The Effective Application of Six Sigma in Software Engineering

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Software Engineering Measurement & Analysis Initiative

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Outline

Six Sigma Fundamentals
Implementation
The “Black Belt” Project
Measurement & Analysis Infrastructure (optional)
Summary

Addenda
• Additional illustration
• Measurement in the CMMI
• Goal-driven measurement references
• PSM references
• “Tooltips” (for several popular analytical methods)
• Six Sigma Solutions for Software

Brief History

1979 - Motorola quality imperative - “roots of Six Sigma”
1981 - Motorola challenge to improve 10 fold in 5 years
1988 - Motorola wins Malcolm Baldrige Quality Award
1991 - Motorola Six Sigma Research Institute established
1992 - Motorola, Texas Instruments, IBM, Kodak, and others initiated efforts to develop the 6σ Black Belt program
1995 - GE mandates Six Sigma rollout; estimates current performance at 3.5 Sigma
1997 - GE invests $250M to train 4,000 Black Belts and 60,000 Green Belts out of workforce of 222,000; recoups $300M same year
1998 - GE calculates Six Sigma payoff at $1.25B

[Stoddard 00]
Who Uses Six Sigma?

3M    Gates Rubber    Northrop Grumman
Amazon.com    General Electric    Raytheon
American Express    General Motors    Rohr
Bank of America    Hewlett Packard    Seagate
Boeing    Honeywell    Six Sigma Advantage
Black & Decker    IDX Systems Corp.    Sony Electronics
Bombardier    JP Morgan    Toshiba
Citigroup    Lantech    Toyota
DuPont    Lockheed Martin    Volkswagen
Eastman Kodak    Motorola    Wire Mole
Ford    PS&J Software    

Many apply Six Sigma to software and systems engineering processes and to IT Operations as well as to product design.

There are many experts in the community.

Frequently Asked Questions

How do I leverage Six Sigma with software process improvement initiatives already underway in my organization?

Should I pick Six Sigma or CMMI? Six Sigma or ITIL?
• Or, how do I convince my management that it’s not an either/or decision?

What evidence is there that Six Sigma works in software and systems engineering?

How do I train software engineers when Six Sigma training is geared for manufacturing?

What are examples of Six Sigma projects in software? In IT?

Isn’t Six Sigma only about advanced statistics?

Exactly what is a software “opportunity”? And, how do I calculate sigma?
Myths

Six Sigma is only for high maturity organizations.

It's all about statistics.

“Six” Sigma is the right performance goal.

Everything has to be six sigma (or x sigma ) performance.

It’s not for government contractors who “don’t focus on profitability.”

“Sigma level” corresponds to defect density.

It is all about defect density.

“We’re Level 5 therefore we must be Six Sigma.”

“We’re doing Six Sigma therefore we must be Level 4.”

What Is Six Sigma?

• a philosophy
• a performance measurement
• an improvement framework
• a set of improvement tools
• a structured approach for business improvement (a business strategy)
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 ProcessSM (PSPSM): 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.

ISO 9000:2000: Defects are the non-fulfillment of a requirement related to an intended or specified use.

Software Reliability: An error is a discrepancy between a computed, observed or measured value and the true value or a human action that results in software containing a fault. A failure is the inability to perform a required function with specified limits. A fault is a defect in the code that can be the cause of one or more failures.

[Humphrey 95], [DACS]
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.

- A non-conformance to a customer-driven specification
- A non-conformance or interruption of the flow or an intervention in the flow

The Customer’s Vantage Point

32-step “workaround” to move info to new version of financial software
Wrong “Statement Ending Balance” when reconciling a mutual fund account using financial software
Bank ATM’s debit accounts but don’t give money
University students unable to enroll due to lingering problems in multi-million-dollar software system
New air traffic control system out of action more than 7 hours resulting in cancelled flights and extended delays
Carrier plane veers right without warning due to computer glitch (emergency landing was a result)
Money from payroll direct deposits missing from bank accounts

[ NYT], [SM]
Six Sigma Metrics

Defect Measures
- Defect Rate, parts per million (ppm)
  - “3.4 ppm” – most-cited metric
- Sigma Level
- Defects per Unit (dpu)
- Defects per Million Opportunities (dpmo)
- Yield

Practitioner Project Measures
- Defect measures
- Cycle time, cost, product performance, variability….
- Bottom-line savings

False Starts on SW Sigma Metrics

From Motorola:
Single, over-riding objective is Customer Satisfaction:
“the degree of confidence a customer has that his (or her) product … expectations will be met by the producer.”

[Stoddard 00], [Stoddard]
What “Sigma Level” is “Right”?

What is your customer telling you?
- about the measure (Is “sigma” the “right” metric?)
- about the target performance

Plus, a general business perspective:
- A 4 sigma company spends >10% of revenues on internal & external repair
- A 6 sigma company spends <1% of revenues on internal & external repair

At Lockheed Martin IS&S
- processes modeled using SWEEP* tool
  - allows tolerances to be set based on present performance
  - allows targets to be set based on future performance
- output of the modeling showed “six sigma” performance

*SWEEP = Software Error Estimation Program

4 Sigma in Everyday Terms

4 Sigma = “99.9% sure”
- 9 hours/year unsafe drinking water
- 107 incorrect medical procedures a day
- 200,000 incorrect drug prescriptions per year
- 18,322 pieces of mishandled mail an hour
- 2,000,000 documents lost by IRS a year
- Two short or long landings at any major airport each day

[Harrold 99], [LMCO 02]
Example Sigma Levels

Sigma Level (ppm for shifted process)

- IRS - Tax Advice (phone-in)
- Restaurant Bills
- Doctor Prescription Writing
- Payroll Processing
- Airline Baggage Handling
- Orders Placed on Factory
- IRS - Tax Advice (phone-in)
- Domestic Airline Flight Fatality Rate

Average Company

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

Example Sigma Levels

<table>
<thead>
<tr>
<th>Sigma Level</th>
<th>PPM per Part or Process Step</th>
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<tr>
<td>1</td>
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<td>(6210)</td>
</tr>
<tr>
<td>5</td>
<td>(233)</td>
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<td>6</td>
<td>(3.4)</td>
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<table>
<thead>
<tr>
<th>Process</th>
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<td>IRS - Tax Advice (phone-in)</td>
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</tr>
<tr>
<td>Restaurant Bills</td>
<td>(66807)</td>
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<tr>
<td>Doctor Prescription Writing</td>
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<tr>
<td>Payroll Processing</td>
<td>(233)</td>
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<td>Airline Baggage Handling</td>
<td>(3.4)</td>
</tr>
<tr>
<td>Orders Placed on Factory</td>
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Statistical Thinking

- Everything is a process
- All processes have inherent variability
- Data is used to understand variation and to drive decisions to improve the processes

Data Spread due to Common Cause Variation

Special Cause Variation

New mean after improvement
(Spread due to common cause variation will re-establish itself.)
In Other Words…

Operating at Six Sigma Implies

Data-driven decision making
Meeting customers’ requirements
Measurable processes
Processes Under Control
Variation has been reduced
Future performance can be predicted
Results of actions can be assessed

Show me the Data!
Six Sigma Frameworks

Six Sigma Improvement: DMAIC
- Define – Measure – Analyze – Improve – Control
- used to improve existing processes and products

Design for Six Sigma: DMADV
- Define – Measure – Analyze – Design – Verify
- DMADV is a process of “Design for Six Sigma” (DFSS)
  - there is not unified approach to DFSS across industry
- used to design new products and processes
- used to redesign an existing process which has been optimized but still does not meet specifications

Both emphasize customer satisfaction and business benefit.
Both focus on critical to quality characteristics.

