Integrating Software Cost and Quality Modeling for Program Risk Management

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Outline

• Research Motivation
• Value-Based Software Quality Model (VBSQM)
• ODC and Domain Specific Extension of VBSQM
• Conclusions and Future Work
Software Assurance Risk Profile

• Software assurance in a competitive world
  – Software quality requirements often conflict with schedule/cost requirements

• How much software quality investment is enough?
  – When to stop testing and release the product

• Our Approaches
  – Combined risk analyses based on VBSQM
    ✴ Determining a risk-balanced “sweet spot” operating point
    ✴ Optimal combinations and application order of risk reduction techniques
Competing on Schedule and Software Quality Investment
– A risk analysis approach

• Risk Exposure RE = \text{Prob (Loss)} \times \text{Size (Loss)}
  – “Loss” – financial; reputation; future prospects, ...

• For multiple sources of loss:
  \[ \text{RE} = \sum_{\text{sources}} \left[ \text{Prob (Loss)} \times \text{Size (Loss)} \right]_{\text{source}} \]
Example RE Profile: Time to Ship

– Loss due to unacceptable software quality

\[ \text{RE} = P(L) \times S(L) \]

- Many defects: high \( P(L) \)
- Critical defects: high \( S(L) \)
- Few defects: low \( P(L) \)
- Minor defects: low \( S(L) \)

Time to Ship (amount of testing)
Example RE Profile: Time to Ship

- Loss due to unacceptable software quality
- Loss due to market share erosion

\[ \text{RE} = \text{P}(L) \times \text{S}(L) \]

- Many defects: high P(L)
  - Critical defects: high S(L)
- Few defects: low P(L)
  - Minor defects: low S(L)
- Many rivals: high P(L)
  - Strong rivals: high S(L)
- Few rivals: low P(L)
  - Weak rivals: low S(L)

Time to Ship (amount of testing)
Example RE Profile: Time to Ship

- Sum of Risk Exposures

\[ RE = P(L) \times S(L) \]

- **Sweet Spot**
  - Few rivals: low \( P(L) \)
  - Weak rivals: low \( S(L) \)
  - Few defects: low \( P(L) \)
  - Minor defects: low \( S(L) \)

- **Many defects:** high \( P(L) \)
  - Critical defects: high \( S(L) \)
  - Many rivals: high \( P(L) \)
  - Strong rivals: high \( S(L) \)
Value-Based Software Quality Model (VBSQM)

- **Time-phased information processing capabilities**
- **Project attributes**
- **Time-phased quality investments**

**Cost-Estimating Relationships (CERs)**

\[
\text{Cost} = f \left[ \begin{array}{c}
\text{IP capabilities (size)}, \\
\text{project attributes}
\end{array} \right]
\]

**Quality-Attribute-Estimating Relationships (QERs)**

\[
D_i = g_i \left[ \begin{array}{c}
\text{Quality investments,} \\
\text{project attributes}
\end{array} \right]
\]

**Value-Estimating Relationships (VERs)**

\[
V_j = h_j \left[ \begin{array}{c}
\text{IP capabilities} \\
\text{quality investment levels Q}_i
\end{array} \right]
\]

**Time-phased**

- IP capability investments
- Quality attribute levels \(D_i\)
- Value components \(V_j\)
- Return On Investment (ROI)
- Combined Risk Analyses
Development Cost of “Required Reliability”: COCOMO II
– calibrated based on 161 industry projects

<table>
<thead>
<tr>
<th>RELY Rating</th>
<th>Defect Impact</th>
<th>Rough MTBF (Mean Time Between Failures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>Loss of Human Life</td>
<td>300K hours</td>
</tr>
<tr>
<td>High</td>
<td>High Financial Loss</td>
<td>10K hours</td>
</tr>
<tr>
<td>Nominal</td>
<td>Moderate recoverable loss</td>
<td>300 hours</td>
</tr>
<tr>
<td>Low</td>
<td>Low, easily recoverable loss</td>
<td>10 hours</td>
</tr>
<tr>
<td>Very Low</td>
<td>Slight inconvenience (1 hour)</td>
<td>0.82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relative Cost/Source Instruction</th>
<th>Added Testing Time (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>0.9</td>
<td>12</td>
</tr>
<tr>
<td>1.0</td>
<td>22</td>
</tr>
<tr>
<td>1.1</td>
<td>34</td>
</tr>
<tr>
<td>1.2</td>
<td>54</td>
</tr>
</tbody>
</table>

