Six Sigma & Software/Systems Process Improvement

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Software Engineering Measurement & Analysis Initiative

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Outline / Objectives

Six Sigma Overview
Applications Survey
Initiative Synergy
Illustration
Six Sigma Is...

A Philosophy

A Metric

An Improvement Framework
Six Sigma Philosophy

Improve customer satisfaction by reducing and eliminating defects

Greater Profits
What is a Defect?

Six Sigma:
- Any product, service, or process variation which prevents meeting the needs of the customer and/or which adds cost, whether or not it is detected.

Personal Software Process℠:
- Defects or faults are the result of errors or mistakes. At a minimum, count a defect every time the program is changed during compile or test, where the change might be one character or multiple statements

[Humphrey 95]

℠Personal Software Process and PSP are service marks of Carnegie Mellon University.
Six Sigma Metrics

“3.4 ppm” – the most-cited metric

Other Measures

- Defect Rate, parts per million (ppm)
- Sigma Level
- Defects per Unit (dpu)
- Defects per Million Opportunities (dpmo)
- Yield
### “3.4” and “Sigma” Metrics

**New Car Buyer’s target:**
- 35 miles per gallon (mpg)
- 29-41 mpg acceptable

<table>
<thead>
<tr>
<th></th>
<th>Lower Spec</th>
<th>Target</th>
<th>Upper Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Car 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Car 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3 Sigma</strong></td>
<td>3</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td><strong>6 Sigma</strong></td>
<td>3/1000</td>
<td></td>
<td>virtually 0</td>
</tr>
<tr>
<td><strong>~3/1000 outside limits</strong></td>
<td></td>
<td></td>
<td>outside limits</td>
</tr>
</tbody>
</table>
“3.4” and “Sigma” Metrics

Historical data:
1.5*standard deviation shift over time

Car 2:
- Mean shifts to 33.5
- “Mean - 6*Std Dev” now extends below lower spec
- Extension corresponds to 3.4 ppm if normal distribution
Assumptions:
- normal distribution
- process mean shift of 1.5σ from nominal is likely
- process mean and standard deviation are known
- defects are randomly distributed throughout units
- parts and process steps are independent
Example Sigma Levels

Sigma Level

<table>
<thead>
<tr>
<th>Sigma Level</th>
<th>PPM per Part or Process Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>1000</td>
</tr>
<tr>
<td>4</td>
<td>10,000</td>
</tr>
<tr>
<td>5</td>
<td>100,000</td>
</tr>
<tr>
<td>6</td>
<td>1,000,000</td>
</tr>
<tr>
<td>7</td>
<td>10,000,000</td>
</tr>
</tbody>
</table>

Note: Sigma Levels vary +/- 1s with source publication date.

Examples:
- IRS - Tax Advice (phone-in)
- Restaurant Bills
- Doctor Prescription Writing
- Payroll Processing
- Air Line Baggage Handling
- Orders Placed on Factory
- US Navy Aircraft Accidents
- Domestic Airline Flight Fatality Rate

[Harrold 98], [Harry 00]
Everything is a process
All processes have inherent variability
Data is used to understand variation and to drive decisions to improve the processes

Special Cause Variation

Data Spread due to Common Cause Variation

Original Mean

New mean after improvement
(Spread due to common cause variation will re-establish itself.)
Everything Is a Process