Six Sigma Toolkit

<table>
<thead>
<tr>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
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</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/Chart</td>
<td>• Data Collection Forms, Plan,</td>
<td>• Decision &amp; Risk Analysis</td>
<td>• Tolerancing</td>
<td>• Time Series methods</td>
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<tr>
<td>• Kano Model</td>
<td>Logistics</td>
<td>• Statistical Inference</td>
<td>• Robust Design</td>
<td>Non-Statistical Controls:</td>
</tr>
<tr>
<td>• Voice of the Customer</td>
<td>• Sampling Techniques</td>
<td>• Control Charts</td>
<td>• Design</td>
<td>• Procedural adherence</td>
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<tr>
<td>• Voice of the Business</td>
<td>• Process Flow Map</td>
<td>• Capability</td>
<td>• PM</td>
<td>• Performance Mgmt</td>
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<tr>
<td>• Quality Function Deployment</td>
<td>• Project Management</td>
<td>• Reliability Analysis</td>
<td>• Preventive activities</td>
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<tr>
<td>• “Management by Fact”</td>
<td>• “Management by Fact”</td>
<td>• Root Cause Analysis</td>
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<td>• -4 What’s</td>
<td>• -4 What’s</td>
<td>• -5 Why’s</td>
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<tr>
<td></td>
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<td>• Systems Thinking</td>
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<pre><code>                                                                   |                                   | • Thinking                                   |                                             |                                             |
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Outline

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Implementation

The “Black Belt” Project

Measurement & Analysis Infrastructure (optional)

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• PSM references
• “Tooltips” (for several popular analytical methods)
• Six Sigma Solutions for Software

Roles

Executive Management

• support of top management is required

Champions

• identify projects, select “belt” candidates, remove barriers

Master Black Belts

• train and mentor Black Belts
• typically work with Black Belts and process owners in a functional area or business unit

Black Belts – the “heart and soul” of Six Sigma initiatives

• lead improvement projects

Greenbelts

• support black belt projects or lead smaller projects
• typically part-time
Training and Certification

Green Belt
• typical training: 1 week to 2 weeks

Black Belt
• DMAIC training: 4 to 5 weeks over 6 months with project
• DFSS training: 2 to 3 weeks over 6 months with project
• certification:
  - completion of certification project
  - completion of training
  - often rated on demonstration of skills

Master Black Belt
• role earned by experience and demonstrated project successes

The “Black Belt” Practitioner

Expectations:
• Influence change
• Provide leadership in applying quantitative methods
• Facilitate teamwork
• Consult with management
• Transfer knowledge and skills to others
• Discover new leveraging opportunities
• Continuously improve their skills
• Participate in the Black Belt network
CIO Magazine: “Quality Model Mania”

CMMI Process Areas

<table>
<thead>
<tr>
<th>Category</th>
<th>Process Areas</th>
</tr>
</thead>
</table>
| Process Management | Organizational Process Focus  
                     | Organizational Process Definition  
                     | Organizational Training  
                     | Organizational Process Performance  
                     | Organizational Innovation and Deployment |
| Project Management | Project Planning (PP)  
                         | Project Monitoring and Control (PMC)  
                         | Supplier Agreement Management (SAM)  
                         | Integrated Project Management  
                         | Risk Management  
                         | Quantitative Project Management (QPM) |
| Engineering     | Requirements Management  
                     | Requirements Development  
                     | Technical Solution  
                     | Product Integration  
                     | Verification  
                     | Validation |
| Support         | Configuration Management  
                     | Process and Product Quality Assurance  
                     | Measurement and Analysis (MA)  
                     | Causal Analysis and Resolution  
                     | Decision Analysis and Resolution |
**CMMI Structure**

- **Appendices**
  - Maturity Level 5
    - OID, CAR
  - Maturity Level 4
    - OPP, QPM
  - Maturity Level 3
    - REQD, TS, PL, VER, VAL, OPF, OPD, OT, IPM, RSKM, DAR
  - Maturity Level 2
    - REQM, PP, PMC, SAM, MA, PPQA, CM

- **Process Management**
  - PAs
    - Goals
    - Practices

**CMMI Staged and Six Sigma**

- **Organization-wide** 6σ improvements and control
- Correlation between key process areas & 6σ methods
- 6σ used within CMM efforts

- **Infrastructure in place**
- Defined processes feed 6σ

- **6σ philosophy & method focus**
  - 6σ “drilldown” drives local (but threaded) improvements
  - 6σ may drive toward and accelerate CMMI solution

- **Six Sigma is enterprise wide.**
  - Six Sigma addresses product and process.
  - Six Sigma focuses on “critical to quality” factors.
Six Sigma and CMMI Continuous

One possible approach:
- Achieve high capability in PAs that build Six Sigma skills: MA, QPM, CAR, OPP
- Use capability to help prioritize remaining PAs

Remaining PAs ordered by business factors, improvement opportunity, etc., which are better understood using foundational capabilities. CMMI Staged groupings and DMAIC vs. DMADV are also factors that may drive the remaining order. [Vickroy 03]

A Mathematical View

\[ y_1, y_2 = f(x_1, x_2, \ldots, x_k) \]

\[ \begin{align*}
  y_1 &= \text{customer satisfaction} \\
  y_2 &= \text{profitability} \\
  x_i &= \text{standards, engineering practices/processes} \\
  &\quad \text{what to do, what is done} \\
  &\quad \text{as characterized and measured by capability models} \\
  x_k &= \text{product innovation, organization policies, marketplace factors and so on}
\end{align*} \]

In this view, cost, quality, schedule, product features are “intermediate” responses: functions of standards & practices, factors for customer satisfaction and profitability.

Six Sigma is a way
to define the axes,
to traverse the response surface and find the optimum.
Tactical Considerations: Implementation

Business objectives should drive the effort

Work within the funding guidelines and constraints of your organization

Leverage existing roles
  - Select engineering process group members as sponsors, possibly as Champions and Black Belts.

Mapping methods
  - Integrate the practices of models, standards, and initiatives into a unified, holistic approach that is appropriate for your organization.

Tactical Considerations: Training

Leverage software and systems-specific measurement training as part of the DMAIC curriculum

Use projects to build repository of examples of analytical methods in context of systems and software

Extend Six Sigma curriculum, for instance
  - Rayleigh distributions
  - reliability fault trees
  - Bayesian modeling

Develop an in-class design project suitable for systems and software engineering or IT
Lockheed Martin IS&S Training & Implementation

Executive Lean Training
- Top Executives - one week off site
- Must understand and promote

Green Belt Training
- One week course (corporate initiated/ unit led)
- Certification (course completion, 1 event, Black Belt Mentor)
- Considering expanding Green Belt training to keep Black Belt training at three weeks

Black Belt Training
- Three week DFSS/Lean course (corporate initiated)
- Certification (course completion, 3 events, mentored one greenbelt to certification)
Lockheed Martin IS&S Training & Implementation

Lean Event Training
- 2-hour training session opens each lean event
- covers tools and methodologies
- geared for those without previous experience

Organizational Training Goals
- green belts to be trained set annually
- black belts to be trained set annually

TRW* Approach to Integration

From TRW* presentation at STC 2002:

- ISO 9000/9001 establishes a fundamental quality management framework
- CMM/CMMI implements processes which reflect industry best practices
- Six Sigma focuses on improvements and measures which lower the cost of doing business

*This organization is now Northrop Grumman Mission Systems
[Hefner 02]
Six Sigma Approach at Northrop Grumman Mission Systems (MS)

Linked with Business Planning and Oversight
- Business planning
- Project selection

Quantitatively Driven
- Six Sigma improvements are quantified

Integrated with Quality Program
- Integrated Training, Awareness, & Policies
- Integrated CMMI & Six Sigma projects
- Integrated tracking and reporting via DB, PRA, etc.

