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Six Sigma Tools for Early Adopters

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The final version of our slides is available at
http://www.sei.cmu.edu/sema/presentations
(cards with this web address are available at the front of the room)

Background

Six Sigma has proven to be a powerful enabler for process improvement

- CMMI adoption
- Process improvement for measurable ROI
- Statistical analysis

This tutorial is about gleaning value from the Six Sigma world, to raise the caliber of engineering, regardless of the corporate stance on Six Sigma

Agenda

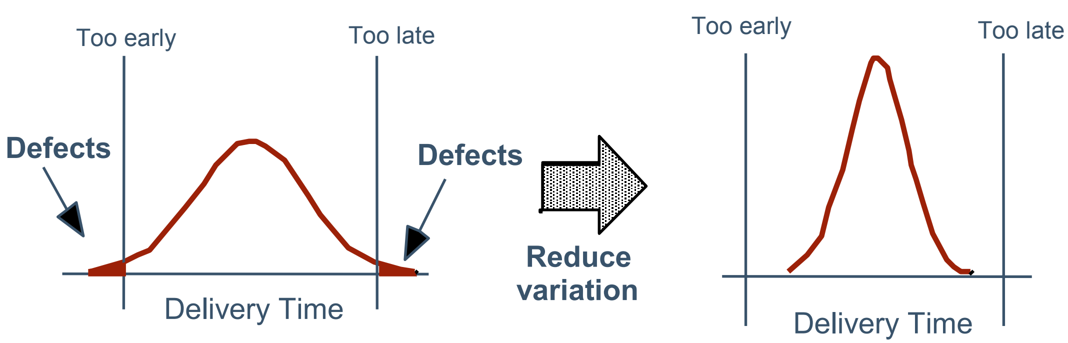
- Six Sigma Benefits for Early Adopters – What the Books Don't Tell You
- The 7 Six Sigma Tools Everyone Can Use
- I Hear Voices
- Dirty Data (and How to Fix It)
- Statistical Process Control – Where Does It Apply to Engineering?
- Convincing Senior Management: The Value Proposition
- Summary
- Cheap Sources of Information and Tools
- MSE Addendum

What is Six Sigma?

Six Sigma is a management philosophy based on meeting business objectives by reducing variation

- A disciplined, data-driven methodology for decision making and process improvement

To increase process performance, you have to decrease variation



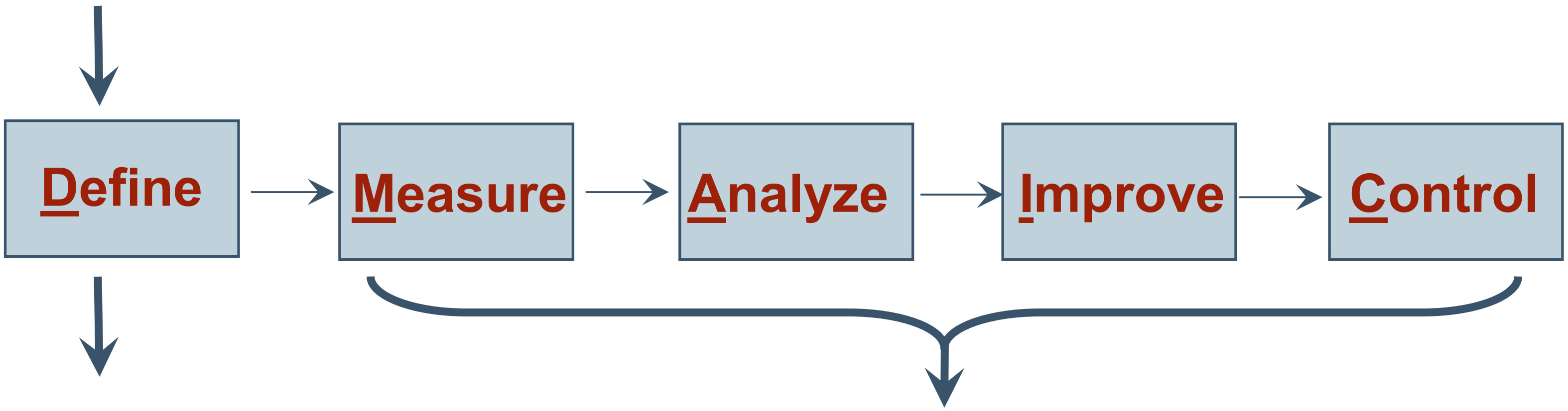
Spread of variation too wide compared to specifications

Spread of variation narrow compared to specifications

- Greater predictability in the process
- Less waste and rework, which lowers costs
- Products and services that perform better and last longer
- Happier customers

A General Purpose Problem-Solving Methodology: DMAIC

Problem or goal statement (Y)



- Refine problem & goal statements.
- Define project scope & boundaries.

- An improvement journey to achieve goals and resolve problems by discovering and understanding relationships between process inputs and outputs, such as
  Y = f(defect profile, yield)
  = f(review rate, method, complexity……)

DMAIC Roadmap

Define → **Measure** → **Analyze** → **Improve** → **Control**

Define	Measure	Analyze	Improve	Control
Define project scope	Identify needed data	Explore data	Identify possible solutions	Define control method
Establish formal project	Obtain data set	Characterize process & problem	Select solution	Implement
	Evaluate data quality	Update improvement project scope & scale	Implement (pilot as needed)	Document
	Summarize & baseline data		Evaluate	

Phase Exit Review

[Hallowell-Siviy 05]

Toolkit

Define	Measure	Analyze	Improve	Control
Benchmark Contract/Charter **Kano Model** Voice of the Customer **Voice of the Business** Quality Function Deployment	GQIM and Indicator Templates Data Collection Methods **Measurement System Evaluation**	**Cause & Effect Diagrams/ Matrix** **Failure Modes & Effects Analysis** **Statistical Inference** Reliability Analysis **Root Cause Analysis, including 5 Whys** **Hypothesis Test**	Design of Experiments Modeling ANOVA Tolerancing Robust Design Systems Thinking Decision & Risk Analysis **PSM Perform Analysis Model**	Statistical Controls: • **Control Charts** • Time Series methods Non-Statistical Controls: • Procedural adherence • Performance Mgmt • Preventive measures

7 Basic Tools (**Histogram, Scatter Plot, Run Chart**, Flow Chart, Brainstorming, **Pareto Chart**), **Control charts** (for diagnostic purposes), **Baseline**, Process Flow Map, Project Management, **"Management by Fact", Sampling Techniques**, Survey Methods, **Defect Metrics**

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Process Improvement – Design for Six Sigma (e.g., DMADV)

Define → **Measure** → **Analyze** → **Design** → **Verify**

Define
- Define project scope
- Establish formal project

Measure
- Identify customers
- Research VOC
- Benchmark
- Quantify CTQs

Analyze
- Explore data
- Design solution
- Predict performance

Design
- Develop detailed design
- Refine predicted performance
- Develop pilot

Verify
- Evaluate pilot
- Scale-up design
- Document

Organizational Adoption: Roles & Responsibilities

Champions – Facilitate the leadership, implementation, and deployment

Sponsors – Provide resources

Process Owners – Responsible for the processes being improved

Master Black Belts – Serve as mentors for Black Belts

Black Belts – Lead Six Sigma projects

- Requires 4 weeks of training

Green Belts – Serve on improvement teams under a Black Belt

- Requires 2 weeks of training

Valuable Tools for Engineers

Six Sigma provides a comprehensive set of tools for:

- Soliciting and understanding customer needs (requirements, delighters, perceptions of quality)
- Defining and improving processes (inputs/outputs, customer/suppliers, essential/nonessential activities, capability, stability/predictability)
- Understanding data (trends, relationships, variation)

These tools can be used even if your organization is not implementing Six Sigma

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➡ The 7 Six Sigma Tools Everyone Can Use

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Measure Guidance Questions

Define → Measure | Analyze → Improve → Control

Define project scope

Establish formal project

Identify needed data

Obtain data set

Evaluate data quality

Summarize & baseline data

- What are the process outputs and performance measures?
- What are the process inputs?
- What info is needed to understand relationships between inputs and outputs? Among inputs?
- What information is needed to monitor the progress of this improvement project?

[MPDI]

Identifying Needed Data

What are the process outputs and performance measures?
What are the inputs?
What are the relationships among outputs and inputs?

We need to find out what contributes to performance:

- What are the process outputs (y's) that drive performance?
- What are key process inputs (x's) that drive outputs and overall performance?

Techniques to address these questions

- segmentation / stratification
- input and output analysis
- Y to x trees
- cause & effect diagrams

Using these techniques yields a list of relevant, hypothesized, process factors to measure and evaluate.

[MPDI]

Controlled and Uncontrolled Factors

Controlled factors are within the project team's **scope of authority** and are **accessed** during the course of the project.

Studying their influence may inform:

- cause-and-effect work during *Analyze*
- solution work during *Improve*
- monitor and control work during *Control*

Uncontrolled factors are factors we do not or cannot control.

We need to acknowledge their presence and, if necessary, characterize their influence on Y.

A robust process is insensitive to the influence of uncontrollable factors.

[MPDI]

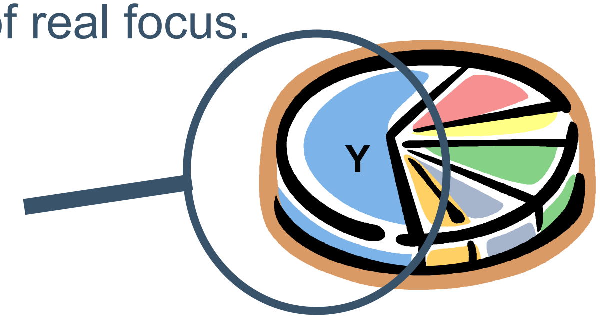
Natural Segmentation

Description

A logical reasoning about which data groupings have different performance, often verified by basic descriptive statistics.

Procedure

- Consider what factors, groupings, segments, and situations may be *driving the mean performance and the variation in Y.*
- Draw a vertical tree diagram, continually reconsidering this question to a degree of detail that makes sense.
- Calculate **basic descriptive statistics**, where available and appropriate, to identify areas worthy of real focus.



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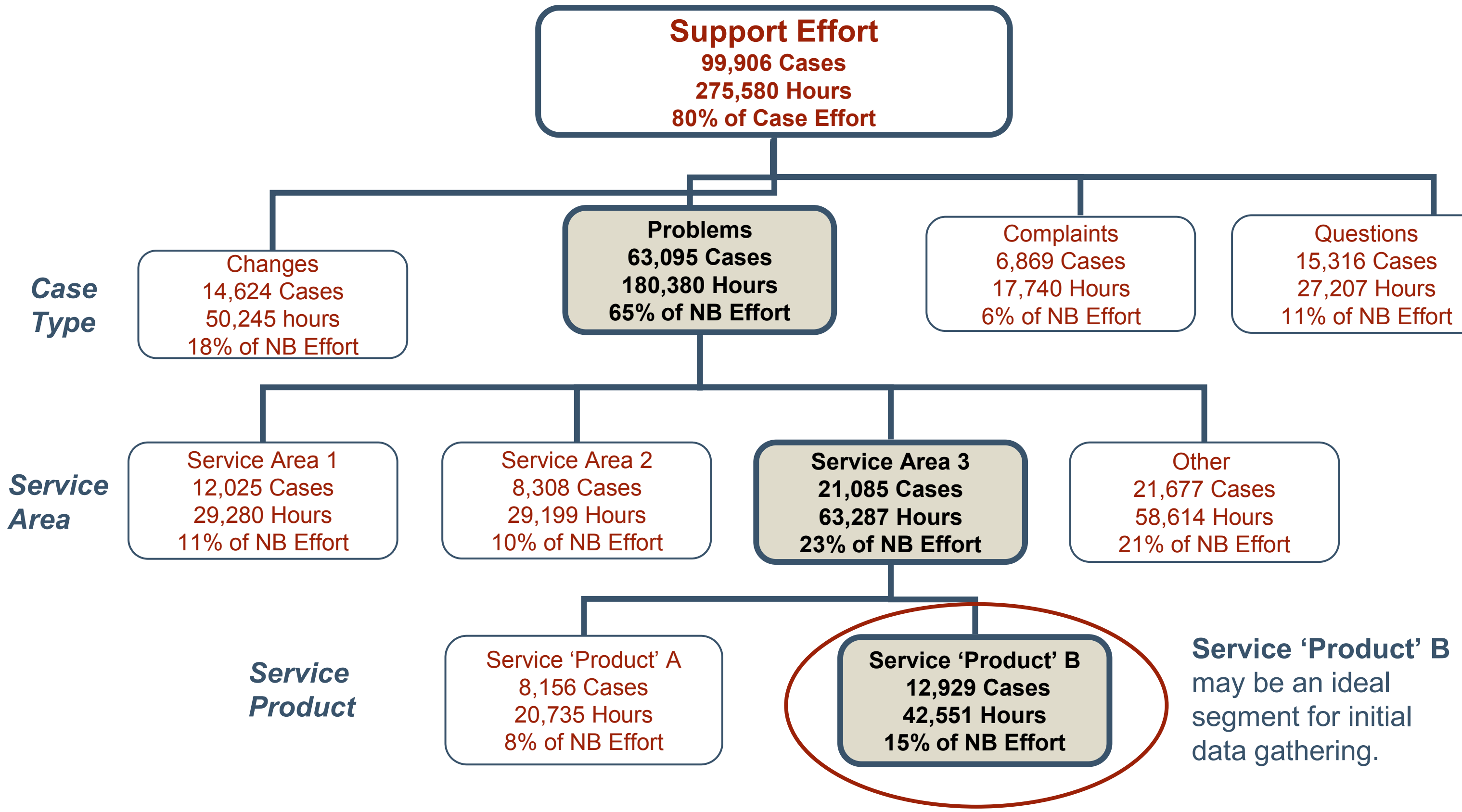
Segmentation Example

