM with actual values
Rerun predictions
Reevaluate risks and take appropriate actions

- Mitigation plans
- Contingency plans
- CAR/OID actions

![Graph showing code components distribution](image)
Build PPM

Updates PPM with most recent actuals
Adjusts for changes in
  • Staff
  • Process definitions
  • PDP
  • Scope/requirements/design

Produce detailed phase PPMs for detailed monitoring during build phase
Monitoring the Build

Multi-mode monitoring (not just PPMs)

- SPC – Micro level performance
- PPM – Macro level performance
- EVMS – Cost/Schedule implications
- Schedule – Critical path/Dependency effects

Each monitors different aspects of the product build (similar strategy/tactics can be used during any phase or for maintenance)
Sigmoid Curve

\[ Y = L + ((U - L) / (1 + \exp[-1 \times ((x - M) / W)]) \]

- \(x\) time
- \(L\) = lower asymptote
- \(U\) = upper asymptote
- \(M\) = Middle point of growth
- \(W\) = width from leaves bottom and gets to top

Robert Stoddard
Rusty Young
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Build – Component Buildup – Predicted

Sigmoid Curve

\[ Y = L + \frac{(U - L)}{(1 + \exp[-1 \times ((x - M)/W)])} \]

- \( x \) time
- \( L \) = lower asymptote
- \( U \) = upper asymptote
- \( M \) = Middle point of growth
- \( W \) = width from leaves bottom and gets to top

These typically would be functions with controllable factors such as elicitation method (JAD, prototyping, reengineering, etc.), team experience, domain experience, # staff, etc.
Build – Component Buildup – Predicted

Sigmoid Curve

\[ Y = L + \frac{(U - L)}{1 + \exp[-1 \times \left(\frac{x - M}{W}\right)]]} \]

- \( x \) = time
- \( L \) = lower asymptote
- \( U \) = upper asymptote
- \( M \) = middle point of growth
- \( W \) = width from leaves bottom and gets to top

Calibration of this model for different domains, customers, etc. and the effects of the controllable factors is critical.
Component buildup can be monitored similarly to the requirements buildup.

Component Build consists of Create, Peer Review, Unit Test.
Monitor Component Build – SPC

Components designed to be homogeneous or segment into homogeneous subsets (note, may result in an S curve for each sub-group)

Stabilize the build process

• Control chart
  – Size
  – Complexity
  – Effort
  – Duration

• May also chose to stabilize
  – Unit test
  – Build peer review

May also perform CAR/OID activies to optimize process

• May cause a modification to the PPM
Monitor Component Build – EVMS

EVMS, PPMs, and SPC are not incompatible

- Each manages different aspects
- Although there is some overlap

Is value earned at

- End of Build
- End of Unit test
- End of Peer review
- Or a percent at each step

When using EVMS, may want to emphasize monitoring

- Cost variance
- CPI

To monitor quality aspects, PPMs can supplement EVMS
Monitor Component Build – Schedule

Don’t forget the critical path
The models and EVMS may indicate no problem

• But the slippage of a single small task on the critical path can be a source of project trouble
• Sometimes the issue will be picked up as a special cause on a control chart, but the CPM implications are unseen and ignored, thus not detecting that the project may be in trouble
There is support for iterative forms of development such as iterative builds and agile methods
- Use sets of linked sigmoid curves
- Refactoring models

Points to the use of multiple linked models
- Don’t have to stick to a single equation
Iterative Build – Component Buildup – Example

Iteration 1

Iteration 2

Robert Stoddard
Rusty Young
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An Example Process Performance Model (PPM) as an input to System Testing
The Situation in Systems Testing

The System Test team receives baselines from various feature teams during the series of system test baselines within each of the product incremental baselines.

The Systems Test team does not have the schedule nor the resources to conduct 100% coverage of all possible test cases.