Enabled by Infrastructure
- Training
- Tools
- Awareness
- Database

Tied to Employee Performance
- Goals, awards
- Job and career paths

Engaged with External Customers
- Visibility
- Participation

3 Keys to Competitive Leverage at Northrop Grumman MS

Six Sigma provides a business strategy to deliver value and develop a sustainable competitive advantage

CMMI provides guidance for measuring, monitoring and managing processes

KM provides a strategy to utilize data and transform it into knowledge to enable informed and decisive management leadership

Six Sigma

CMMI

Knowledge Management

KM provides a strategy to utilize data and transform it into knowledge to enable informed and decisive management leadership

Six Sigma is a business strategy to deliver value and develop a sustainable competitive advantage
Northrop Grumman MS Training and Implementation

Started implementing Six Sigma in 2001

Trained over 3000 Green Belts (80 hours), and over 200 Black Belts (160 hours)

Completed several hundred projects covering all functional areas
  • Customer involvement and award fee citations

About half of the projects are improving an engineering process

[Hefner 03A]

Northrop Grumman MS: Notes from the Field

CMMI & Six Sigma
  • “Northrop Grumman was able to accelerate achievement of Levels 4 and 5 using Six Sigma”
  • “Six Sigma is an enabler for measuring the value of specific improvements”
  • “Six Sigma provides a way to connect process improvement and business value”
  • “Six Sigma projects can help focus and measure CMMI-driven process improvements”
  • “..conducting Level 5 SCAMPI appraisals in 5-6 days… significant cost savings”

[Facemire 04], [Hefner 04]

Presentations available at http://groups.yahoo.com/group/6S_SWSE

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Additional Notes from the Field

Honeywell
• PSP/TSP & Six Sigma
  - “TSP provides the data needed to apply Six Sigma”

JP Morgan
• Capability Maturity Model (CMM) & 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.”

Tata Consultancy Services
• CMM and Six Sigma
  - “…a development Center…. used SW-CMM and Six Sigma concepts to reduce its in-process failure costs from 5 to 1 percent…."

Wipro
• enterprise integrated system, incl. ISO 9001, CMM, P-CMM, TL9000, British Standard 7799, Six Sigma
  - “…Six Sigma methodologies brought in quantitative understanding, cost savings, and performance improvement towards product quality.”
  - “Six Sigma… brought about a focused customer-centric and data-driven paradigm to product and process quality…"

[Pavlik 00], [A-M 99], [Demery 01], [Keeni 03], [Keeni 03], [Wipro 04]
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What Is a Black Belt Project?

Business importance
• Financial expectations: $100-150K (US) savings, at least
• Endorsed and approved by management

Duration: 3-6 months recommended

Objectives are quantitative and include at least one of the following:
• Improve customer satisfaction.
• Optimize the supply chain.
• Reduce defects.
• Reduce cycle time.
• Improve first-pass yield.
• Reduce variability.
• Optimize product performance.
• Optimize process performance.
• Reduce costs.
• Reduce the cost of quality.
Survey of Applications

Motorola
- inspection data analysis & unit test optimization
- risk-based software inspections
- design of experiments methods & test cases
- complexity analysis & resource allocations
- quantitative risk management via uncertainty modeling

General Electric
- DFSS
- Six Sigma & Extreme Programming

[Stoddard 00], [Kelliher 01]
Also see “Six Sigma Solutions for Software” (from Motorola) in addenda

IDX
- schedule variance reduction for customer install projects
  - goal: 25% reduction; first year results: 50% reduction

Raytheon
- CMMI process definition accomplished via Six Sigma projects

Lockheed Martin IS&S
- Six Sigma and Technology Change Management program integrated

Northrop Grumman MS
- CMMI appraisal time reductions (to 5-6 days)

[Buehler 03], [Lane 04], [LMC 02], [Hefner 03]
Survey of Applications

Wipro
- problem resolution in critical business areas such as
  - requirements development, server optimization, service improvement, product performance
- engineering processes enhanced with Six Sigma tools
- results from overall integrated approach include
  - 40% productivity increase
  - 60% field defect reduction
  - 12% schedule adherence improvement

Anonymous IT Call Center
- customer satisfaction improvement without cost increase

[Wipro 04], [Hallowell 04]

Composite Project Illustration

Problem and goal statement (Y):
- minimize latent defects released
- minimize mean time between failure in the field
- improve time to market (as function of test time, defect density)

Define → Measure → Analyze → Improve → Control

- Problem & goal statements
- Define boundaries
- Process maps
- “Management by Fact”
- Discovery: paretos, histograms, distributions, c&e
- Understanding: root cause, critical factors
- Improvement: adjust critical factors, redesign
- Performance: on target, with desired variation

Y = f(defect profile, yield)
   = f(review rate, method, complexity…….)
A Very High-Level Process

Engineering Support Processes
- Understand Customer Needs
- System Analysis
- Decision Analysis

Engineering Development Life Cycle Processes
- Requirements Definition & Architecture Development
- Verify & Validate System of System
- System of System Transition to Operations
- Support to Operations

Program Management & Control Processes
- Program & Project Planning
- Risk Management
- Ensure Product Quality
- Configuration Mgmt, Ctrl
- Monitor, Control Effort
- Quantitative Management

Organizational Processes
- Define and Improve SE Processes
- Manage Product Evolution
- Manage SE Support Environment
- Knowledge Mgmt
- Supplier/Subcontractor Coordination

Project Boundaries

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

- **Code**
  - Resources
  - Code Stds
  - LOC counter
  - Interruptions
  - Code
  - Data: Defects, Fix time, Defect Injection Phase, Phase duration

- **Compile**
  - Executable Code
  - Test Plan, Technique
  - Operational Profiles
  - Executable Code
  - Data: Defects, Fix time, Defect Injection Phase, Phase duration

- **Unit Test**
  - Functional Code
  - Data: Defects, Fix time, Defect Injection Phase, Phase duration

- **Inspection**
- **Rework**
Drilldown to Inspection Process

What are the sources of variation? the control knobs?

Plan \rightarrow Detect Defects \rightarrow Troubleshoot \rightarrow Correct Defects

- Artifacts to inspect
  - Artifact size
  - Reviewers
  - Data repository
- Review Rate
- Checklists
- Inspection method, procedure
- Proficiency
- Taxonomy interpretations

- Critical Inputs
- Noise
- Standard Procedure
- Control Knobs

What would you list?

Data feed DMAIC project process

Starting Out…

Collecting basic data
- inspections

Refining processes
- cause & effect matrix
- pareto analysis

Improving
- injecting fewer defects
- detecting defects earlier
- removing them efficiently
- process stability

Initial Defect Density

Defects/KLOC

PSP-based Design Review | PSP-based Code Review
Code | Compile | Test

Post-improvement Defect Density

Defects/KLOC

PSP-based Design Review | PSP-based Code Review
Code | Compile | Test
Rayleigh Distribution

Error Discovery Data and Rayleigh Fitted Histograms

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<th>Stage</th>
<th>Estimated</th>
<th>Actual</th>
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<tbody>
<tr>
<td>Preliminary Design</td>
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<td>Detailed Design</td>
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Cause-Effect Model Using Bayesian Modeling

- Historical HW FFR
- HW Simulation Results
- HW Test Results
- Field Test Results
- ALT Results
- Product FFR
- SW Reuse
- SW Design Assessment
- SW Reqs Assessment
- SW Domain Expertise
- SW Code Assessment
- SW Process Maturity
- SW Testing Results
- SW Testing Results
- CASRE Results
- SW Process Maturity
- SW Code Assessment
- SW Reqs Assessment
- SW Design Assessment
- Historical HW FFR
**CASRE* Predictions**

Actual field defects = f(CASRE predicted defects)  
CASRE predicted defects = f(weekly arrival rate of SW failures, weekly test intensity measures)

$3M/year savings from premature SW releases

[Stoddard], "CASRE = Computer Aided Software Reliability Estimation"

---

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**Addenda**  
• Additional illustration  
• Measurement in the CMMI  
• Goal-driven measurement references  
• PSM references  
• “Tooltips” (for several popular analytical methods)  
• Six Sigma Solutions for Software

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Six Sigma Measurement

What if….
• You are launching a black belt improvement project or designing a new product (or process) and have no software measures?
• You are trying to select and prioritize projects for your Six Sigma project portfolio and have no measures?
• You have some measures on some projects that are inconsistently applied across the organization?
• You have defect, cost and schedule measures on only a portion of the software life cycle?