Call Center Support Costs



NB = Non-billable

Segmentation vs. Stratification

Segmentation—

- grouping the data according to one of the data elements (e.g., day of week, call type, region, etc.)
- gives discrete categories
- in general we focus on the largest, most expensive, best/worst – guides “where to look”

Stratification—

- grouping the data according to the value range of one of the data elements (e.g., all records for days with “high” volume vs. all records with “low” volume days)
- choice of ranges is a matter of judgment
- enables comparison of attributes associated with “high” and “low” groups—what’s different about these groups?
- guides diagnosis

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Process Mapping

Process map—a 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

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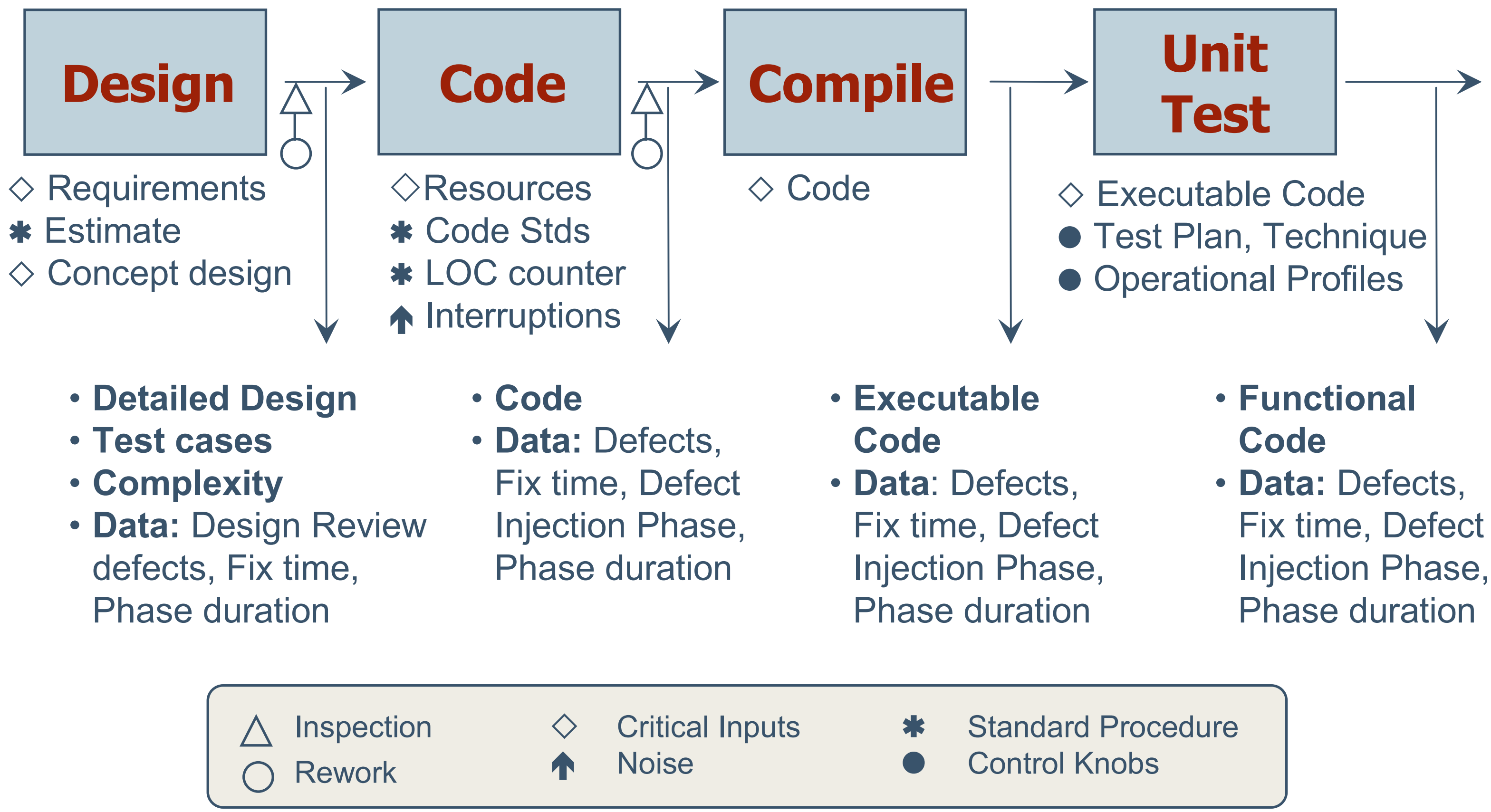
Example: Development Process Map



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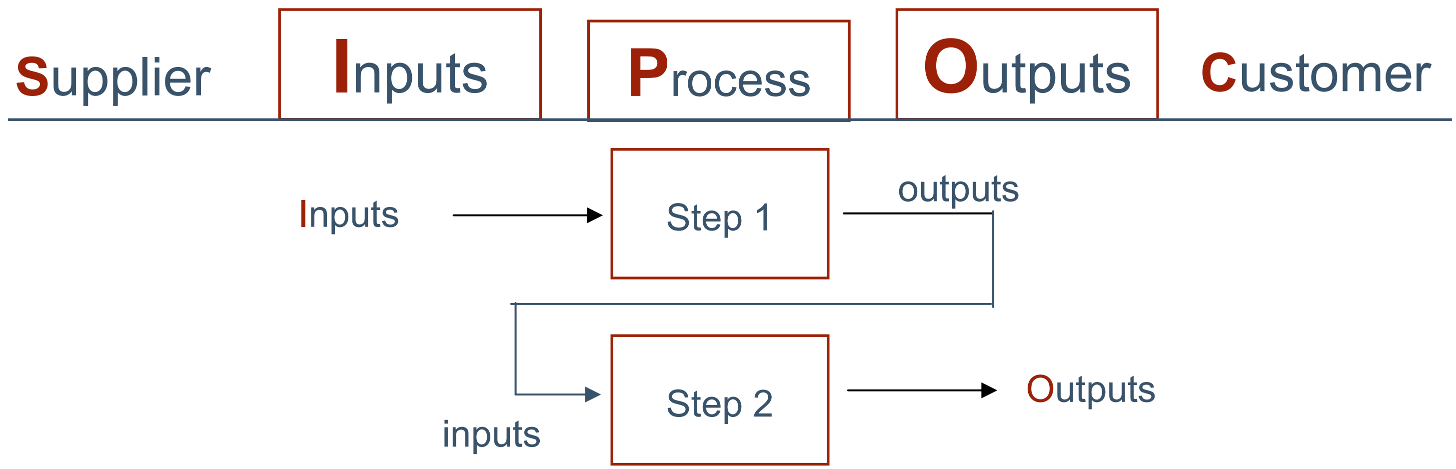
Input / Output Analysis



Assess the Inputs:

- Controllable: can be changed to see effect on key outputs (also called “knob” variables)
- Critical: statistically shown to have impact on key outputs
- Noise: impact key outputs, but difficult to control

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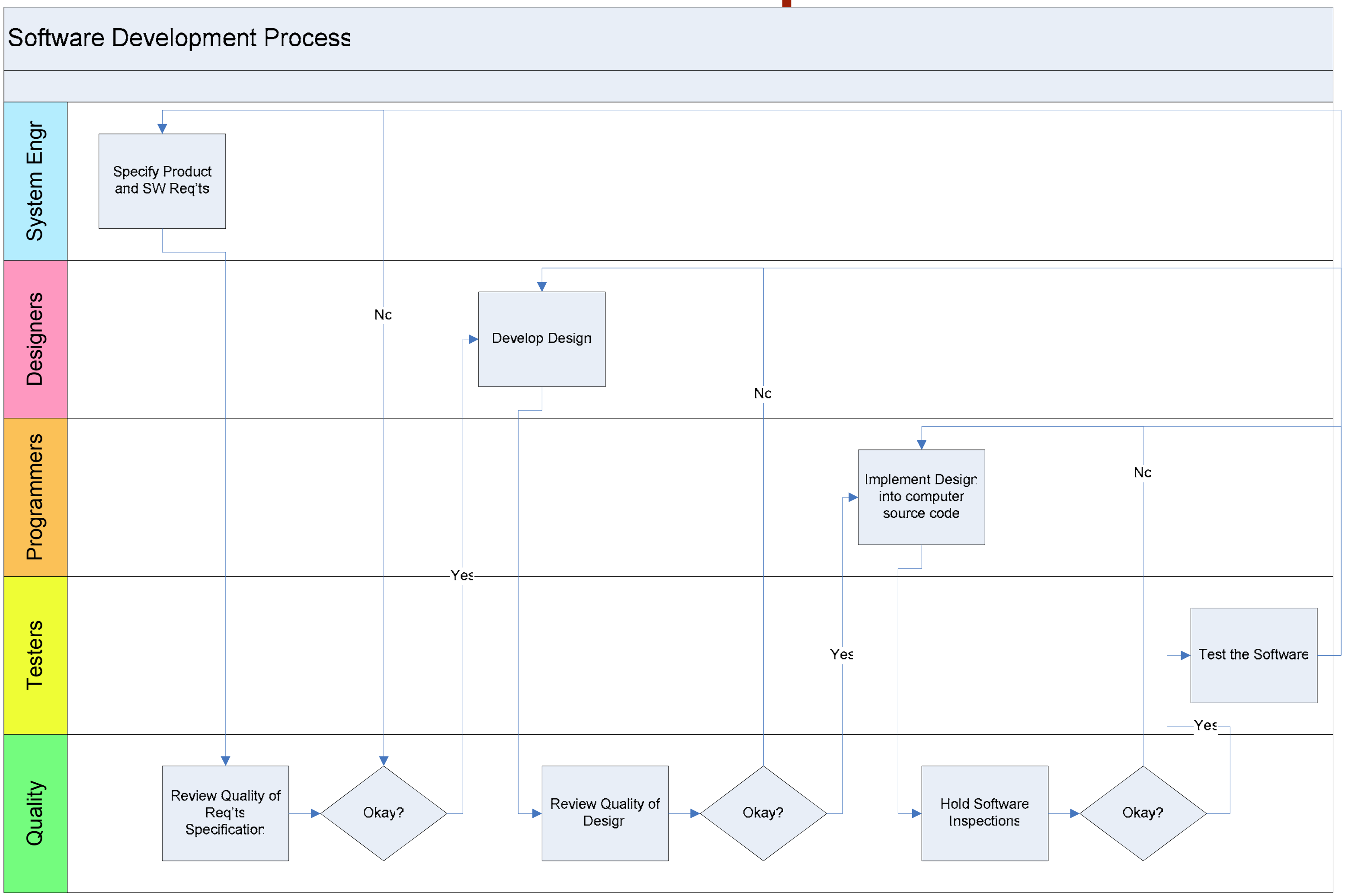
Alternative Process Map—Swim Lanes



Measure Guidance Questions

Define → **Measure** Analyze → Improve → Control

Define	Measure
Define project scope	**Identify needed data**
Establish formal project	**Obtain data set**
	Evaluate data quality
	Summarize & baseline data

- What does the data look like upon initial assessment? Is it what we expected?
- What is the overall performance of the process?
- Do we have measures for all significant factors, as best we know them?
- Are there data to be added to the process map?
- Are any urgently needed improvements revealed?
- What assumptions have been made about the process and data?

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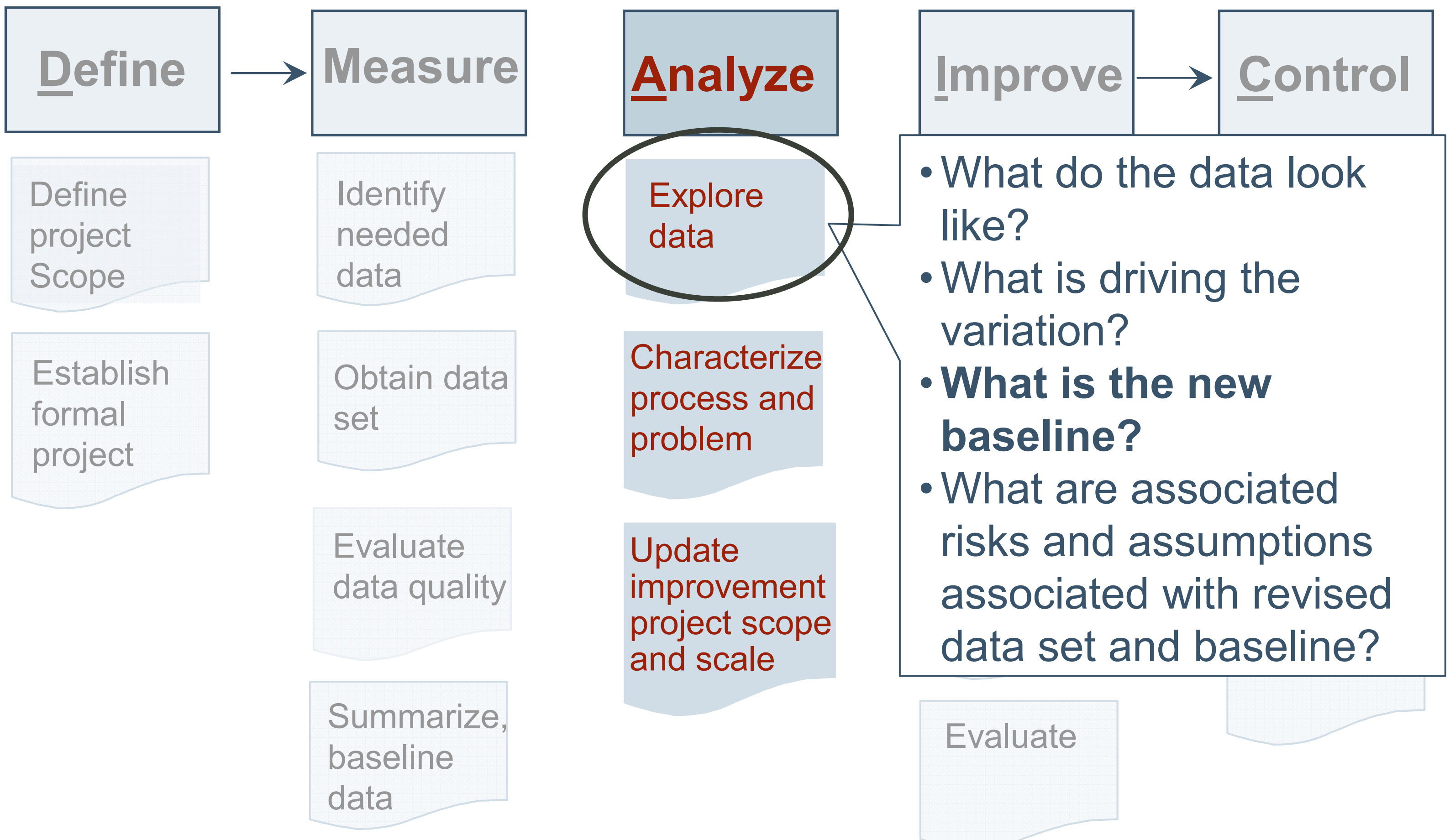
Analyze Guidance Questions



- What do the data look like?
- What is driving the variation?
- **What is the new baseline?**
- What are associated risks and assumptions associated with revised data set and baseline?