Example: Software Engineering
Six Sigma Improvement Framework

Define ➔ Measure ➔ Analyze ➔ Improve ➔ Control
# Six Sigma Toolkit

<table>
<thead>
<tr>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Benchmark</td>
<td>- 7 Basic Tools</td>
<td>- Cause &amp; Effect Diagrams</td>
<td>- Design of Experiments</td>
<td>Statistical Controls:</td>
</tr>
<tr>
<td>- Baseline</td>
<td>- Defect Metrics (i.e., “ppm”)</td>
<td>- Failure Modes &amp; Effects Analysis</td>
<td>- Modeling</td>
<td>- Control Charts</td>
</tr>
<tr>
<td>- Contract/Charter</td>
<td>- Data Collection Forms, Plan, Logistics</td>
<td>- Decision &amp; Risk Analysis</td>
<td>- Tolerancing</td>
<td>- Time Series methods</td>
</tr>
<tr>
<td>- Kano Model</td>
<td>- Sampling Techniques</td>
<td>- Statistical Inference</td>
<td>- Robust Design</td>
<td>Non-Statistical Controls:</td>
</tr>
<tr>
<td>- Voice of the Customer</td>
<td></td>
<td>- Control Charts</td>
<td></td>
<td>- Procedural adherence</td>
</tr>
<tr>
<td>- Voice of the Business</td>
<td></td>
<td>- Capability</td>
<td></td>
<td>- Performance Mgmt</td>
</tr>
<tr>
<td>- Quality Function Deployment</td>
<td></td>
<td>- Reliability Analysis</td>
<td></td>
<td>- Preventive activities</td>
</tr>
<tr>
<td>- Process Flow Map</td>
<td></td>
<td>- Root Cause Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Project Management</td>
<td></td>
<td>- 5 Why’s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Management by Fact”</td>
<td></td>
<td>- Systems Thinking</td>
<td></td>
<td></td>
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<tr>
<td>- 4 What’s</td>
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Design for Six Sigma (DFSS)

New solutions
  • Rather than analysis of existing processes

Focus
  • Customer and business
  • Emphasis on critical-to-quality characteristics

Useful tools
  • Modeling, simulation, lean, systems thinking
Applications

Six Sigma applications for Systems and Software Engineering are emerging
Survey of Applications

Allied Signal
- 1997 air supply control system shutdowns
- Black Belt project team commissioned to find solution

Motorola
- Inspection data analysis & unit test optimization
- Design of experiments methods & test cases
- Complexity analysis & resource allocations
- Quantitative risk management via uncertainty modeling

General Electric
- DFSS
- Six Sigma & Extreme Programming

[Harry 00], [Stoddard 00], [Kelliher 01]
Motorola & GE presentations available at http://seir.sei.cmu.edu
Survey of Applications 2

Honeywell

- PSP\textsuperscript{SM}/TSP\textsuperscript{SM} & Six Sigma
  - “TSP provides the data needed to apply Six Sigma”

JP Morgan

- Capability Maturity Model\textsuperscript{®} (CMM\textsuperscript{®}) & Six Sigma
  - “…Six Sigma methodology is beneficial on all levels of maturity.”

NCR

- CMM & Six Sigma
  - “…helps organizations working towards Level 4 & 5 deliver the best business results.”

[Pavlik 00], [A-M 99], [Demery 01]
Presentations available at http://seir.sei.cmu.edu
Initiative “Synergy”

CMM®
- Level 1-3
- Level 4-5

CMM Integration℠ (CMMI℠)

Personal Software Process℠ (PSP℠)

Team Software Process℠ (TSP℠)

© Capability Maturity Model and CMM are registered in the U.S. Patent and Trademark Office.℠ CMM Integration, CMMI, Personal Software Process, PSP, Team Software Process and TSP are service marks of Carnegie Mellon University.
CMM and Six Sigma*

5. Organization-wide $6\sigma$ improvements and control
   - Correlation between key process areas & $6\sigma$ methods
   - $6\sigma$ used within CMM efforts

4. Process measured and controlled

3. Defined processes feed $6\sigma$

2. $6\sigma$ philosophy & method focus
   - $6\sigma$ “drilldown” drives local (but threaded) improvements

1. $6\sigma$ may drive toward and accelerate CMM solution

Six Sigma is enterprise-wide.
Six Sigma focuses on “critical to quality” factors.

*Similar comments apply to CMMI
CMMI & Six Sigma*

“Within” CMMI
- Quantitative Project Management (QPM)
- Organizational Process Performance (OPP)
- Organizational Innovation and Deployment (OID)
- Measurement & Analysis (MA)
- Capability Levels
- Generic Practices

“Around” CMMI
- SEPG process improvement rollout
- Assessment methods
- Prioritization of process areas

*Similar comments apply to CMM
Illustration – “Define” 1

Business Driver

• Need 10% cost reduction in order to compete in the marketplace and stay in business

Baseline data (PSP)

• Productivity: 19 LOC/hr
• 33% of development time spent fixing defects
• Approximately 250 defects/KLOC
Illustration – “Define” 2

Goal:
• Reduce or prevent defects to reduce cost

Quantitatively speaking:
• Reduce cycle time by 22 minutes/program
• Reduce fix time by 1.3 minutes/defect
• Reduce defects by 6/program
• Reduce defect density to 190 defects/LOC