Are these your realities?
Which comes first, the chicken or the egg?
• Six Sigma
• Measures

Universal Measurement Interests

What “canonical measures” should we use?
• cost, schedule, functionality, quality

The operational definitions of these are context specific.

There is no single “silver bullet,” comprehensive, one-size-fits-all set of measures and indicators.

There are, however, reference lists, methods and processes that will get you started.
Measurement Interests by Role

How do measurement interests vary with role or position?
• many similar areas of measurement
• possible differences in granularity or reporting frequency

For instance, consider a contracted project

**Acquirer Interests**
- Contractor’s Performance
  - Schedule & Progress
  - Resources & Cost
  - Product Quality
- Acquisition Org. Performance
  - Processes
  - Documents Produced

**Contractor Interests**
- Schedule & Progress
- Resources & Cost
- Product Size & Stability
- Product Quality
- Process Performance
- Technology Effectiveness
- Customer Satisfaction

A Six Sigma project may also need to use these measures.
Sources for Measures

**Goal-Driven (Software) Measurement (GDM)**

**USER DEFINES INDICATORS & MEASURES**

Based On:
- what’s needed to manage the User’s goals
- decisions and decision criteria related to managing the user’s goals

**Practical Software & Systems Measurement**

<table>
<thead>
<tr>
<th>Common Issue Area</th>
<th>Measurement Category</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREDEFINED</td>
<td>PREDEFINED</td>
<td>PREDEFINED</td>
</tr>
</tbody>
</table>
Goal-Driven Measurement (GDM)

When using goal-driven measurement, the primary question is NOT:

“What metrics should I use?”

rather, it is:

“What do I want to know or learn?”
“What decision do I want to make?”

Goal-driven measurement is NOT based on a predefined set of metrics.

[GQIM 96]
Practical Software & Systems Measurement (PSM)

This measurement process is funded by the DoD and is freely available at [http://www.psmisc.com](http://www.psmisc.com).

PSM process identifies project-specific issues:
- issues grouped into common software issue areas
- measurement categories correspond to issue areas
- each measurement category has a candidate set of proven measures

Measures are selected based on availability, environment, and other factors.

---

PSM Common Software Issues – Measurement Categories

<table>
<thead>
<tr>
<th>Schedule and Progress</th>
<th>Resources and Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Milestones Performance</td>
<td>- Personnel</td>
</tr>
<tr>
<td>- Work Unit Progress</td>
<td>- Financial Performance</td>
</tr>
<tr>
<td>- Incremental Capability</td>
<td>- Environment Availability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product Size and Stability</th>
<th>Product Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Product Size and Stability</td>
<td>- Functional Correctness</td>
</tr>
<tr>
<td>- Functional Size and Stability</td>
<td>- Supportability - Maintainability</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Process Performance</th>
<th>Technical Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Process Compliance</td>
<td>- Technology Suitability</td>
</tr>
<tr>
<td>- Process Efficiency</td>
<td>- Impact</td>
</tr>
<tr>
<td>- Process Effectiveness</td>
<td>- Technology Volatility</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer Satisfaction</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- Customer Feedback</td>
<td></td>
</tr>
<tr>
<td>- Customer Support</td>
<td></td>
</tr>
</tbody>
</table>

---

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© 2004 by Carnegie Mellon University  Version 1.0  page 70
Modified Indicator Template

Indicator Name/Title
Objective
Questions
Visual Display
Communicate Results
Perspective
Input(s)
Data Elements
Definitions
Data Collection
How
When/How Often
By Whom
Form(s)
Data Reporting
Responsibility for Reporting
By/To Whom
How Often

Establish Measurement Objectives
Specify Measures
Collect Data
Specify Data Collection Procedures
Analyze
Analysis
Evolution
Feedback Guidelines
X-reference

Additional Modifications by clients
- streamlined data collection & reporting sections using “swimlane” diagrams
- Addition of “corrective action guidelines”
- Subprocess selection (for CMMI)

[Q(I)JM], [DZ 02]

Indicator Classifications

GQ(I)M
Roll-up For Higher Management

Success Indicators
Have the goals been achieved? What is the impact of the tactics?

Success Criteria
Goal
Strategy to accomplish the goal
Tasks to Accomplish goal
Task 1
Task 2
Task 3
Task n

Analysis Indicators
What are results of specific tasks?

PSM
Institute

Progress Indicators
How well are plans proceeding?

PSM, GQ(I)M

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Version 1.0
Page 71
Data Analysis Dynamics

Getting Started
- Identify the goals
- Black box process view
- Is the data right?
- Do I have the right data?

Decision point:
- If the data is not perfect, do I move forward or obtain better data?

Initial Evaluation
- What should the data look like?
- What does the data look like?
- Can I characterize the process, product, problem?

Decision point:
- Can I address my goals right now?
- Or is additional analysis necessary at the same or deeper level of detail?
- Can I move forward?

Moving Forward
- Further evaluation
- Decompose data, process

Decision point:
- Do I take action?
- What action do I take?

Repeat until root cause found, at target with desired variation

Performance Analysis Model

Technical Adequacy
Development Performance
Growth and Stability
Resources and Cost
Schedule and Progress
Customer Satisfaction
Product Quality

[PSM 00]
Performance Analysis Checklist 1

Single indicator issues:
- Do actual trends correspond to planned trends, such as progress, growth, and expenditures? How big is the variance?
- Does the variance appear to be gradually growing each month?
- Are actual values exceeding planned limits, such as open defects, changes, and resource utilization?
- Are outliers or other anomalies affecting the results?

Performance Analysis Checklist 2

Integrated indicator issues:
- Is the source of the problem evident?
  - Change in functionality, unplanned rework, etc.
- Are growing problems in one area a leading indicator of other problems later in the project?
  - Requirements creep impact on schedule
- Do multiple indicators lead to similar conclusions?
  - Lack of progress correlates with low staffing
- Does other project information contradict performance results?
  - Milestones being met but open defect counts are increasing
Typical Pattern of Software Problems

- Changed Requirements
- Software Size growth
- Effort Over-runs
- Schedule Slip
- Rework
- Quality Shortfalls

Illustration: Goal Structure

- Meet Customers’ Needs
  Owner:
  Stabilize Current Information Systems
  Owner:
    Improve Product Delivery
    Owner:
      Provide “whole product” support
    Improve product field performance
  Develop a quality team (right people, right time, right job)
  Owner:
    Stabilize Software Engineering Processes
    Owner:
    Establish Acquisition Processes
    Owner:
  Engineer the Future Systems
  Owner:
    Deliver Future Systems
  Owner:
  Engineer the Future Systems
  Owner:

Illustration: Success Criteria Stabilize Engineering Processes

Two key success indicators (excerpted from indicator templates)
- Status of ownership, training, documentation, configuration management of processes (evolve into procedural adherence)
- Status of training, detailed view

Add indicators to reflect appraisal results and procedures
- Select one or two for routine reporting

Middle Mgmt dashboard: Sr. Mgmt Scorecard

Sr. Mgmt Rollup
- quality trends (the in-process piece; maps to VAL, MA, PPQA)
- selected project EV data

Middle Mgmt dashboard
- system documentation and testing

Analysis Indicators

Goal: Stabilize Engineering Processes

Strategy to accomplish goal
- Reference models: CMMI, IEEE/ISO 12207
- Aim for CMMI capability in selected PAs: MA, REQM, RD, VAL, PMC, PP, PPQA (transition & institutionalization), VER, CM, RSK, CAR