- Safety-critical: 1.26
- In-house support software: 1.0
- Commercial cost leader: 0.92
- Commercial quality leader: 1.10
- Early beta-test: 0.82
Cost of “Reduced Delivered Defect Density”: COQUALMO

- **Software Size estimate**
- **Software platform, project, product and personnel attributes**
- **Defect removal profile levels**
  - Automated Analysis
  - Peer Reviews
  - Execution Testing and Tools
- **Defect Introduction Model**
- **Defect Removal Model**
- **Number of residual defects, Defect density per unit of size**
- **Software development effort, cost and schedule estimate**
# COQUALMO Defect Removal Rating Scales

COCOMO II p.263

<table>
<thead>
<tr>
<th></th>
<th>Very Low</th>
<th>Low</th>
<th>Nominal</th>
<th>High</th>
<th>Very High</th>
<th>Extra High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automated Analysis</strong></td>
<td>Simple compiler syntax checking</td>
<td>Basic compiler capabilities</td>
<td>Compiler extension Basic req. and design consistency</td>
<td>Intermediate-level module Simple req./design</td>
<td>More elaborate req./design Basic dist-processing</td>
<td>Formalized specification, verification. Advanced dist-processing</td>
</tr>
<tr>
<td><strong>Peer Reviews</strong></td>
<td>No peer review</td>
<td>Ad-hoc informal walk-through</td>
<td>Well-defined preparation, review, minimal follow-up</td>
<td>Formal review roles and Well-trained people and basic checklist</td>
<td>Root cause analysis, formal follow Using historical data</td>
<td>Extensive review checklist Statistical control</td>
</tr>
<tr>
<td><strong>Execution Testing and Tools</strong></td>
<td>No testing</td>
<td>Ad-hoc test and debug</td>
<td>Basic test Test criteria based on checklist</td>
<td>Well-defined test seq. and basic test coverage tool system</td>
<td>More advance test tools, preparation. Dist-monitoring</td>
<td>Highly advanced tools, model-based test</td>
</tr>
</tbody>
</table>
COQUALMO Defect Removal Estimates
– Nominal Defect Introduction Rate (60 defects/KSLOC)

Delivered Defects / KSLOC (DDK)

Composite Defect Removal Rating
– Assuming nominal defect introduction rates

VL Low Nom High VH XH
Relations Between COCOMO II and COQUALMO

• COQUALMO rating scales for levels of investment in defect removal via automated analysis, peer reviews, and execution testing and tools have been aligned with the COCOMO II RELY rating levels.

• Bidirectional mapping between COCOMOII RELY and COQUALMO defect removal profile
Typical Marketplace Competition
Value Estimating Relationships

Internet Services, Wireless Infrastructure:
Value Loss vs. System Delivery Time

Fixed-schedule Event Support:
Value of On-time System Delivery

Off-line Data Processing:
Value Loss vs. System Delivery
How much Software Quality Investment is Enough?

Combined Risk Exposure

\[ \text{RE} = P(L) \times S(L) \]

<table>
<thead>
<tr>
<th></th>
<th>VL</th>
<th>L</th>
<th>N</th>
<th>H</th>
<th>VH</th>
<th>RELY</th>
</tr>
</thead>
<tbody>
<tr>
<td>COCOMO II:</td>
<td>0</td>
<td>12</td>
<td>22</td>
<td>34</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>COQUALMO:</td>
<td>1.0</td>
<td>.475</td>
<td>.24</td>
<td>.125</td>
<td>.06</td>
<td>.06</td>
</tr>
<tr>
<td>Early Startup:</td>
<td>.33</td>
<td>.19</td>
<td>.11</td>
<td>.06</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>Commercial:</td>
<td>1.0</td>
<td>.56</td>
<td>.32</td>
<td>.18</td>
<td>.10</td>
<td>.10</td>
</tr>
<tr>
<td>High Finance:</td>
<td>3.0</td>
<td>1.68</td>
<td>.96</td>
<td>.54</td>
<td>.30</td>
<td>.30</td>
</tr>
<tr>
<td>Market Risk:</td>
<td>.008</td>
<td>.027</td>
<td>.09</td>
<td>.30</td>
<td>1.0</td>
<td>RE_m</td>
</tr>
</tbody>
</table>