Summarizing & Baselining the Data

What is baselining?

Establishing a snapshot of performance (distribution of the process behavior) and/or the characteristics of a process.

Why should we baseline performance?

It provides a basis by which to measure improvement.

How is it done?

- Describe the organization's performance using
  - the 7 basic tools
  - a map of the process of interest, including scope (process boundaries) and timeframe
- Compare to best-in-class
  - benchmarking
- Gather data
  - sample appropriately

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The 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, etc.)
  - check sheets

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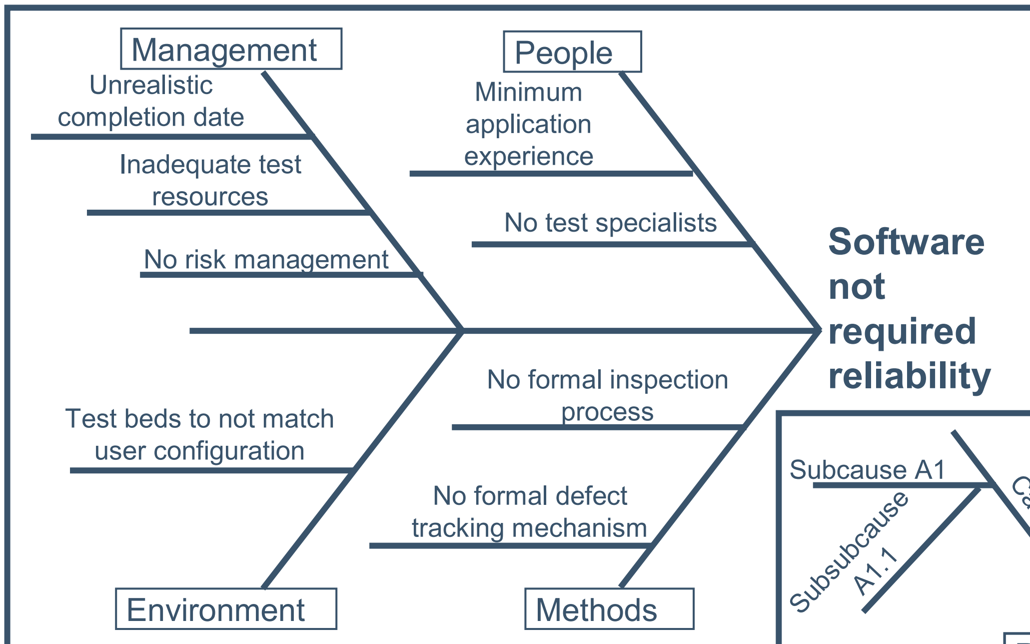
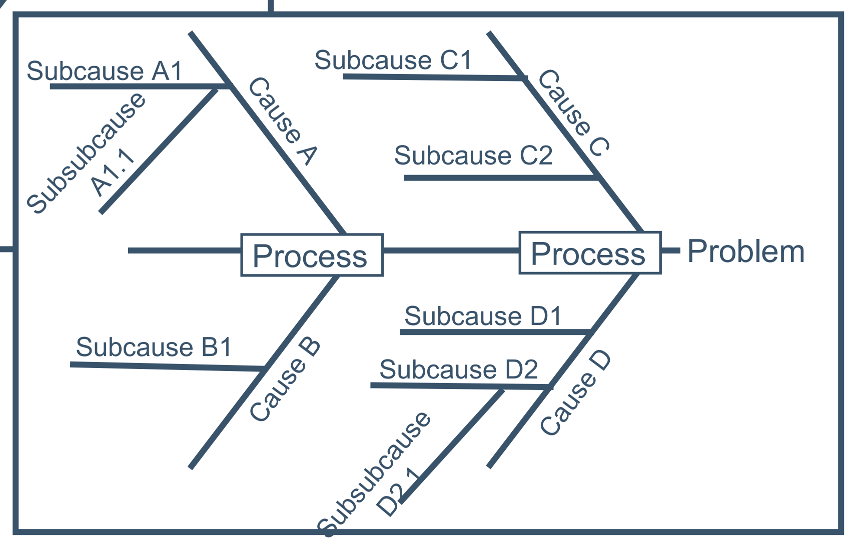
7 Basic Tools: Cause & Effect



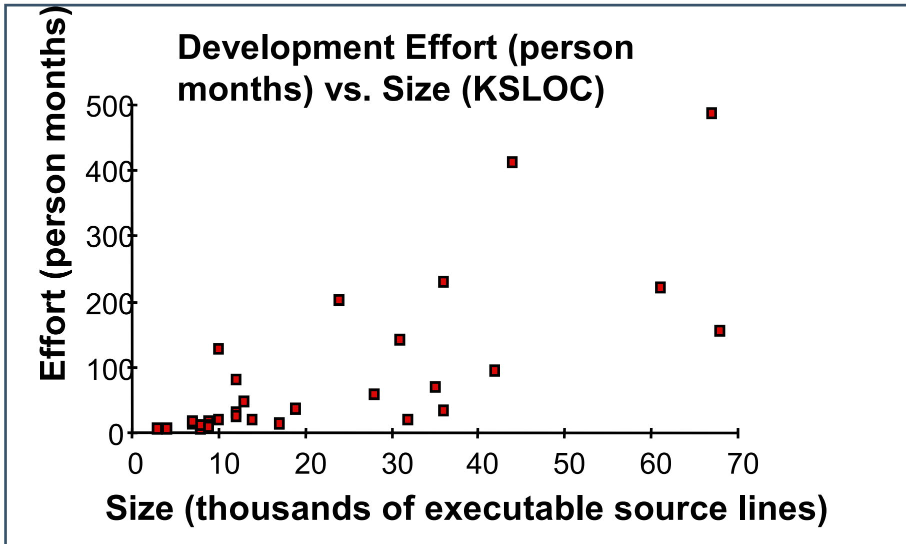
Traditional diagram



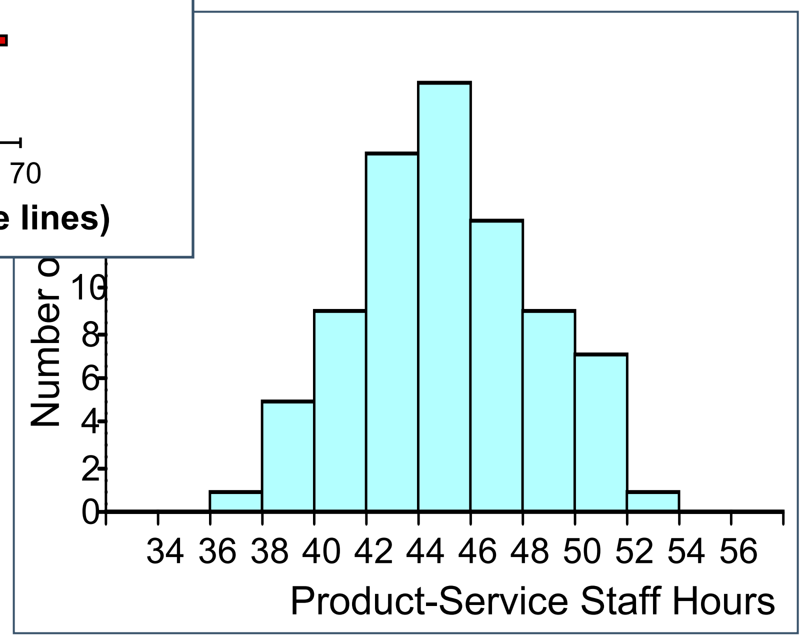
Variation

[MPDI; original source: Westfall]

7 Basic Tools: Chart Examples 2



Scatter Plot



Histogram

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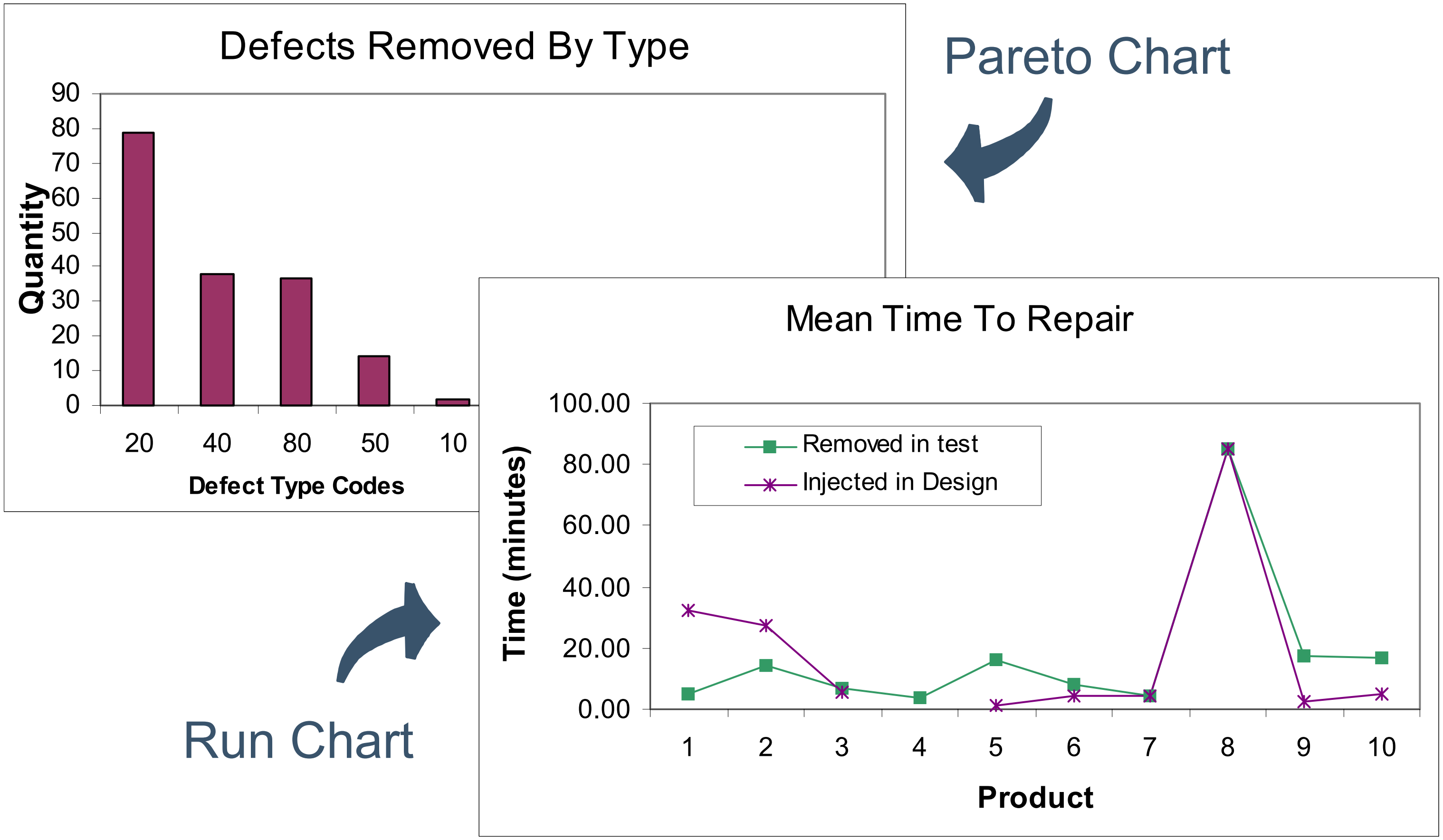
7 Basic Tools: Chart Examples