Tasks to Accomplish goal
- From engineering list, all of which map to the selected CMMI PAs
  - document requirements
  - scrub test procedures
  - remove all known defects
- From SPI plan
  - review and document internal processes

Success Indicators
- thumbnails shown here; supplement with appraisal indicators
- Middle Mgmt Rollup
  - selected SPI plan EV data

Progress Indicators
- start, finish dates
- with progress noted (move toward EV)
Outline

Six Sigma Fundamentals
Implementation
The “Black Belt” Project
Measurement & Analysis Infrastructure (optional)

Summary

Addenda
- Additional illustration
- Measurement in the CMMI
- Goal-driven measurement references
- PSM references
- “Tooltips” (for several popular analytical methods)
- Six Sigma Solutions for Software

CMMI, Software & IT Best Practices and Six Sigma: Recent History

Many papers and presentations comparing the details of CMM, CMMI and Six Sigma
- what are the differences? the similarities?
- how do they map at the PA, goal, practice level? (CMMI view)
- how do they map at the philosophy, framework, toolkit, metric levels? (Six Sigma view)
- how to tailor Six Sigma training for software?

Some papers extending to ISO, TSP, Balanced Scorecard, Measurement & Analysis practices

Technical depth and reports of field experience have increased with time

Venues have included SEPG Conferences, STC Conferences, Crosstalk, and ASQ’s Software Quality Professional
Advancing the State of Six Sigma and Software & Systems Engineering: Sharing Experiences

Discussion Groups
• http://groups.yahoo.com/group/6S_SWSE
• http://software.isixsigma.com

Experiences, Examples & Benefits
• http://seir.sei.cmu.edu
  • See “measurement domain”
• http://groups.yahoo.com/group/6S_SWSE
• http://software.isixsigma.com
• Six Sigma series in ASQ’s Software Quality Professional

Advancing the State of the Practice: New Developments

The SEI is exploring Six Sigma as a transition enabler for software and systems engineering best practices.

We assert that Six Sigma with best practice initiatives will result in
• more effective decisions about which process improvements to implement via one or more improvement models
• accelerated implementation of process improvements
• more accurately measured effects
Advancing the State of the Practice: New Developments

In support of this project, the SEI is currently gathering case study evidence from organizations implementing Six Sigma (DMAIC or DFSS) with

- CMMI in software or systems engineering process improvement
- CMMI and the Information Technology Infrastructure Library (ITIL), Control Objectives for Information and related Technology (CobIT) or other IT improvement methodologies in IT Operations

Advancing the State of the Practice: Future Work

The current research project may involve
- a state-of-the-practice questionnaire
- an technical information exchange event regarding Six Sigma, CMMI, ITIL and COBIT

Also, we plan to briefly address links between
- DFSS
- architecture best practices such as the Architectural Tradeoff Analysis Method\textsuperscript{SM}
- engineering process areas of CMMI

And, we will continue refining the tactical views that compare CMMI and Six Sigma
Advice from an SEPG2004 Panel

Six Sigma is not just standard deviation; it is a tool box of methods for process adoption, transition, and improvement.

Six Sigma has evolved and continues to evolve. Many new players to this domain are bringing in a variety of ideas on how to refine Six Sigma and apply it to software.

Beware of those who are merely repackaging existing process improvement ideas into a Six Sigma product. Synergy is fine but repackaging can mislead the audience and actually miss out on the important principles upon which Six Sigma is built.

Summary Comments

Six Sigma is a holistic business improvement initiative that can be successfully applied to software/systems engineering and IT.

Six Sigma should be integrated with other selected models, standards, and practices into a unified approach that is appropriate for your organization.

Six Sigma enables a data-driven approach to process improvement, which in turn can accelerate the improvements and the related adoption of models and standards.

Established measurement and analysis methods support Six Sigma measurement infrastructure and root cause analysis.
Customer satisfaction is key driver

All efforts should link to business results

Contact Information

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Measurement & Analysis Initiative
jmsiviy@sei.cmu.edu
412-268-7994
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[Demery 01] Demery, Chris and Michael Sturgeon, Six Sigma and CMM Implementation at a Global Corporation, NCR, SEPG 2001

[Facemire 04] Facemire, Jeff, and Hortensia Silva, Experiences with Leveraging Six Sigma to Implement CMMI Levels 4 and 5, Northrop Grumman Mission Systems, SEPG 2004

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[Harry 00] Harry, Mikel, Six Sigma: The Breakthrough Management Strategy Revolutionizing the World’s Top Corporations, Doubleday, 2000

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[Hexasab 02] Adapted, with permission, from ‘Cause & Effect Matrix Tool Tips’ written by Sharon Gregory, Hexagon Solutions and Beyond, Inc.

[isixsigma] From http://isixsigma.com


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[SIM] News articles from http://www.stickyminds.com News Center’s 30-day rolling archive: Californians’ Direct Deposits to Bank of America listed as Missing 3/17/02, Travel Plans Torn Apart: Chase 3/20/02, Mizuho Accounts Erroneously Depited Due to ATM Malfunction 04/03/02, RMN (Royal Melbourne Institute of Technology) Software System Still Bug-Ridden 04/02/02, Computer Glitch Caused Jet Scare 03/25/02.
[Snee 01] Snee, Ronald D., Dealing with the Achilles’ Heel of Six Sigma Initiatives: Project Selection is the Key to Success, Quality Progress, March 2001
[Stoddard] Adapted, with permission, from information provided by Robert Stoddard, Motorola, Inc.

Additional Reading: SEPG2004 Panelist Picks

Lean Thinking, James P. Womack and Daniel T. Jones, Simon & Schuster, 1996
Measuring the Software Process, William A. Florac and Anita D. Carleton, Addison-Wesley, 1999
Design for Six Sigma in Technology and Product Development, C.M. Creveling et. al., Prentice Hall, 2002 (and all other books by Creveling)
Sailing Through Six Sigma - Book & CD Set, Michael Brassard and Diane Ritter, Brassard & Ritter LLC, 2002
Additional Reading 1

Six Sigma Books (not software-specific):
Breyfogle, III, Forrest W., Cupello, James M., Meadows, Becki, Managing Six Sigma, John Wiley & Sons.

Web pages & Web sites (All URLs valid as of presentation delivery date):
International Quality Federation, http://www.iqfnet.org (Follow the black belt links)
Six Sigma Academy, http://www.6-sigma.com
Smarter Solutions, http://www.smartersolutions.com
Software Engineering Information Repository: http://seir.sei.cmu.edu (Follow links to Measurement area then to Six Sigma)

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Additional Reading 3

More papers, presentations, journal articles


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Northrop Grumman’s Six Sigma Roadmap, ASQ Six Sigma Forum, http://www.sixsigmaforum.com/protection/articles/btb06/ ss aerospace_1.shtml (membership required)


Smith, Bonnie and Emily Adams, LeanSigmaSM: Advanced Quality, ASQ Annual Quality Conference, April 2001


Young, Tim, Merging Six Sigma and IT, Six Sigma Forum Magazine, February 2002

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References on statistics and analytical tools

General Statistics

Davis, Wallace III, Using Corrective Action to Make Matters Worse, Quality Progress, October 2000


Wheeler, Donald, Understanding Variation – The Key to Managing Chaos, SPC Press, 1993

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Florac, William A., and Anita D. Carleton, Measuring the Software Process, Addison-Wesley, 1999

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Lean Thinking/Business Strategies


Dettmer, William, Goldratt’s Theory of Contraints: A Systems Approach to Continuous Improvement, American Society for Quality, 1987

Bayesian Modeling

Addenda

Additional illustration

Measurement in the CMMI

Goal-driven measurement references

PSM references

Tooltips
  • management by fact
  • voice of the client
  • process mapping
  • 7 basic tools

Six Sigma Solutions for Software

Illustration – “Define”

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”

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”

- Design
  • Requirements
  • Estimate
  • Concept design
- 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

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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

![Pie chart showing removed defects fix time](image)

![Pie chart showing injected defects fix time](image)

Illustration – “Improve”

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

![Graph showing defect density](image)

![Mean comparison: defect density](image)
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: Monitoring and Control

Problem Statement

Productivity & Root Cause
- Prioritization & Root Cause
- Counter Measures & Activities
- Who
- When
- Baseline

Baseline

Goal: 21 LOC/hr

About 1/2 of goal.
In normalized terms, ~1 LOC/hr increase.