**OUR NEED:** A PPM used by each feature team during the handoff of a feature baseline to System Test, whereby the feature team will predict the relative likelihood of a list of defect types. This will enable prioritized, efficient testing!
Details of the System Testing PPM

The outcome, \( Y \), is the relative likelihood of occurrence of the different standard defect types (e.g. nominal categories such as: logical, data, and algorithmic)

The x factor used in this prediction example is a measure of staff turnover of the feature development team prior to System Test (e.g. continuous data as a percentage)

This x factor was chosen because it historically surfaced as a significant factor in explaining types of defects found in System Test.
Background Information on the Data

We collected historical data (of the defect type and the staff turnover of the responsible feature team) for a large volume of defects found in System Test.

Operational definitions and training were conducted to ensure consistency and repeatability of defect types found in System Test, as well as, the staff turnover rates for feature teams reaching System Test.
<table>
<thead>
<tr>
<th></th>
<th>Defects-Test</th>
<th>Turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Logical</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>Logical</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>Data</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Data</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Algorithmic</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>Data</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>Data</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>Data</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>Logical</td>
<td>28</td>
</tr>
<tr>
<td>10</td>
<td>Data</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>Data</td>
<td>11</td>
</tr>
</tbody>
</table>
Development of the System Test PPM - 2
This will accomplish Nominal Logistic Regression to handle a Y factor that is Discrete.
## Whole Model Test

<table>
<thead>
<tr>
<th>Model</th>
<th>-LogLikelihood</th>
<th>DF</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>8.925626</td>
<td>2</td>
<td>17.85125</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Full</td>
<td>56.245396</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced</td>
<td>65.171022</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSquare (U)</td>
<td>0.1370</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Observations (or Sum Wgts) 61

Converged by Gradient

## Lack Of Fit

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>-LogLikelihood</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack Of Fit</td>
<td>34</td>
<td>18.169720</td>
<td>36.33944</td>
<td></td>
</tr>
<tr>
<td>Saturated</td>
<td>36</td>
<td>38.075676</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitted</td>
<td>2</td>
<td>56.245396</td>
<td>0.3602</td>
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</tr>
</tbody>
</table>

## Parameter Estimates

<table>
<thead>
<tr>
<th>Term</th>
<th>Estimate</th>
<th>Std Error</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>4.49519702</td>
<td>1.5437487</td>
<td>8.48</td>
<td>0.0036*</td>
</tr>
<tr>
<td>Turnover</td>
<td>-0.3296347</td>
<td>0.1064655</td>
<td>9.59</td>
<td>0.0020*</td>
</tr>
<tr>
<td>Intercept</td>
<td>3.68084598</td>
<td>1.239601</td>
<td>8.82</td>
<td>0.0030*</td>
</tr>
<tr>
<td>Turnover</td>
<td>-0.218423</td>
<td>0.076182</td>
<td>8.22</td>
<td>0.0041*</td>
</tr>
</tbody>
</table>
Development of the System Test PPM - 5
Once we decide on the final form of the PPM, we will use it in two primary ways:

1) As each feature team proceeds through development, the team will anticipate the final staff turnover rate at the point of System Test based on turnover to-date, and then evaluate the PPM at these updated values to predict the likelihood of the types of defects. If this prediction is unacceptable, they will take immediate action to address the staff turnover rate while still possible.
Intended Use of this System Test PPM - 2

Once we decide on the final form of the PPM, we will use it in two primary ways:

2) System Test will use the prediction to decide if the feature is suitable to enter System Test. If not, the feature team may have to take risk reduction actions.
Updating this System Test PPM

As more features are tested and defects are found, they will continue to record the type of defects found and the corresponding information of the staff turnover of the responsible feature team.

When a group of defects from System Test have been recorded, the organization may choose to add this additional data to the existing data set and then repeat the exercise of developing the nominal logistic regression.

Ultimately, the organization may pursue inclusion of additional x factors that are believed to explain the defect types surfacing in System Test.
Tutorial Summary

We have shown practical examples of process performance models used in a variety of ways across the lifecycle.

The methods depicted are not rocket science and may be performed by practitioners, without becoming statisticians.

The greatest challenge in implementing process performance models is not the quantitative or statistical science, but rather...

It is the domain expertise to decide what are the business-important outcomes worthy of prediction, and what are the controllable, sub-process factors likely to prove significant in predicting that outcome.
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