Pareto Chart

Run Chart

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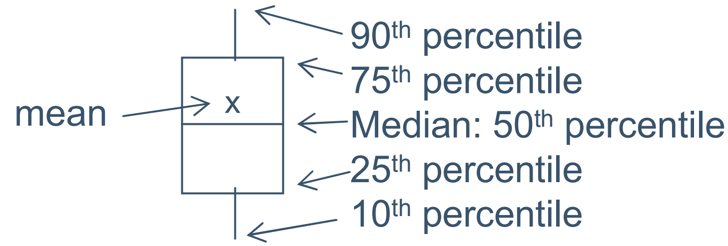
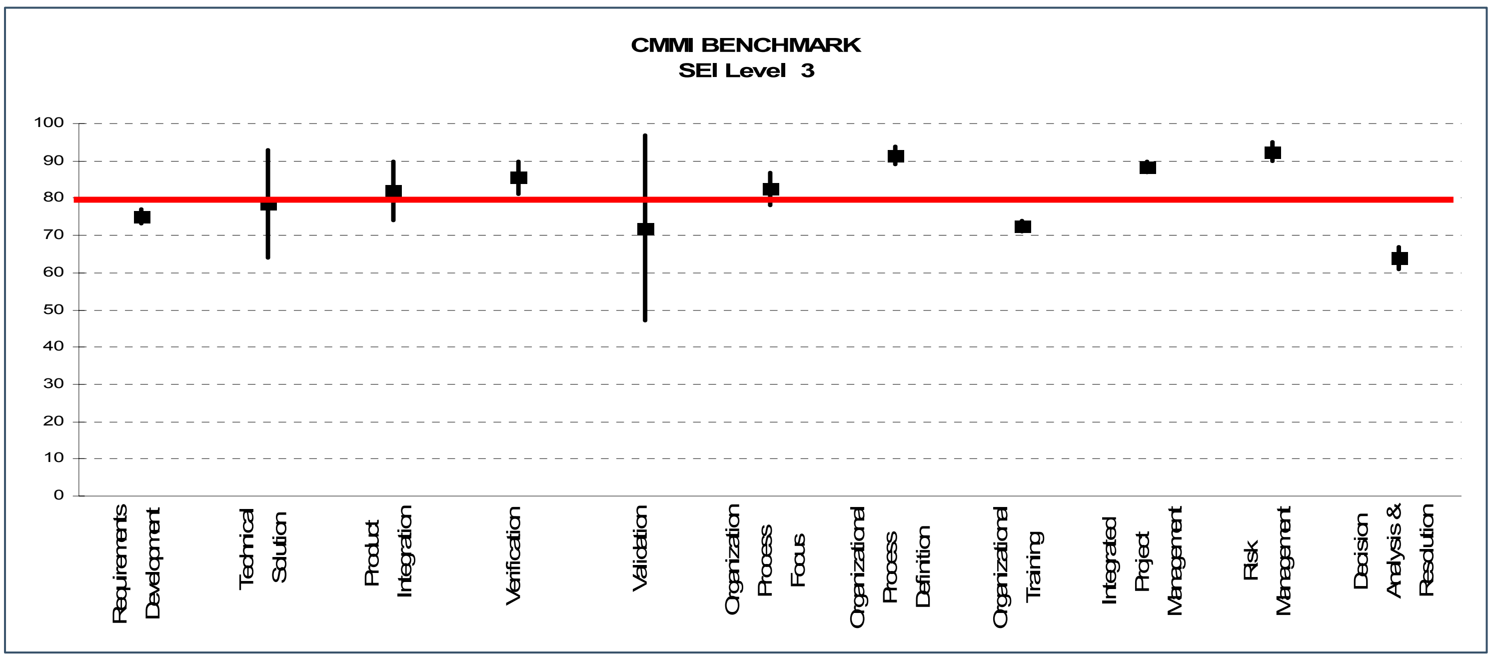
7 Basic Tools: Chart Examples

Box & whisker plot

for assessment data

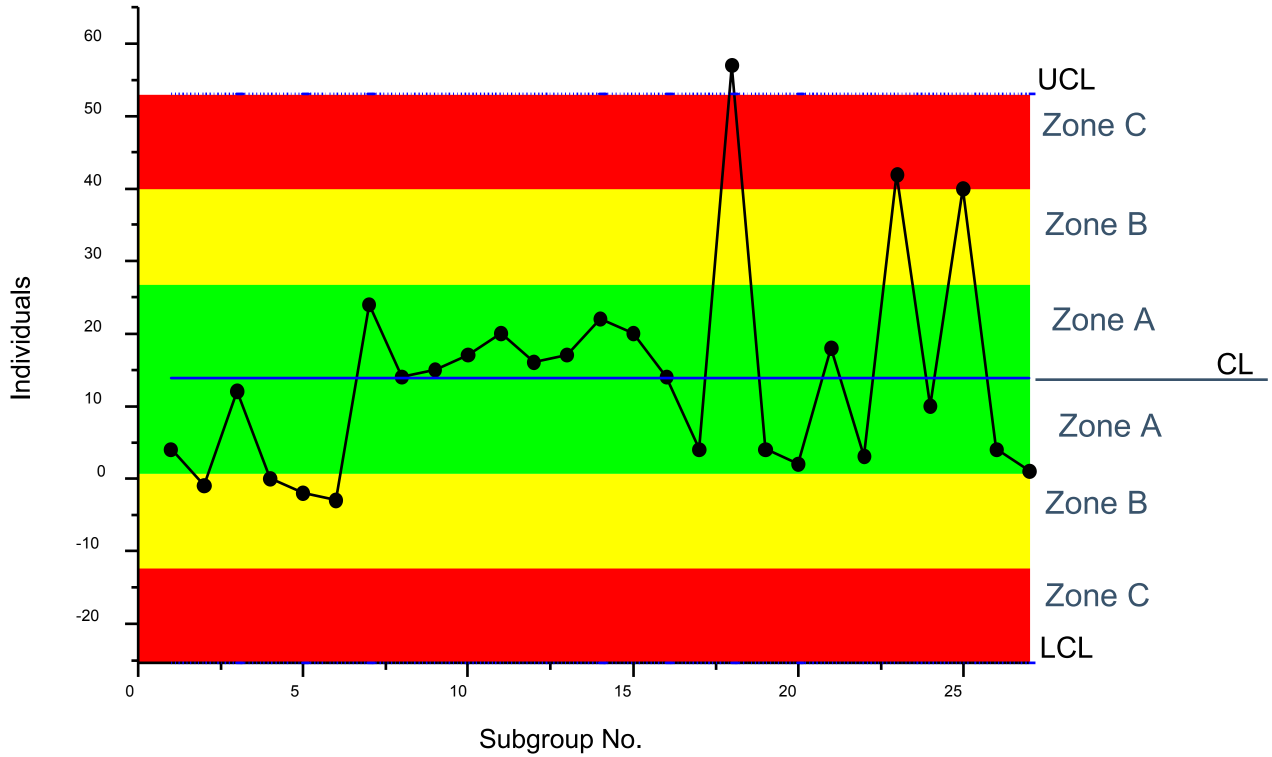




[MPDI]

7 Basic Tools: Chart Examples

SPC Chart: Individual, Moving Range



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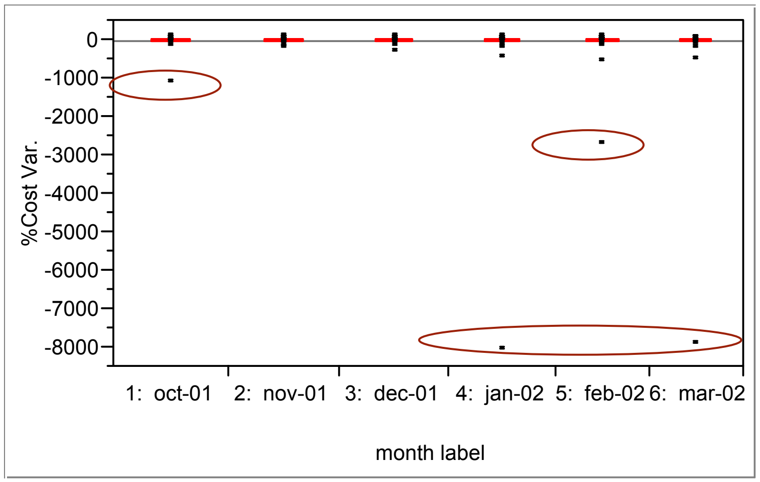
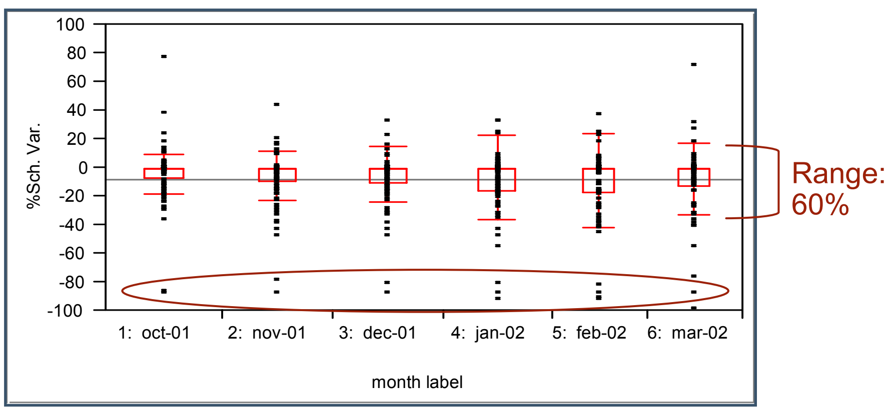
Example: Cost/Schedule Monthly Performance Baseline





All Org Units, all projects, October to March

- Reminder: This is (current actual – most recent estimate)
- Averages within spec, and close to 0
- Need to examine extreme values, especially for cost
- Even if extreme values are outliers, it looks like we need to investigate variability

[MPDI]

Descriptive Statistics

Measures of **central tendency**: location, middle, the balance point.

Mean = (the average) $\frac{\text{sum of n measured values}}{\text{n}}$ $= \frac{10486.3}{46} = 227.9$ *(the center of gravity by value)*

Median = the midpoint by count

Mode = the most frequently observed point

Measures of **dispersion**: spread, variation, distance from central tendency.

Range maximum - minimum

σ^2 $$\text{Variance} = \frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n}$$ *Average squared distance from the population mean*

σ $$\text{Standard Deviation} = \sqrt{\text{Variance}}$$ *In the units of the original measures; indicator of the spread of points from the mean*

Graphical Methods Summary

Purpose	Graphical Method
See Relationships in Data	***Scatter plot***
See Time Relationships	***Time series run chart***
See Variation of Y with 1 X	***Box Plot chart***
See Variation of Y w/2^{+} X's	***Multi-variable chart***
Prioritize 2^{+} X's to focus on	***Pareto chart***
Check Normality of Data	***Normal plot***
Predict relationships in Data	***Regression Predicted Line***

[MPDI]

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➡ I Hear Voices

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MSE Addendum

The Voices of Six Sigma

Six Sigma includes powerful techniques for understanding the problem you are trying to solve

- Voice of Customer
- Voice of Process
- Voice of Business

These techniques are useful in non-Six Sigma settings for understanding:

- Customer requirements and needs
- Process performance and capability
- Business priorities and trends

Voice of Customer (VOC)

A process used to capture the requirements/feedback from the customer (internal or external)

- Proactive and continuous
- Stated and unstated needs
- “Critical to Quality (CTQ)”- What does the customer think are the critical attributes of quality?

Approaches:

- Customer specifications
- Interviews, surveys, focus groups
- Prototypes
- Bug reports, complaint logs, etc.
- House of Quality

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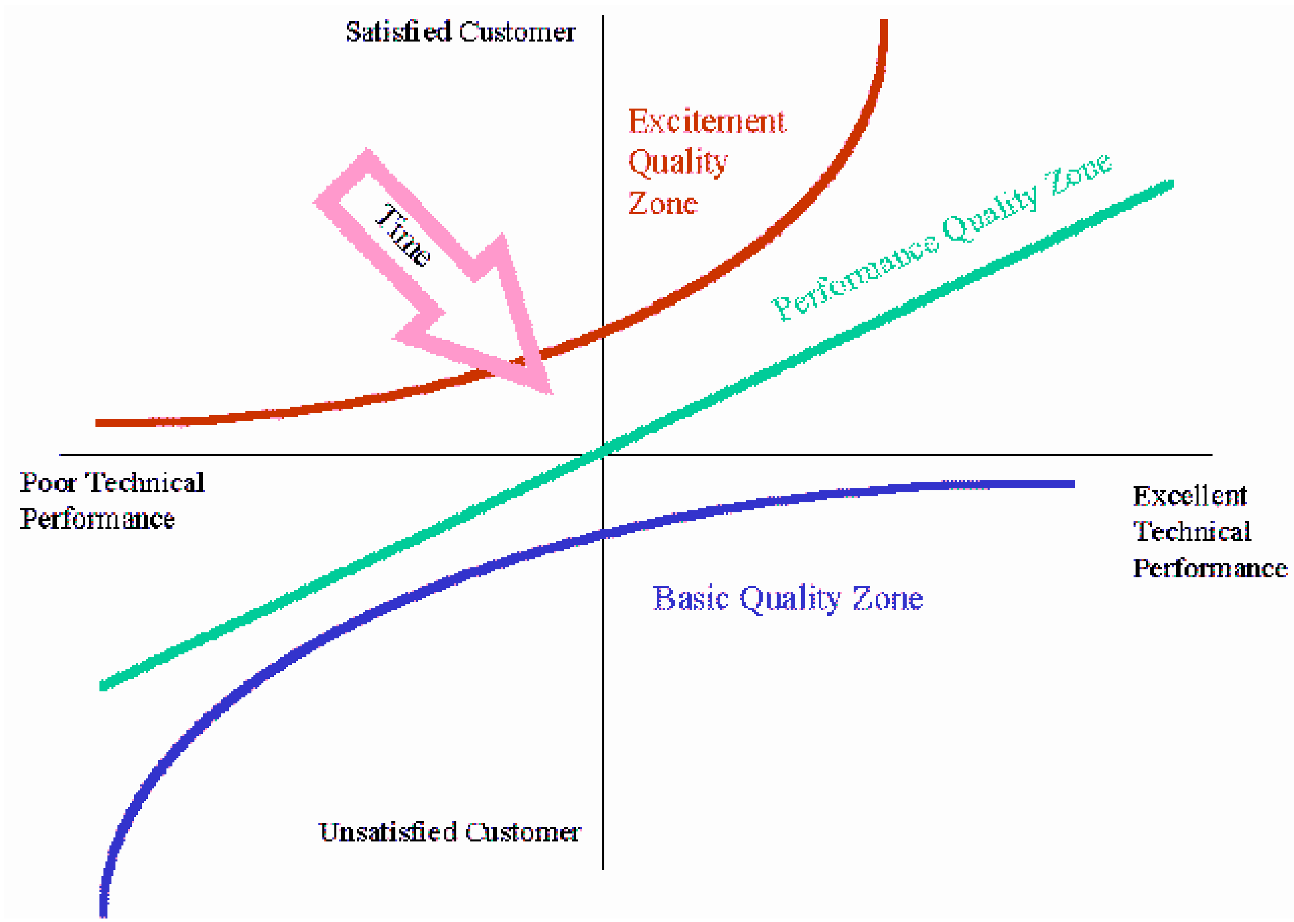
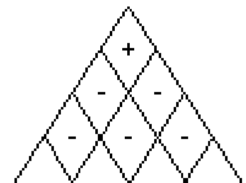
Kano Diagram