Customers A, B and C, representing x% of market share, are facing budget/cost constraints and require a 10% cost reduction in our product line XYZ in order to continue doing business with us. Baseline data shows that 33% of software development time is spent detecting and correcting defects.

Goal: 21 LOC/hr
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
Addenda

Additional illustration

Measurement in the CMMI

Goal-driven measurement references

PSM references

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Six Sigma Solutions for Software
Measurement-Related Process Areas (PAs)

- **Project Management**
  - Project Planning, Project Monitoring and Control, Software Acquisition Management
  - Integrated Project Management, Risk Management, Quantitative Project Management

- **Process Management**
  - Organization Process Focus, Organization Process Definition
  - Quantitative Project Management, Organization Process Performance, Organization Innovation and Deployment

- **Engineering**
  - Requirements Management, Verification, Validation

- **Support**
  - Measurement and Analysis, Process and Product Quality Assurance
  - Causal Analysis and Resolution

Measurement-Related Generic Practices

"Monitor and control the process against the plan and take appropriate corrective action." (GP2.8)

"Collect work products, measures, measurement results, and improvement information derived from planning and performing the process to support the future use and improvement of the organization’s processes and process assets." (GP3.2)

Two uses of measurement:
- project management
- process improvement

As the organization matures, the sophistication and uses of measurement increase.
Measurement and Analysis PA

Objectives:
- The integration of measurement and analysis activities into project processes supports the following:
  - Objective planning and estimating
  - Tracking actual performance against established plans and objectives
  - Identifying and resolving process-related issues
  - Providing a basis for incorporating measurement into additional processes in the future

Goals
- Align Measurement and Analysis Activities
- Provide Measurement Results
- Institutionalize a Managed Process
Engineering Process Areas

Addenda

Additional illustration
Measurement in the CMMI
Goal-driven measurement references
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Six Sigma Solutions for Software
Goal-Driven Measurement 1

When using goal-driven measurement, the primary question is NOT:

“What metrics should I use?”

rather, it is:

“What do I want to know or learn?”
“What decision do I want to make?”

Goal-driven measurement is NOT based on a predefined set of metrics.

Goal-Driven Measurement 2

Today:
Set business goals

Establish indicator structure & expectations

GOAL(s)

Questions

Indicators

Measures

Goals

Business => Sub-Goals => Measurement

Senior Management Team

Senior Management Team

What do I want to know or learn?

SLOC  Staff-hours  Trouble Reports  Milestone dates

definition checklist

Indicator Template

Objective Question

Infrastructure Assessment

Analysis & Diagnosis

Action Plans
Goal-Driven Measurement

**Business Goals**

- Improve customer satisfaction by reducing defects.

**Measurement Goals**

- What are our business goals?
  - Improve customer satisfaction by reducing defects.

**Questions**

- What do we want to achieve in order to satisfy our business goals?
  - Reduce post-delivery defects to “N” per thousand lines of code (KLOC)

- What questions will help us plan & manage progress toward our goal?
  - Where are defects introduced & removed?
  - How effective are peer reviews?

**Measures**

- What measures are necessary to answer these questions?
  - Defects detected in peer review, testing...

---

**Goal-Driven Software Measurement**

1. Identify your business goals
2. Identify what you want to know or learn
3. Identify your subgoals
4. Identify the entities and attributes
5. Formalize your measurement goals
6. Identify your measurement questions & indicators
7. Identify the data elements
8. Define and document measures and indicators
9. Identify the actions needed to implement your measures
10. Prepare a plan
Addenda

Additional illustration
Measurement in the CMMI
Goal-driven measurement references

PSM references

Tool tips
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Six Sigma Solutions for Software

Example of Mapping

<table>
<thead>
<tr>
<th>Software Issues - Categories - Measures Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Issue Area</td>
</tr>
<tr>
<td>Schedule &amp; Progress</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Incremental capability</td>
</tr>
</tbody>
</table>

[PSM00]
Performance Analysis Model 2

The Performance Analysis Model shows data relationships in seven common areas of concern.

Resources and cost: the balance between the work to be performed and personnel resources assigned to the project.

Schedule and progress: the completion of major milestones and individual work units.

Growth and stability: the stability of the functionality or capability required of the software.

Product quality: the ability of the delivered product to support the user's need without failure.

REF: PSM 00
[PSM00]

Performance Analysis Model 3

Technical adequacy: this relates to the viability of the proposed technical approach such as software reuse, use of COTS software components etc.

Development performance: the capability of the development team relative to project needs.

Customer satisfaction: the customer concerns with time, quality, performance and service.

REF: PSM 00
[PSM00]
Addenda

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PSM references

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• 7 basic tools

Six Sigma Solutions for Software

“Tool Tips” Outline

Reference overview (description, procedure, tips, examples) for
• Management by Fact
• Voice of the Customer
• Process Mapping
• 7 Basic Tools
• Lean

Brief highlights for
• Cause and Effect Matrix
• Quality Function Deployment
• Bayesian Modeling
• Systems Thinking
Tool Tip: Management by Fact (MBF)

Description (CMMI M&A, QPM, CAR)
- a concise summary of quantified problem statement, performance history, prioritized root causes and corresponding countermeasures for the purpose of data-driven project management

Management by Fact
- uses the facts
- eliminates bias
- tightly couples resources and effort to problem-solving

MBF: Procedure

Identify and select problem (M&A, QPM)
- use “4 Whats” to help quantify the problem statement
- quantify gap between actual and desired performance

Determine root cause (M&A, CAR)
- separate beliefs from facts
- use “7 Basic Tools”
- use “5 Whys”

Generate potential solutions and select action plan (M&A, OID)
- Must be measurable/sustainable
- Specific/assignable ownership
- Understand expected results from each action

Implement solutions and evaluate (M&A, OPP, OID)
- Compare data before and after solution
- Document actuals and side effects
- Compare with desired benchmark
### 4 Whats

**Customer satisfaction scores are too low.**

- **What is too low?**

  Compared to best-in-class benchmark of 81%, we are at 63%.

- **What is the impact of this gap?**

  It represents lost revenue and earnings potential?

- **What is the correlation between customer satisfaction and revenue?**

  Each percent of customer satisfaction translates to 0.25 percent of market share which equals $100M US revenue.

- **What is the lost potential?**

  Final problem statement:

  Customer satisfaction is 18% lower than best-in-class benchmark, which corresponds to a potential lost revenue of $1.8B US.

### 5 Whys

**The marble in the Jefferson Memorial was deteriorating.**

- **Why?**

  The deterioration was due to frequent cleanings with detergent.

- **Why?**

  The detergent was used to clean bird droppings from local sparrows.

- **Why?**

  The sparrows were attracted by spiders.

- **Why?**

  The spiders were attracted by midges.

- **Why?**

  The midges were attracted by the lights.