… or a combination that produces 21 LOC/hr
Illustration – “Define, Measure”

PSP-based Process Map:

- **Design**
  - Requirements
  - Estimate
  - Concept design
  - Detailed Design
  - Test cases
  - Data:
    - Design Review defects
    - Fix time
    - Phase duration

- **Code**
  - Resources
  - Code
  - Data:
    - Defect Quantity
    - Fix time
    - Defect Injection Phase
    - Phase duration

- **Compile**
  - Code
  - Executable Code
  - Test Plan

- **Test**
  - Executable Code
  - Functional Code
  - Data:
    - Defect Quantity
    - Fix time
    - Defect Injection Phase
    - Phase duration
Illustration – “Analyze”

Opportunities to reduce repair time

- Defects removed in test: 78% of repair time
- Defects injected in design: 25% of repair time
- Defects injected in code: 56% of repair time
- Syntax defects in general: 63% of defects

Removed Defects Fix Time
Baseline programs 1-6

- Code: 2%
- Compile: 20%
- Test: 78%

Injected Defects Fix Time,
Baseline programs 1-6

- Test: 19%
- Design: 25%
- Code: 56%
Illustration – “Improve”

Improvement Plan at Program 6
- Syntax checklist
- Well-timed reviews
- Subcategories within defect types

![Defect Density Chart]

![Mean Comparison: Defect Density Chart]
Illustration – “Control”

Tracking performance

- Quantitative goal statement
- Hypothesized root causes
- Countermeasures & contribution to impact
- Key impact indicators

Direct causes (from countermeasures):
- Fewer defects injected in code & test
- Defects removed earlier, faster (i.e., in design & code)

Root cause (need new countermeasures):
- “Re-learning” curve
Illustration – Analysis Summary

Tools used in full analysis included

- Process Mapping
- Descriptive statistics
- Means comparisons & significance testing
- Plots
  - Pie Charts
  - Trends
  - Phase profiles
  - Histograms
  - Pareto charts
  - Correlation plots
- Cause & Effect Diagrams
- “Management by Fact”

Focus was exploratory, investigative
- Ready for stability & control monitoring
# Illustration – Scaling up

## Illustration

- Quickly drilled down from high level cost goal to personal improvement
- Defined process in place
- Measures in place
- Continuous incremental improvements
- Event-based “step-change” improvements
- Re-learning curve
- Personal data
- Used productivity as one of impact measures

## Real Life

- Drill down may be complex, may span wide breadth of organization
- May need to select or define process
- May need to develop measures
- Continuous incremental improvements
- Event-based “step-change” improvements
- Constantly changing skills, technologies
- Non-attributed data (e.g., team, project)
- Excessive productivity focus may drive unwanted behaviors

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Advancing the State of $6\sigma$ & SW/SE

Repository of Examples
- [http://seir.sei.cmu.edu](http://seir.sei.cmu.edu)
- concrete visualization
- relationship to models, initiatives
- variety of tools
- many views
  - project, process, product
  - software, systems
  - maturity/capability levels

Repository of Benefits
Summary

Customer satisfaction is key driver

All efforts should link to business results
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# References

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<tbody>
<tr>
<td>[Demery 01]</td>
<td>Demery, Chris and Michael Sturgeon, Six Sigma and CMM Implementation at a Global Corporation, NCR, SEPG 2001, (slides available to SEIR contributors at <a href="http://seir.sei.cmu.edu">http://seir.sei.cmu.edu</a>)</td>
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<td>References</td>
<td></td>
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<tr>
<td>------------</td>
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</tbody>
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Additional Reading 1

Books (General Six Sigma Topics, not software-specific):


Web pages & Web sites:


International Quality Federation, [www.iqfnet.org](http://www.iqfnet.org) (Follow the black belt links)

Six Sigma Academy, [www.6-sigma.com](http://www.6-sigma.com)

Software Engineering Information Repository: [http://seir.sei.cmu.edu](http://seir.sei.cmu.edu) (Follow links to Measurement area then to Six Sigma)

Additional Reading 2

Journals (URLs subject to change without notice)


6 Sigma Con, Quality Digest, May 2000, http://www.qualitydigest.com/may00/html/sixsigmacon.html


Card, David, Sorting out Six Sigma and the CMM, IEEE Software, May/June 2000