Quality Function Deployment

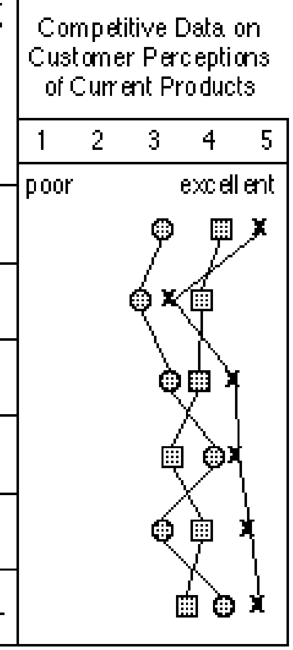
A link between customer attributes and design parameters

- What attributes are critical to our customers?
- What design parameters are important in driving those customer attributes?
- What should the design parameter targets be for the new design?



Design Parameters

Customer Requirements	Importance (%)	Number of teeth per gear	Lubricant	Tooth thickness	Manufacturing precision
Speed (low wait time)	25		-		0
Quiet	10	+	++	-	+
Crisp and accurate sound	9				
Low cost	12	--	-	+	-
Compact	10		0	-	+
Reliable	34	-	0	+	++



Requirements Development

VOC approaches provide powerful methods for eliciting, analyzing, and validating requirements

Can overcome common problems by:

- Identifying ALL the customers
- Identifying ALL their requirements
- Probing beyond the stated requirements for needs
- Understanding the requirements from the customers' perspective
- Recognizing and resolving conflicts between requirements or between requirement providers

Voice of Process

Characteristics of the process:

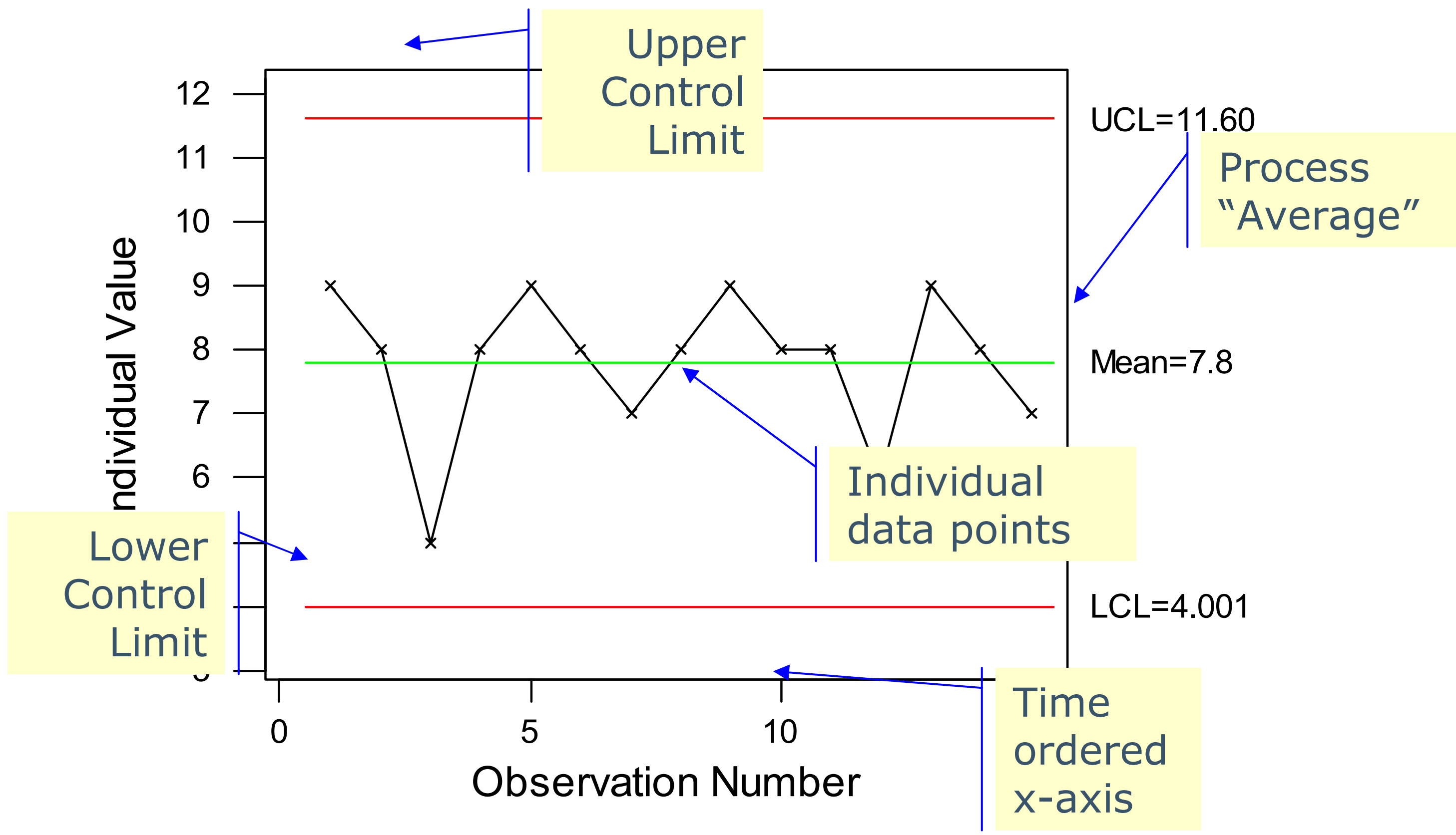
- What it is capable of achieving
- Whether it is under control
- What significance to attach to individual measurements - are they part of natural variation or a signal to deal with?

Control Chart

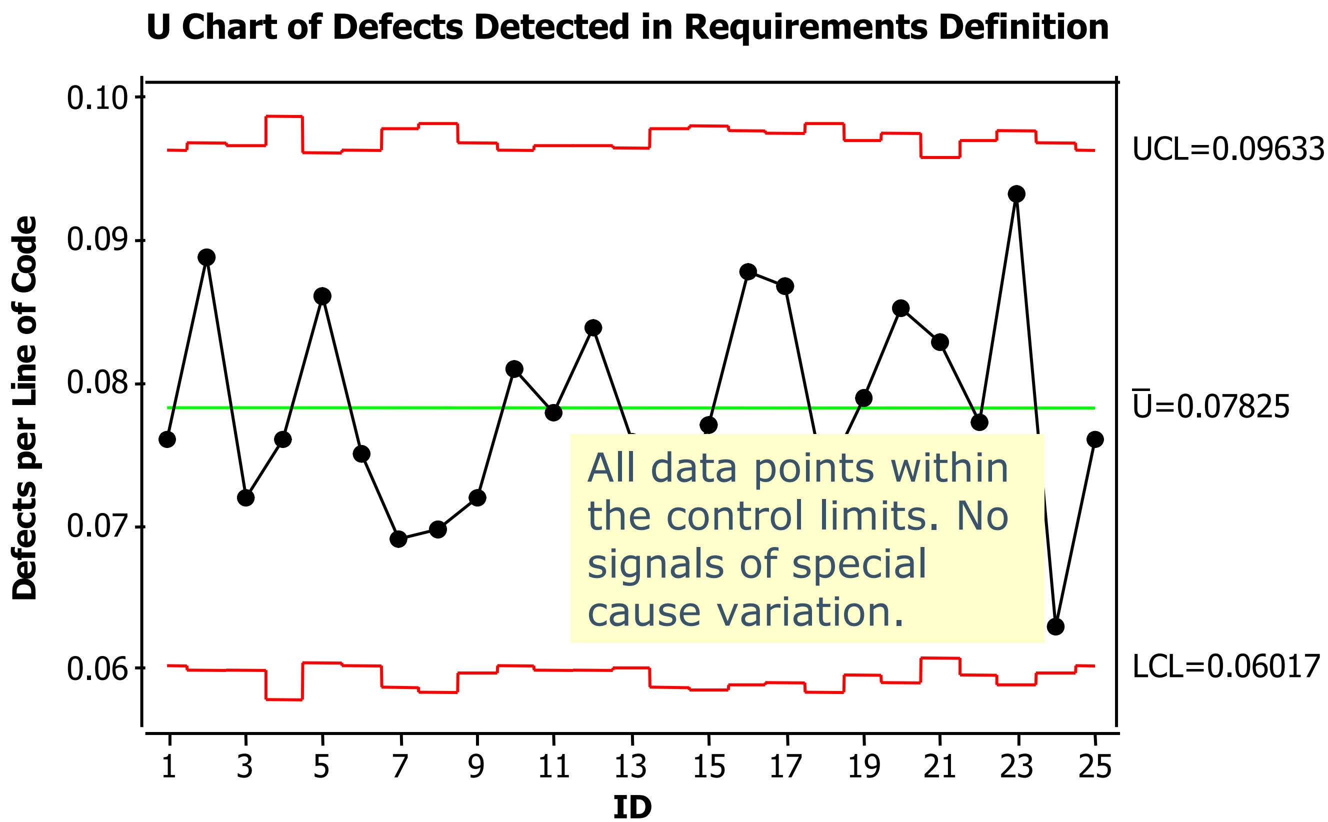
A time-ordered plot of process data points with a centerline based on the average and control limits that bound the expected range of variation

Control charts are one of the most useful quantitative tools for understanding variation

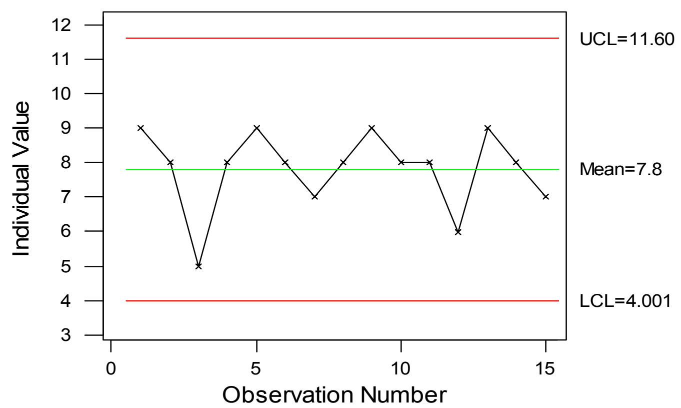
Key Features of a Control Chart



A Stable (Predictable) Process

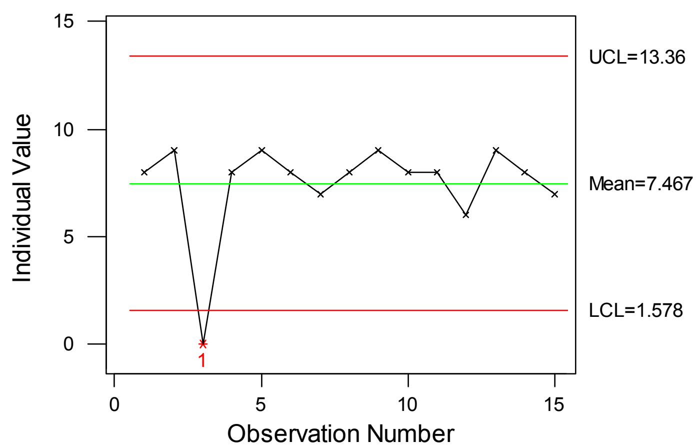


Variation



Common Cause Variation

- *Routine* variation that comes from within the process
- Caused by the natural variation in the process
- Predictable (stable) within a range