**Solution:** Delay turning on the lights until later at dusk.
**MBF: Format**

**FACTUAL STATEMENT OF PROBLEM, PERFORMANCE TRENDS & OBJECTIVES**

- Graph of performance over time
- Graph of supportive or more detailed information

**Prioritization & Root Cause**
- List of gaps in performance and true root cause

**Counter Measures & Activities**
- List of specific actions, who has ownership and due date

**Impact, Capability**
- List of expected benefits and impact of each countermeasure

---

**MBF: Example**

**Problem Statement**

Customers in the software engineering area of control systems are facing budget and constraint with no ability to cut the cost of software development to continue doing business with us. Baseline data shows that 20% of software development time is spent detecting and correcting defects.

**Graph of Productivity**

<table>
<thead>
<tr>
<th>Program Number</th>
<th>LOC/Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

**Graph of Change in Defect Density**

<table>
<thead>
<tr>
<th>Program</th>
<th>Defects/KLOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Improve</td>
<td></td>
</tr>
<tr>
<td>Post-Improve</td>
<td></td>
</tr>
</tbody>
</table>

**Graph of Defects Density**

- Productivity: LOC/Hour
- Change in Defect Density: Defects/KLOC
- Defects Density: Defects/KLOC

**Prioritization & Root Cause**

- High levels of defects & similar defects that are repaired in <10 minutes of any class of defects: 50% reduction in time, relative to historical data

**Counter Measures & Activities**

- Build a cause & effect diagram to be used for next round of analysis, improvement planning
- Increase correction efficiency by seeking all occurrences of a defect upon the detection of the first occurrence
- Increase and log (new) usage of off-line programs to test small pieces of functionality
- Create & Use a syntax checklist

**Impact, Capability**

- Increase and log (new) usage of off-line programs to test small pieces of functionality
- Goal is 50% reduction in time, relative to historical data
- Improve subcategory data collection to use for developing a more directed design review
- Build a cause & effect diagram to be used for next round of analysis, improvement planning

---

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Tool Tip: Voice of the Client (VOC)

Description (IPM – where customer is part of group, IPPD)
- a method to describe the stated and unstated needs or requirements of the customer
- can be captured in a variety of ways: direct discussion or interviews, surveys, focus groups, customer specifications, observation, warranty data, field reports, complaint logs, etc.

VOC: Usage

Feeds Quality Function Deployment (QFD)

Risks (track via RSKM and DAR techniques)
- anecdotal, not quantitative
- difficult to get “the right answer”
- humans are PERFECT FILTERS!
- it is very easy to induce bias in VOC

Tips
- use existing information with care – it may be biased or too narrowly focused
- always use more than one source
- customer visits allow direct discussion and observation
- customer visits allow immediate follow-up questions and unexpected lines of inquiry
VOC Interviews: Procedure 1

Define the customer.

Select customers to interview.
  • Always interview more than one.

Plan interview. (use verification & validation techniques)
  • Develop a checklist/guideline.
  • Teams of 3: “Moderator,” “Scribe,” “Observer”

Conduct interviews. (collect metrics for trend analysis)
  • Customer statements & observations need to be recorded VERBATIM.
  • Keep asking “why.”

VOC Interviews: Procedure 2

Create VOC table. (RM, RD)
  • Interpret verbatim statements into new meanings.
  • Document source of VOC or re-worked VOC.
    - “I” if internally changed or generated (by team)
    - “E” if externally generated (by customer) or not changed by team
  • Classify each statement as:
    - a real need ➔ feeds QFD
    - a technical solution
    - a feature requirement ➔ feeds QFD
    - not a true need (e.g., cost issue, complaint, technology, hopes dreams, etc.)
  • Quantify, Analyze, Prioritize
VOC: Example Table

New process initiative under consideration
• interview statements recorded verbatim and classified
• column added for keyword sorting

Further development
• “interpreted” comments about the organization’s true
goals, the overlap of initiatives (and so on)
• evaluation for common themes
• additional data collection may be needed

<table>
<thead>
<tr>
<th>Customer comment</th>
<th>Interpreted, reworded</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>We are already at maturity level x, so why do more?</td>
<td>E ✓ ✓</td>
<td>competing initiatives</td>
</tr>
</tbody>
</table>

VOC: Analysis

<table>
<thead>
<tr>
<th>Prioritization Method</th>
<th>Customer Time</th>
<th>Preparation Complexity</th>
<th>Analysis Complexity</th>
<th>Quality of Resulting Prioritization</th>
<th>Number of customers needed</th>
<th>Number of Needs to Prioritize</th>
<th>Recommend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of Response</td>
<td>short</td>
<td>low</td>
<td>low</td>
<td>low</td>
<td>large</td>
<td>large</td>
<td>NO</td>
</tr>
<tr>
<td>Constant Sum</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
<td>medium</td>
<td>small</td>
<td>Yes</td>
</tr>
<tr>
<td>Rating</td>
<td>short</td>
<td>low</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
<td>med-large</td>
<td>Yes</td>
</tr>
<tr>
<td>Simple Ranking</td>
<td>medium</td>
<td>low</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
<td>small-med</td>
<td>Yes</td>
</tr>
<tr>
<td>Q-Sort</td>
<td>short</td>
<td>low</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
<td>large</td>
<td>Yes</td>
</tr>
<tr>
<td>Paired Comparison</td>
<td>long</td>
<td>medium</td>
<td>high</td>
<td>high</td>
<td>large</td>
<td>small</td>
<td>Yes</td>
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<tr>
<td>Regression</td>
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<td>medium</td>
<td>high</td>
<td>high</td>
<td>large</td>
<td>small-med</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Tool Tip: Process Mapping

Description
- representation of major activities/tasks, subprocesses, process boundaries, key process inputs, and outputs

INPUTS
(Sources of Variation)
- People
- Material
- Equipment
- Policies
- Procedures
- Methods
- Environment
- Information

PROCESS STEP
A blending of inputs to achieve the desired outputs

OUTPUTS
(Measures of Performance)
- Perform a service
- Produce a Product
- Complete a Task

Mapping: Usage

Feeds other tools (OID, OPP, CAR)
- Cause and Effects Matrix
- Failure Modes and Effects Analysis (FMEA)
- Control Plan Summary
- DOE planning

Tips for mapping current processes (OPP)
- Go to the actual place where the process is performed.
- Talk to the actual people involved in the process and get the real facts.
- Observe and chart the actual process.
- Consider creating “as is” and then “to be” maps.

Reality is invariably different from perception - few processes work the way we think they do!
**Mapping: Terms**

**Controllable Inputs**: Key Process Input Variables (KPIVs) that can be changed to see the effect on Key Process Output Variables (KPOVs). Sometimes called “Knob” Variables.

**Critical Inputs**: KPIV’s that have been statistically shown to have a major impact on the variability of the KPOVs.

**Noise Inputs**: Input variables that impact the KPOVs but are difficult or impossible to control. Example: Environmental variables such as humidity, ambient temperature, etc.

**Standard Operating Procedures**: A standard procedure for running the process.

---

**Mapping: Example**

*Inspection process from earlier illustration*

- **Plan**
  - Artifacts to inspect
    - Artifact size
    - Reviewers
    - Data repository

- **Detect Defects**
  - Review Rate
  - Checklists
  - Inspection method, procedure
  - Proficiency
  - Taxonomy interpretations

- **Troubleshoot**
  - What would you list?
  - Defect Log
  - Record of plan
  - Direct Cause
  - Root Cause
  - Corrective Action

- **Correct Defects**
  - What would you list?
  - Critical Inputs
  - Noise
  - Standard Procedure
  - Control Knobs
  - Inspection
  - Rework
Mapping Variation: Value Map

Identify the process to map.
Identify the boundaries.
Create input-process-output for the critical processes.
Create the process map.
Color code each step identifying value.
• green = value added
• red = non value added
• yellow = non value added but necessary
Identify hand-off points, queues, storage, and rework loops in the process.
Quantitatively measure the map (throughput, cycle time, and cost).
Validate map with process owners.

Value Mapping: Example

*Initial Assessment will:
• Determine Impact Assessment
• Identify Stakeholder
• Coordinate with Product/Process Owner
• Perform Impact Analysis
Process Map Practice

Complete the inspection process map presented in this “tool tip.”