Market Share Erosion

Early Startup

Commercial

High Finance

Sweet Spot

Added % test time

Market Share Erosion

P_q(L)

S_q(L)

S_q(L)

S_q(L)

RE_m
Value/Risk-Driven Testing: 40% Gain

Combined Risk Exposure

\[ RE = P(L) \times S(L) \]

**COCOMO II:**
- VL: 0
- L: 12
- N: 22
- H: 34
- VH: 54
- Added % test time: 54

**COQUALMO:**
- Pq(L): 0.06
- Sq(L): Pareto
- VL: 1.0
- L: 0.475
- N: 0.24
- H: 0.125
- VH: 0.06

**Value-Based:**
- Combined Risk Exposure: 3.0
- RE = P(L) * S(L)
- Sweet Spot

**Value-Neutral:**
- Added % test time: 12
- Pq(L): 0.125
- Sq(L): Linear
- VL: 3.0
- L: 2.33
- N: 1.65
- H: 0.975
- VH: 0.30

**Market Risk:**
- REm: 0.008
- P(L): 0.027
- S(L): 0.9
- H: 0.30

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ODC COQUALMO and Failure/Defect Model

COQUALMO inputs including mitigations

ODC COQUALMO - domain tuned

ODC defect distributions

Failure/Defect Model

Failures

Defect Types
Calculating Probability of Loss

Failures

- Loss of Power
- Sensor Failure
- Lost Sensor Communication

Completeness
Ambiguity/Testability
Interface
Timing
Data Values/Initialization

ODC Defect Types

\[
\text{Probability (Loss)} = \sum_{i=1}^{\text{# defect categories}} \% \text{Contribution}_i \times \text{Probability}_i
\]
Example Defect Contributions to Failures

Historical Failure Data

<table>
<thead>
<tr>
<th>Defect Contribution Percent</th>
<th>Loss of Power</th>
<th>Sensor Failure</th>
<th>Lost Sensor Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambiguity/Testability</td>
<td>Ambiguity/Testability</td>
<td>Ambiguity/Testability</td>
<td>Ambiguity/Testability</td>
</tr>
<tr>
<td>Completeness</td>
<td>Completeness</td>
<td>Completeness</td>
<td>Completeness</td>
</tr>
<tr>
<td>Data Values/Initialization</td>
<td>Data Values/Initialization</td>
<td>Data Values/Initialization</td>
<td>Data Values/Initialization</td>
</tr>
<tr>
<td>Interface</td>
<td>Interface</td>
<td>Interface</td>
<td>Interface</td>
</tr>
<tr>
<td>Timing</td>
<td>Timing</td>
<td>Timing</td>
<td>Timing</td>
</tr>
</tbody>
</table>

Failure Categories: Loss of Power, Sensor Failure, Lost Sensor Communication
Failure Probability vs. Defect Density (I)

Probability of Lost Sensor Communication Due to Timing Defect

Probability

Timing Defects / KSLOC

nominal
Failure Probability vs. Defect Density (II)

Relative Probability of Lost Sensor Communication Due to Timing Defect

- Relative Probability
- Timing Defects/ KSLOC

Nominal
Conclusion and Future Work

• Integrating Cost, Quality Model and VERs supports combined risk analyses on software quality assurance

• ODC and domain specific extensions of VBSQM help select optimal combinations and application order of risk reduction techniques

• Refine COQUALMO and VBSQM models on Autonomy Software
Thank You

Questions and Comments