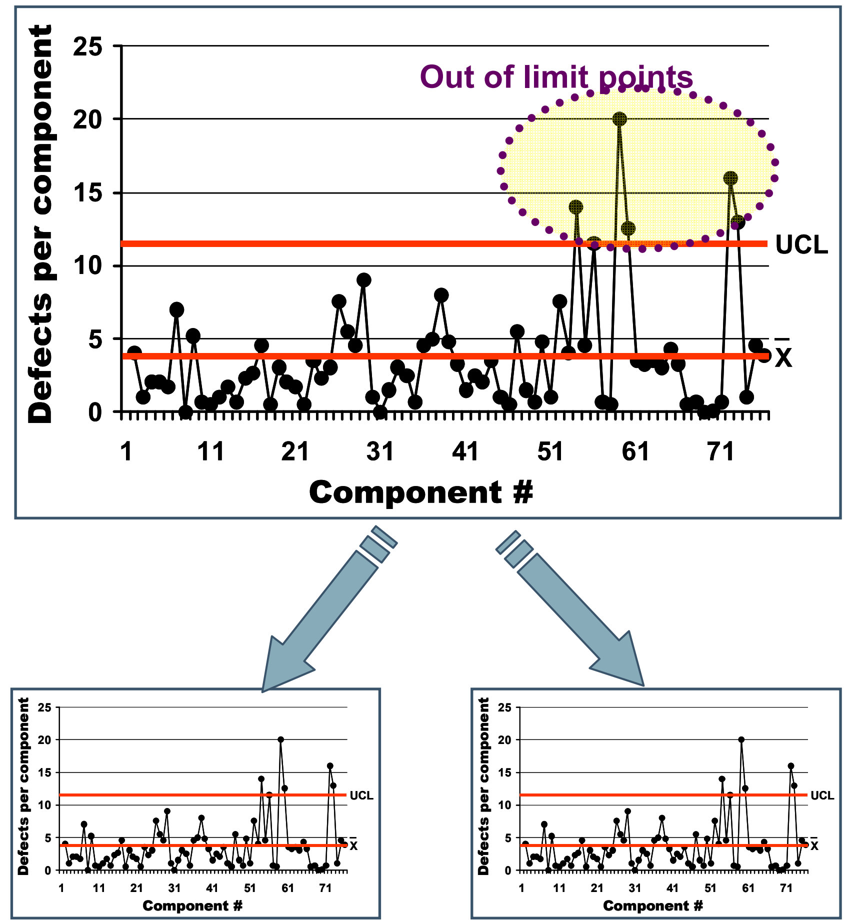
Special Cause Variation

- *Assignable* variation that comes from outside the process
- Caused by a unexpected variation in the process
- Unpredictable

What if the Process Isn't Stable?

You may be able to explain out of limit points by observing that they are due to an variation in the process

- E.g., peer review held on Friday afternoon
- You can eliminate the points from the data, if they are not part of the process you are trying to predict



You may be able to segment the data by an attribute of the process or attribute of the corresponding work product

- E.g., different styles of peer reviews, peer reviews of different types of work products

Voice of Business

The "voice of the business" is the term used to describe the stated and unstated needs or requirements of the business/shareholders.

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Evaluating Data Quality

Does the measurement system yield accurate, precise, and reproducible data?

- A measurement system evaluation (MSE) addresses these questions
- It includes understanding the data source and the reliability of the process that created it.

Frequently occurring problems include the following:

- wrong data
- missing data
- Skewed or biased data

Sometimes, a simple “eyeball” test reveals such problems

More frequently, a methodical approach is warranted.

[MPDI]

Discussion: What if I Skip This Step?

What if…

- All 0's in the inspection database are really missing data?
- "Unhappy" customers are not surveyed?
- Delphi estimates are done only by experienced engineers?
- A program adjusts the definition of "line of code" and doesn't mention it?
- Inspection data doesn't include time and defects prior to the inspection meeting?
- Most effort data are tagged to the first work breakdown structure item on the system dropdown menu?
- The data logger goes down for system maintenance in the first month of every fiscal year?
- A "logic error" to one engineer is a "___" to another

Which are issues of validity? Bias? Integrity? Accuracy?
How might they affect your conclusions and decisions?

[MPDI]

Evaluating Data Quality: Simple Checks

Use common sense, basic tools, and good powers of observation.

Look at the frequency of each value:

- Are any values out of bounds?
- Does the frequency of each value make sense?
- Are some used more or less frequently than expected?

Supporting tools and methods include

- process mapping
- indicator templates
- operational definitions
- descriptive statistics
- checklists

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Practical Tips

Map the data collection process.

- Know the assumptions associated with the data

Look at indicators as well as raw measures.

- Ratios of bad data still equal bad data

Data systems to focus on include the following:

- Manually collected or transferred data
- Categorical data
- Startup of automated systems

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Formal MSE Provides Answers…

- How ***big*** is the measurement error?
- What are the ***sources*** of measurement error?
- Is the measurement system ***stable*** over time?
- Is the measurement system ***capable***?
- How can the measurement system be ***improved***?

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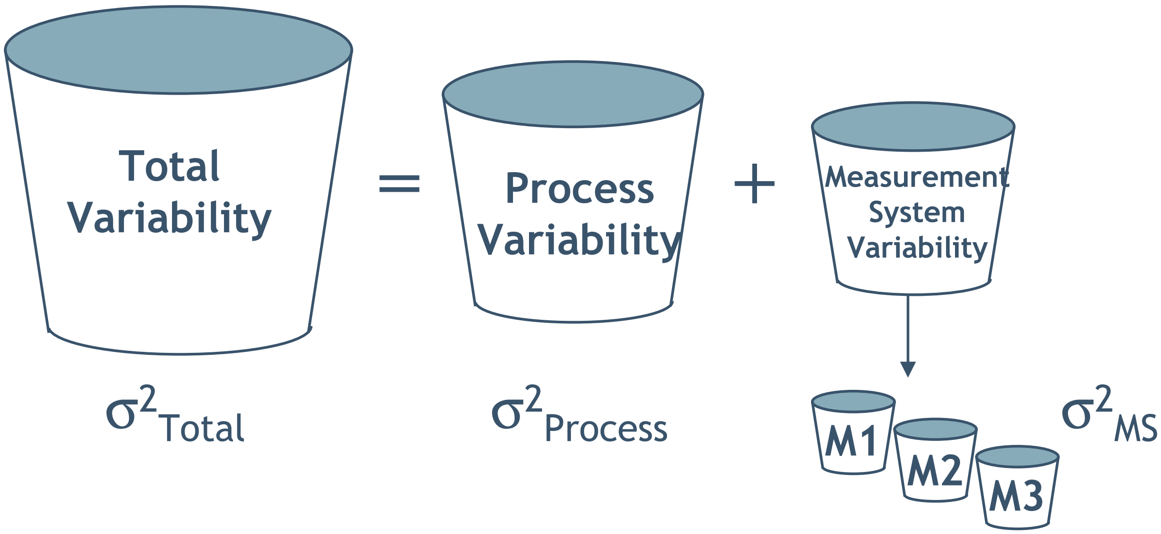
Sources of Variation in a Formal MSE



The variation of a process is the sum of variation from all process sources including measurement error.

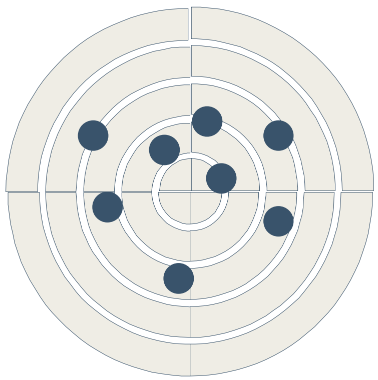
[MPDI]

Characteristics of a Formal MSE

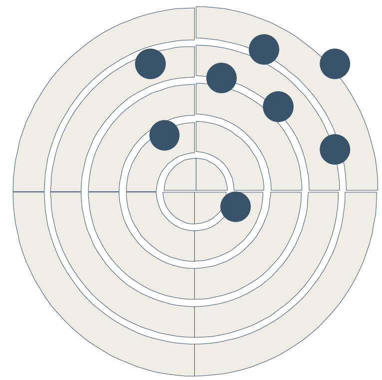
- Precision (reproducibility and repeatability – R&R)
- Accuracy (bias)
- Stability over time

[MPDI]

Accuracy (Bias)



Accurate



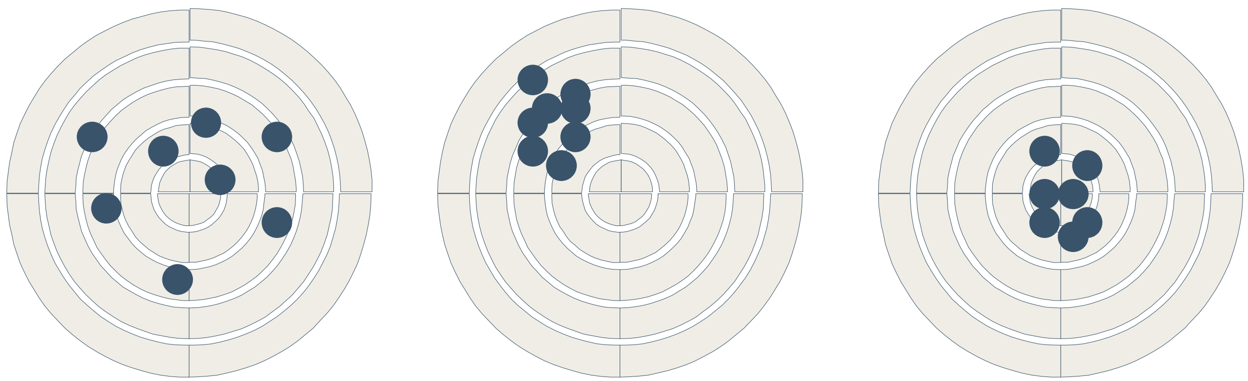
Not accurate

Accuracy—The closeness of (average) reading to the correct value or accepted reference standard.

[MPDI]

Precision vs. Accuracy

(σ) (μ)



Accurate but not precise

Precise but not accurate

Both accurate and precise

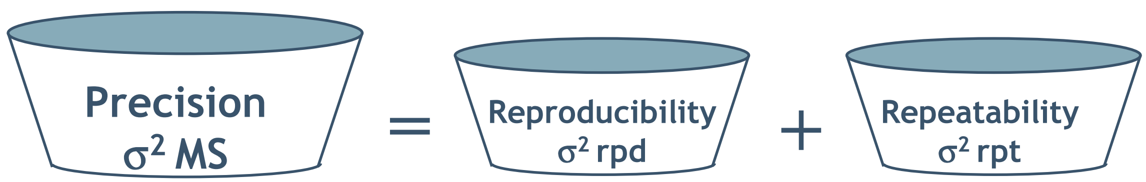
[MPDI]

Precision

Spread refers to the standard deviation of a distribution.

The standard deviation of the measurement system distribution is called the **precision**, σ_{MS}.

Precision is made up of two sources of variation: **repeatability** and **reproducibility**.



[MPDI]

Repeatability

Repeatability is the inherent variability of the measurement system.

Measured by σ_{RPT}, the standard deviation of the distribution of repeated measurements.

The variation that results when repeated measurements are made under identical conditions:

- same inspector, analyst
- same set up and measurement procedure
- same software or document or dataset
- same environmental conditions
- during a short interval of time

? What are your repeatability issues?

[MPDI]

Reproducibility

Reproducibility is the variation that results when different conditions are used to make the measurement:

- different software inspectors or analysts
- different set up procedures, checklists at different sites
- different software modules or documents
- different environmental conditions;

Measured during a longer period of time.

Measured by $\sigma_{RPD.}$

? What are your reproducibility issues?

[MPDI]

Simple MSE for Continuous Data—1

- Have **10 objects** to measure (projects to forecast, modules of code to inspect, tests to run, etc…; variables data involved!).
- Have **3 appraisers** (different forecasters, inspectors, testers, etc…).
- Have **each person repeat the measurement at least 2 times for each object**.
- Measurements should be made independently and in random order.
- **Calculate the measurement system variability** (see addenda).
- **Calculate the %GRR metric** to determine acceptability

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MSE Metrics-Precision

%Gauge Repeatability & Reproducibility (%GR&R):

The fraction of total variation consumed by measurement system variation.

$$\%GRR^{*} = \frac{\sigma_{MS}}{\sigma_{Total}} x100\ \%$$

* Automotive Industry Action Group (AIAG) MSA Reference Manual, 3rd edition

How Much Variation is Tolerable?

	If the %GRR is…	Then measurement error is…
	<10%	**Acceptable**
	between **10% & 30%**	**Unacceptable for "critical" measurements** (You should improve the measurement process.)
	>30%	**Unacceptable**

* Reference Automotive Industry Action Group (AIAG) MSA Reference Manual, 3rd edition

MSE Calculations for Attribute Data 1

(see addenda for formulas, example)

Conducting measurement system evaluation on attribute data is slightly different from the continuous data.

Two approaches for Attribute Data will be discussed:

- Quick rule of thumb approach
- Formal statistical approach (see addenda)

[MPDI]

MSE Calculations for Attribute Data 2

Quick Rule of Thumb Approach

1. Randomly select 20 items to measure
   - Ensure at least 5-6 items barely meet the criteria for a "pass" rating.
   - Ensure at least 5-6 items just miss the criteria for a "pass" rating.
2. Select two appraisers to rate each item twice.
   - Avoid one appraiser biasing the other.
3. If all ratings agree (four per item), then the measurement error is acceptable, otherwise the measurement error is unacceptable.

[MPDI]

Analyze Guidance Questions

Define → Measure | **Analyze** | Improve → Control

Define
- Define project Scope
- Establish formal project

Measure
- Identify needed data
- Obtain data set
- Evaluate data quality
- Summarize, baseline data

Analyze
- **Explore data**
- **Characterize process and problem**
- **Update improvement project scope and scale**

Explore data:
- What do the data look like?
- What is driving the variation?
- What is the new baseline?
- What are associated risks and assumptions associated with revised data set and baseline?