Or, create a new inspection process map based on your experience.

Tool Tip: 7 Basic Tools

Description

- Fundamental data plotting and diagramming tools
  - Cause & Effect Diagram
  - Histogram
  - Scatter Plot
  - Run Chart
  - Flow Chart
  - Brainstorming
  - Pareto Chart

- The list varies with source. Alternatives include
  - Statistical Process Control Charts
  - Descriptive Statistics (mean, median and so on)
  - Check Sheets
7 Basic Tools: Usage

PLOT, PLOT, PLOT!
• use these tools to describe the process
• expand and extend the charts as needed

Used throughout Six Sigma projects and within many other tools:
• MBF
• troubleshooting as a result of “out of control” point

Many accomplishments are built on these tools **alone**.

Handy resource: “The Memory Jogger”

[Memory Jogger: http://www.goalqpc.com]
7 Basic Tools: Cause & Effect

[Diagram showing cause and effect relationships with nodes such as Management, People, Environment, Software not required reliability, and methods.

Variation

[Box & Whisker Plot for assessment data with mean, 90th percentile, 75th percentile, median, 50th percentile, 25th percentile, and 10th percentile shown on the chart.

7 Basic Tools: Chart Variations

Box & Whisker Plot for assessment data

[Box & Whisker Plot for CMMI Benchmark SEI Level 3 with various metrics and data points.

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Tool Tip: Lean

“An organization working together to make continuous improvements without large capital investment”

Purpose
• brings the right people together to understand the process and make immediate improvements to the process.
• evaluates opportunities to reduce cycle time, cost, inventory and eliminate all waste.

Lean: Terms & Usage

Kaizen - Make people's jobs easier by taking them apart, studying them, and making improvements.
• “KAI” - take apart and make anew
• “ZEN” - think, make good the actions of others, do good deeds and help others

Kaizen tips (VAL, M&A, QPM, CAR, OPP)
• Get rid of old assumptions.
• Look for ways to make things happen now.
• Say “NO” to the status quo.
• Don’t worry about being perfect.
• It doesn’t have to cost money.
• If something's wrong, fix it on the spot.
• Ask “WHY” five times to get to the root cause.
• Look for wisdom from many people rather than one.
• Never stop improving.
• Full-time participation of team members.
• Keep all affected employees informed of changes.
Lean: Six Sigma Representation

<table>
<thead>
<tr>
<th># of Parts (Steps)</th>
<th>±3σ</th>
<th>±4σ</th>
<th>±5σ</th>
<th>±6σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>93.32%</td>
<td>99.37%</td>
<td>99.97%</td>
<td>99.9996%</td>
</tr>
<tr>
<td>7</td>
<td>91.63%</td>
<td>95.73%</td>
<td>99.83%</td>
<td>99.97%</td>
</tr>
<tr>
<td>10</td>
<td>90.08%</td>
<td>93.96%</td>
<td>99.66%</td>
<td>99.96%</td>
</tr>
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<td>99.42%</td>
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<td>89.52%</td>
<td>99.9992%</td>
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<td>85.54%</td>
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<tr>
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<td>79.43%</td>
<td>99.9999%</td>
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<td>69.90%</td>
<td>50.36%</td>
<td>73.21%</td>
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</tr>
<tr>
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<td>53.72%</td>
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<td>12.59%</td>
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<tr>
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<td>6.68%</td>
<td>99.9999%</td>
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<td>1700</td>
<td>23.90%</td>
<td>0.00%</td>
<td>0.51%</td>
<td>99.9999%</td>
</tr>
</tbody>
</table>

Lean: Kaizen Procedure

Top Mgmt Kick-off of event
Determine Team Objectives and Goals
Lean/Six Sigma Training
Map as-is Process
Identify Waste in the process
Use root cause analysis to evaluate issues
Brainstorm solutions
Evaluate the solutions against the objectives
Report to Sponsor
Implement validated solutions to improve the process
Standardize: Map the to-be / improved process
Report to Sponsor
Lean: Staffing Analysis Example 1

"As Is" Logical Process Map

[LMCO 02]

Lean: Staffing Analysis Example 2

"To be" Logical Process Map

[LMCO 02]
Lean: Staffing Analysis Example

Time Value Map:
As Is = 19 hours

Time Value Map:
To Be = 7 hours

Legend
R = Request
Q = Query
S = Select data
T = Test Report
A = Analysis
F = Format
P = Pivot table
D = Deliver
* = Variable wait time

63% reduction in cycle time

Legend
R = Request
Q = Query
S = Select data
T = Test Report
A = Analysis
F = Format
P = Pivot table
D = Deliver
* = Variable wait time

Additional Analytical Tools

Quality Function Deployment (RM, RD)
• designs what customers REALLY want
• prevents designing unnecessary product features

Bayesian Modeling (VER, VAL, PI)
• alternative to classical regression-based models
• accounts for prior knowledge and likelihood
• network diagrams show cause & effect relationships

Systems Thinking (TS, DAR, M&A, QPM, OPP)
• for chronic, describable, important problems with previous unsuccessful attempts to solve
• several tools to map and understand process

See Addendum for additional information about selected tools.
Addenda

Additional illustration
Measurement in the CMMI
Goal-driven measurement references
PSM references
Tooltips
• management by fact
• voice of the client
• process mapping
• 7 basic tools

Six Sigma Solutions for Software
Motorola Six Sigma Solutions for SW

Six Sigma Solutions for Software

- Reverse Engineering
- Analysis and Effecting Changes
- Code Metrics
- Code Optimization
- Data and Control Flow Analysis
- Auto Code Generation
- Traceability
- Metrics
- Fault & Success Trees
- Polka
- Technical Risk Analysis
- Begin Robust Design planning
- Performance Engineering
- Software "ilities" defined and planned
- Mistake proofing process and product

Motorola Six Sigma Solutions for SW

Six Sigma Solutions for Software

- Marketing
- Systems
- Req’s
- Design
- Code
- Test
- Maint
- Engr
- Engr

- Metrics
- Design for Reuse
- Evaluation of Design Attributes
- Design Robustness
- Error-handling and error degradation
- Usability and Human Reliability Engr
- Behavioral Analysis
- Designed Experiments
- Traceability
- Memory
- Throughput
- Auto Code Generation
- Reverse Engineering
- Timing

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- Error-handling and error degradation
- Usability and Human Reliability Engr
- Behavioral Analysis
- Designed Experiments
- Traceability
- Memory
- Throughput
- Auto Code Generation
- Reverse Engineering
- Timing
Motorola Six Sigma Solutions for SW

Across the entire software lifecycle

- Field Data Analysis
- Customer Satisfaction Data
- Reverse Engineering
- Impact and Change Analysis
- Modeling and Planning Maintenance
- Empirical Investigations

- Product Risk Analysis
- Reverse Engineering
- Various models

- Software Maintainability Measures
- Product Risk Analysis
- Reverse Engineering
- Impact and Change Analysis
- Modeling and Planning Maintenance
- Empirical Investigations

6th ASQ Annual Quality Congress
Six Sigma Solutions for Software

- Marketing Systems
- Req's Design Code Test Maint

- Engr

- Engr

- Problem-solving and root cause methods
- Analysis of process performance
- Correlation of software process and product attributes (leading indicators)
- Project Mgt Forecasting
- Quality Analysis
- Managing Org Change
- Good Enough Software

- Principal Component Analysis
- PERT & Critical Chain
- Pareto

- Fishbone Diagrams
- Project Mgt Forecasting
- Quality Analysis
- Managing Org Change
- Good Enough Software

- Uncertainty Modeling
- Learning Organization

- PERT & Critical Chain
- Pareto

- Fishbone Diagrams
- Project Mgt Forecasting
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Stoddard 02

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