[MPDI]

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Exploring the Data

What do the data look like?
What is driving the variation?

Probing questions during data exploration:

- What *should* the data look like? And, does it?
  - first principles, heuristics or relationships
  - mental model of process (refer to that black box)
  - what do we expect, in terms of cause & effect
- Are there yet-unexplained patterns or variation? If so,
  - conduct more Y to x analysis
  - plot, plot, plot using the basic tools
- Are there hypothesized x's that can be removed from the list?

Objective - To completely identify the Y's, little y's, and x's

[MPDI]

Exercise: Outliers

What is an outlier?

- a data point which does not appear to follow the characteristic distribution of the rest of the data
- an observation that lies an abnormal distance from other values in a random sample from a population

- Consider this cost variance data:
  - 13, 22, 16, 20, 16, 18, 27, 25, 30, 333, 40 ??
  - average = 50.9, standard deviation = 93.9

If "333" is a typo and should have been "33"

- corrected average = 23.6, corrected standard deviation = 8.3

But, what if it's a real value?

In groups of 3

- Share your approach for deciding if and when to remove extreme values from data sets.

[Frost 03], [stats-online]

Removing Outliers

There is not a widely-accepted automated approach to removing outliers.

Approaches

- Visual
  - examine distributions, trend charts, SPC charts, scatter plots, box plots
  - couple with knowledge of data and process
- Quantitative methods
  - interquartile range
  - Grubbs' test

[Frost 03], [stats-online]

Interquartile Range

Description

- A quantitative method for identifying possible outliers in a data set

Procedure

1. Determine 1st and 3rd quartiles of data set: Q1, Q3
2. Calculate the difference: interquartile range or IQR
3. Lower outlier boundary = Q1 – 1.5*IQR
4. Upper outlier boundary = Q3 + 1.5*IQR

[MPDI]

Interquartile Range: Example

1

333
40
30
27
25
22
20
18
16
16
13

Q3 → 30

Q1 → 16

2

Interquartile Range

30 – 16 = 14

4

Upper outlier boundary

30 + 1.5*14 = 51

3

Lower outlier boundary

16 – 1.5*14 = -5

Procedure

1. Determine 1st and 3rd quartiles of data set: Q1, Q3
2. Calculate the difference: interquartile range or IQR
3. Lower outlier boundary = Q1 – 1.5*IQR
4. Upper outlier boundary = Q3 + 1.5*IQR

Example adapted from “Metrics, Measurements, & Mathematical Mayhem,” Alison Frost, Raytheon, SEPG 2003

Tips About Outliers

Outliers can be clue to process understanding: learn from them.

If outliers lead you to measurement system problems,

- repair the erroneous data if possible
- if it cannot be repaired, delete it

Charts that are particularly effective to flag possible outliers include:

- box plots
- distributions
- scatter plots
- control charts (if you meet the assumptions)

Rescale charts when an outlier reduces visibility into variation.

Be wary of influence of outliers on linear relationships.

[MPDI]

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When Not to Remove Outliers

When you don't understand the process.

Because you "don't like the data points" or they make your analysis more complicated.

Because IQR or Grubbs method "says so."

When they indicate a "second population."

- Identify the distinguishing factor and separate the data.

When you have very few data points.

Innocent until proven guilty

[MPDI]

Summary: Addressing Data Quality Issues

Identify & remove data with poor quality

Identify & remove outliers

- Remember: innocent until proven guilty

If you remove significant amounts of data

- Repair your measurement system

Quantify variation due to measurement system

- Reduce variability as needed

Determine the risks of moving ahead with process and product analysis

- Identify interpretation risks
- Identify magnitude of process/product problems relative to data problems
- Identify undesirable consequences of not proceeding with data-driven process improvement, even in the face of data quality issues

Agenda

- Six Sigma Benefits for Early Adopters – What the Books Don't Tell You
- The 7 Six Sigma Tools Everyone Can Use
- I Hear Voices
- Dirty Data (and How to Fix It)
- ➡ Statistical Process Control – Where Does It Apply to Engineering?
- Convincing Senior Management: The Value Proposition
- Summary
- Cheap Sources of Information and Tools
- MSE Addendum

A Typical Six Sigma Project in Engineering

- The organization notes that systems integration has been problematic on past projects (budget/schedule overruns)
- A Six Sigma team is formed to scope the problem, collect data from past projects, and determine the root cause(s)
- The team's analysis of the historical data indicates that poorly understood interface requirements account for 90% of the overruns
- Procedures and criteria for a peer review of the interface requirements are written, using best practices from past projects
- A pilot project uses the new peer review procedures and criteria, and collects data to verify that they solve the problem
- The organization's standard SE process and training is modified to incorporate the procedures and criteria, to prevent similar problems on future projects

Applicability to Engineering

System engineering processes are fuzzy

- Systems engineering "parts" are produced using processes lacking predictable mechanizations assumed for manufacturing of physical parts
- Simple variation in human cognitive processes can prevent rigorous application of the Six Sigma methodology
- Process variation can never be eliminated or may not even reduced below a moderate level

Results often cannot be measured in clear $ savings returned to organization

- Value is seen in reduced risk, increased customer satisfaction, more competitive bids, …

Additional Challenges

Difficulty in collecting subjective, reliable data

- Humans are prone to errors and can bias data
- E.g., the time spent in privately reviewing a document

Dynamic nature of an on-going project

- Changes in schedule, budget, personnel, etc. corrupt data

Repeatable process data requires the project/organization to define (and follow) a detailed process

Analysis requires that complex SE processes be broken down into small, repeatable tasks

- E.g., peer review

The Engineering Life-Cycle

Requirements Analysis	Top Level Design	Detailed Design	Integration	Test

The development process has many sources of variation

- Process
- Measurement system
- Personnel
- Product
- Technology
- Management actions

A stable (quantifiable) process must be chosen which is short, and has limited sources of variation

- Must also have value in being predictable

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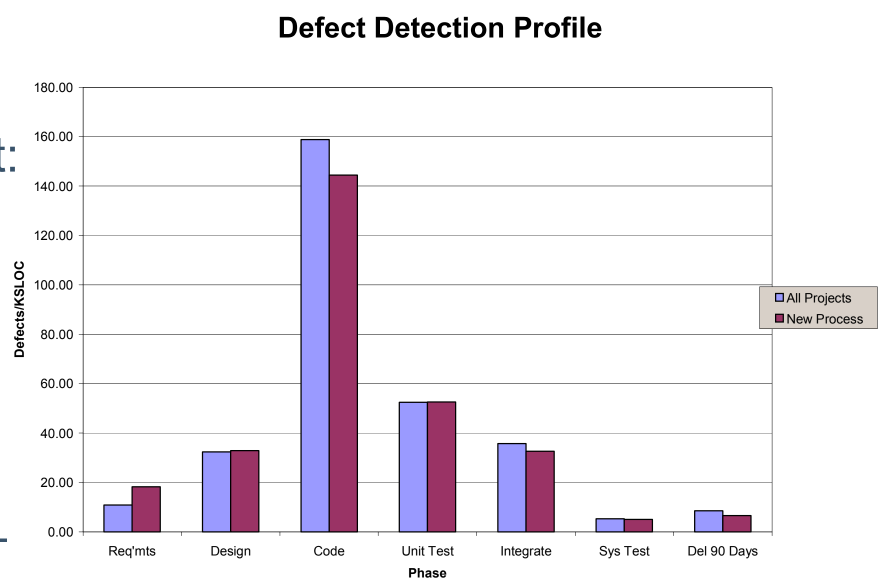
Typical Choices in Industry

Most customers care about:

- Delivered defects
- Cost and schedule

So organizations try to predict:

- Defects found throughout the lifecycle
- Effectiveness of peer reviews, testing
- Cost achieved/actual (Cost Performance Index – CPI)
- Schedule achieved/actual (Schedule Performance Index – SPI)



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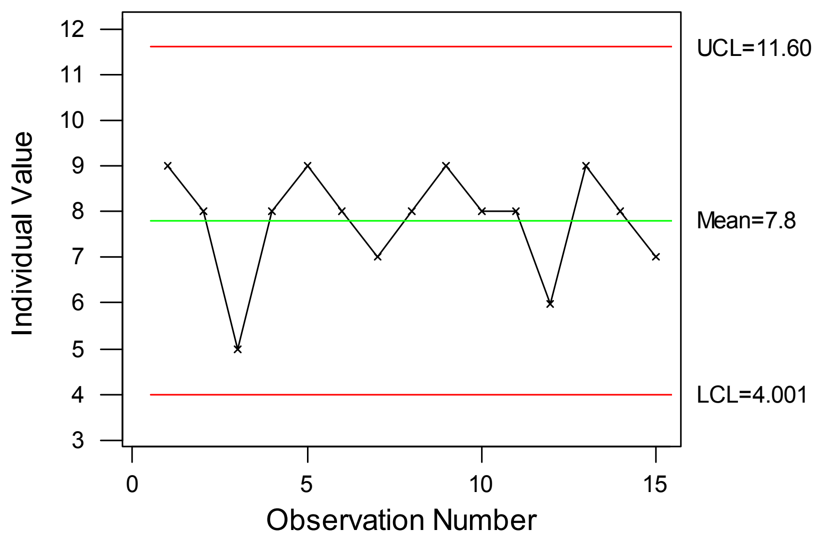
Peer Reviews

Can we predict the number of errors found in a peer review?

Could generate a control chart of errors detected over multiple reviews

Must assume:

- Product errors are normally and uniformly distributed
- Same quality of reviews (number/ability of reviewers)
- No other special causes (process is stable)



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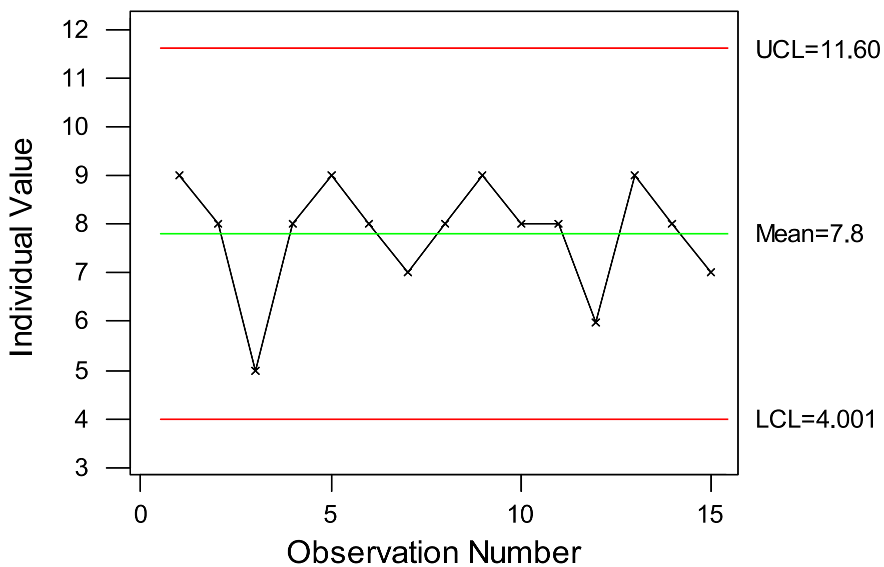
Quantitative Management

Suppose your project conducted several peer reviews of similar code, and analyzed the results

- Mean = 7.8 defects/KSLOC
- +3σ = 11.60 defects/KSLOC
- -3σ = 4.001 defects/KSLOC

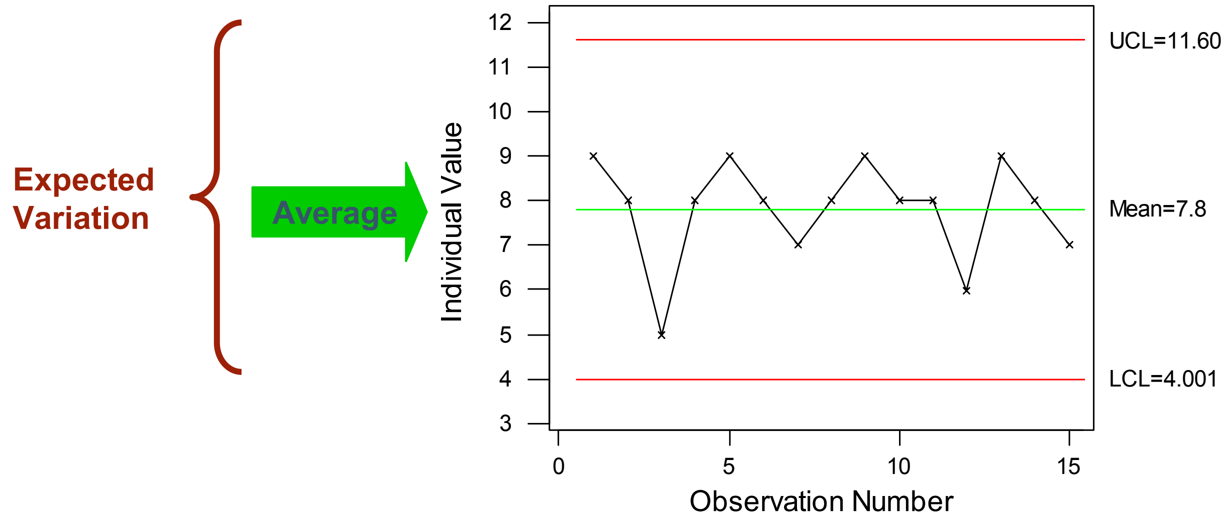


What would you expect the next peer review to produce in terms of defects/ KSLOC?

What would you think if a review resulted in 10 defects/KSLOC?

3 defects/KSLOC?

Understanding the Process



Useful in evaluating future reviews

- Was the review effective?
- Was the process different?
- Is the product different?

→ **Corrective and preventative actions**

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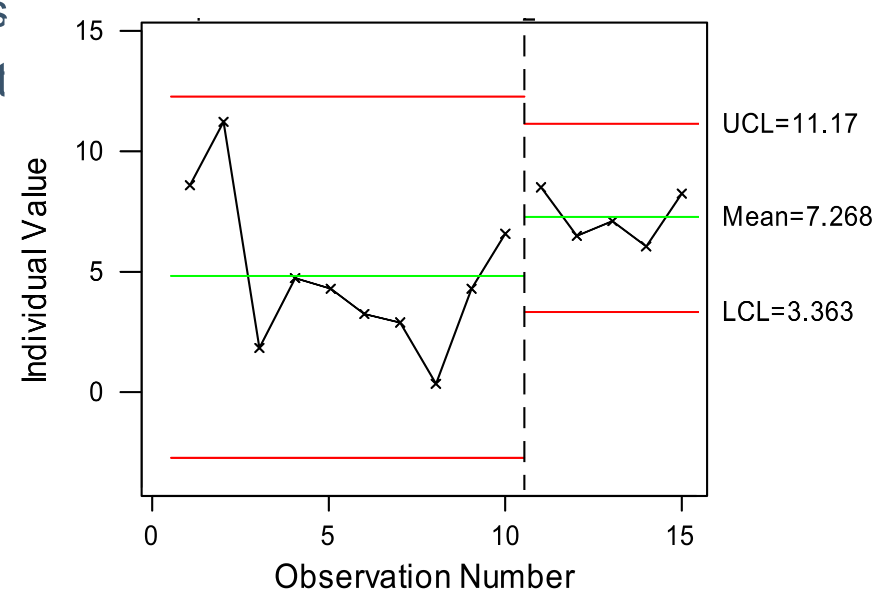
Improving the Process

Reduce the variation

- Train people on the process
- Create procedures/checklist
- Strengthen process audits

Increase the effectiveness (increase the mean)

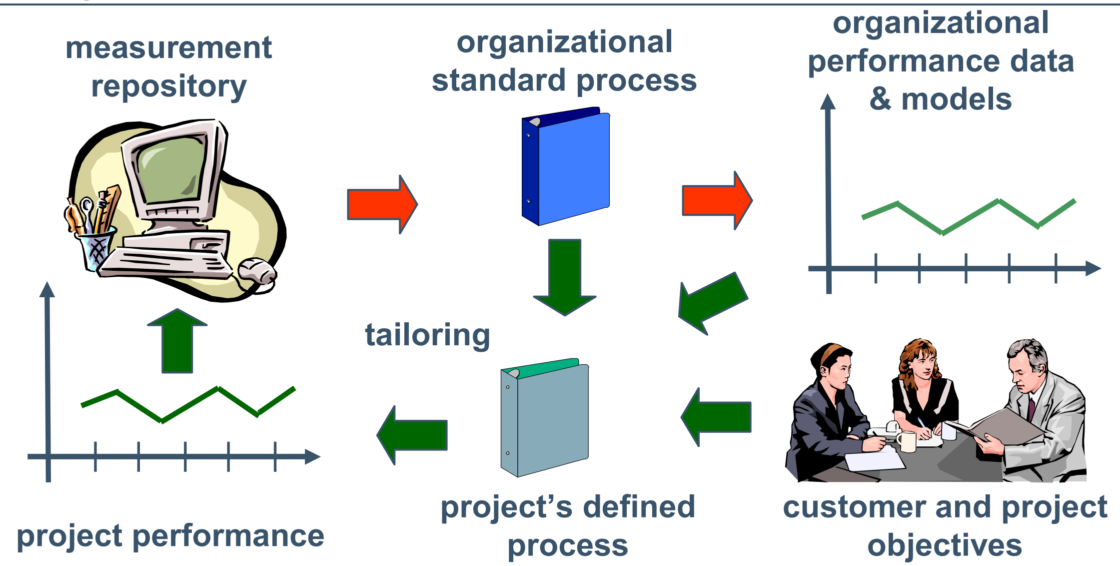
- Train people
- Create checklists
- Reduce waste and re-work
- Replicate best practices from other projects



CMMI Level 4

Organizational Process Performance

- Establishes a quantitative understanding of the performance of the organization's set of standard processes



Quantitative Project Management

- Quantitatively manage the project's defined process to achieve the project's established quality and process-performance objectives.

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How Six Sigma Helps Process Improvement

PI efforts often generate or have little direct impact on the business goals

- Confuses ends with means; results measured in activities implemented, not results

Six Sigma delivers results that matter to managers (fewer defects, higher efficiency, cost savings, …)

Six Sigma concentrates on problem solving in small groups, focused on a narrow issue

- Allows for frequent successes (3-9 months)

Six Sigma focuses on the customer's perception of quality

How Six Sigma Helps CMMI Adoption

For an individual process:

- CMM/CMMI identifies what activities are expected in the process
- Six Sigma identifies how they can be improved (efficient, effective)

SG 1 Establish Estimates
- SP 1.1 Estimate the Scope of the Project
- SP 1.2 Establish Estimates of Project Attributes
- SP 1.3 Define Project Life Cycle
- SP 1.4 Determine Estimates of Effort and Cost

SG 2 Develop a Project Plan
- SP 2.1 Establish the Budget and Schedule
- SP 2.2 Identify Project Risks
- SP 2.3 Plan for Data Management
- SP 2.4 Plan for Project Resources
- SP 2.5 Plan for Needed Knowledge and Skills
- SP 2.6 Plan Stakeholder Involvement
- SP 2.7 Establish the Project Plan

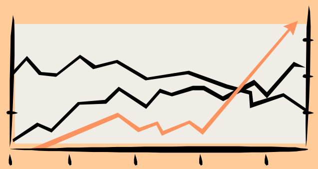
SG 3 Obtain Commitment to the Plan
- SP 3.1 Review Subordinate Plans
- SP 3.2 Reconcile Work and Resource Levels
- SP 3.3 Obtain Plan Commitment

Example – Project Planning

- **Could fully meet the CMMI goals and practices, but still write poor plans**
- **Six Sigma can be used to improve the planning process and write better plans**

Approaches to Process Improvement

Data-Driven (e.g., Six Sigma, Lean)



Clarify what your customer wants (Voice of Customer)

- Critical to Quality (CTQs)

Determine what your processes can do (Voice of Process)

- Statistical Process Control

Identify and prioritize improvement opportunities

- Causal analysis of data

Determine where your customers/competitors are going (Voice of Business)

- Design for Six Sigma

Model-Driven (e.g., CMM, CMMI)

Determine the industry best practice

- Benchmarking, models

Compare your current practices to the model

- Appraisal, education

Identify and prioritize improvement opportunities

- Implementation
- Institutionalization

Look for ways to optimize the processes

Agenda

Six Sigma Benefits for Early Adopters – What the Books Don't Tell You

The 7 Six Sigma Tools Everyone Can Use

I Hear Voices

Dirty Data (and How to Fix It)

Statistical Process Control – Where Does It Apply to Engineering?

➡ Convincing Sr. Management: The Value Proposition

Summary

Cheap Sources of Information and Tools

MSE Addendum

What Is Your Current Reality?

What are your managers saying? Asking?

How do your views differ?

What would you like to convince them of?

- What is your value proposition?

Example: NGC Mission Systems

The Six Sigma adoption decision

Started as a CEO mandate, but embraced by the organization

- Seen as a way to enable data-drive decision making
- Integrated with CMMI and other PI initiatives
- Engaged customers, who saw it as a way to solve their problems

With experience, people saw that Six Sigma:

- Was more than statistics
- Could be applied to engineering
- Greatly accelerated the understanding and adoption of CMMI Levels 4 and 5
- Resulted in both hard and soft savings that could be quantified

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Example: Motorola

The CMMI adoption decision: Will it benefit existing Six Sigma initiatives?

Executive sponsorship and ***engagement***

- Benchmarked with execs from a successful company: to witness the benefits first hand
- Execs gave the sales pitch -- their personal leadership sold it
- Established upward mentoring: MBB coach & CMMI expert for each exec

Deployment - Leveraging executive “pull”

- Execs controlled adoption schedule, to meet critical business needs
- Modified the reward and recognition structure
- “Rising star” program for both technical and management tracks
- Training began at the top and worked its way down

Execution – Speaking the language of executives and the business

- Calculated costs & benefits of all proposals; listed the intangibles
- Risk reduction: Start small, pilot, and build on successes

[Siviy 05-2]

Change Management

$$D \times V \times F > R$$

D = Dissatisfaction with the present

V = Vision for the Future

F = First (or next) Steps

R = Resistance

[Beckhard]

What Drives Process Improvement?

Performance issues: product, project—

- and, eventually, process issues

Regulations and mandates

- Sarbanes Oxley
- "Level 3" requirements to win contracts

Business issues and "burning platforms"

- lost market share or contracts
- continuous cost and cycle time improvement
- capitalizing on new opportunities

**There is compliance-driven improvement,
and there is performance-driven improvement.**

Value Proposition: Six Sigma as Strategic Enabler

The SEI conducted a research project to explore the feasibility of Six Sigma as a transition enabler for software and systems engineering best practices.

Hypothesis

- Six Sigma used in combination with other software, systems, and IT improvement practices results in
  - better selections of improvement practices and projects
  - accelerated implementation of selected improvements
  - more effective implementation
  - more valid measurements of results and success from use of the technology

Achieving process improvement… better, faster, cheaper.

Research Conclusions

Six Sigma is feasible as an enabler of the adoption of software, systems, and IT improvement models and practices (a.k.a., “improvement technologies”).

The CMMI community is more advanced in their joint use of CMMI & Six Sigma than originally presumed.

Noting that, for organizations studied, Six Sigma adoption & deployment

- was frequently decided upon at the enterprise level, with software, systems, and IT organizations following suit
- was driven by senior management’s previous experience and/or a burning business platform
- was consistently comprehensive.

[IR&D 04]

Selected Supporting Findings 1

Six Sigma helps integrate multiple improvement approaches to create a seamless, single solution.

Rollouts of process improvement by Six Sigma adopters are mission-focused, flexible, and adaptive to changing organizational and technical situations.

Six Sigma is frequently used as a mechanism to help sustain—and sometimes improve—performance in the midst of reorganizations and organizational acquisitions.

Six Sigma adopters have a high comfort level with a variety of measurement and analysis methods.

[IR&D 04]

Selected Supporting Findings 2

Six Sigma can accelerate the transition of CMMI.

- moving from CMMI Maturity Level 3 to 5 in 9 months, or from SW-CMM Level 1 to 5 in 3 years (the typical move taking 12-18 months per level)
- underlying reasons are strategic and tactical

When Six Sigma is used in an enabling, accelerating, or integrating capacity for improvement technologies, adopters report quantitative performance benefits using measures they know are meaningful for their organizations and clients. For instance,

- ROI of 3:1 and higher, reduced security risk, and better cost containment

[IR&D 04], [Hayes 95]

CMMI-Specific Findings

Six Sigma is effectively used at all maturity levels.

Participants assert that the frameworks and toolkits of Six Sigma exemplify what CMMI high maturity requires.

Case study organizations do not explicitly use Six Sigma to drive decisions about CMMI representation, domain, variant, and process-area implementation order. However, participants agree that this is possible and practical.

CMMI-based organizational assets enable Six Sigma project-based learnings to be shared across software and systems organizations, enabling a more effective institutionalization of Six Sigma.

[IR&D 04]

Why does this work?

Let's decompose

- Arsenal of tools, and **people trained to use them**
- Methodical problem-solving methods
- Common philosophies and paradigms
- Fanatical **focus on mission**

How Does this Work? 1

Six Sigma helps process improvement

- PI efforts sometimes have little directly measurable impact on the business goals
- Six Sigma delivers results that matter to managers (fewer defects, higher efficiency, cost savings, …)
- Six Sigma concentrates on problem solving in small groups, focused on a narrow issue
- Six Sigma focuses on the customer's perception of quality

CMMI helps Six Sigma

- CMM/CMMI focuses on organizational change

[Hefner 04]

How Does this Work? 2

Specific DMAIC-CMMI Relationships

Overall

- DMAIC: a problem solving approach
- CMMI: a process & measurement deployment approach

PAs that align with DMAIC include the following:

- MA, GPs
- QPM, CAR, OID (either "continuous" or high-maturity view)

A DMAIC project may leverage these existing processes:

- PP, PMC, IPM
- OPP for organization level execution, mgmt, oversight

PAs through which DMAIC may be incorporated into organizational process definition include the following:

- OPF, OPD

[Siviy 05-1]

How Does this Work? 3

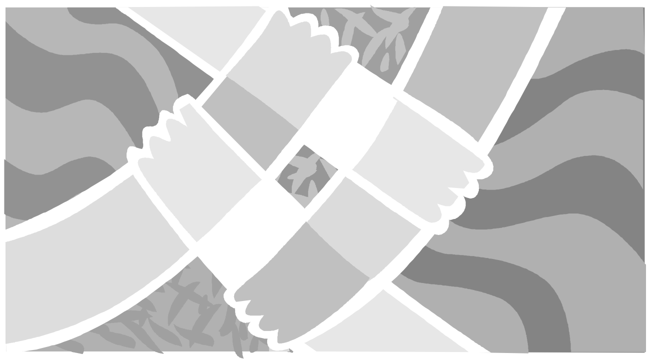
Specific DMAIC-CMMI Relationships

PAs “eligible” for DMAIC-based improvement

- all

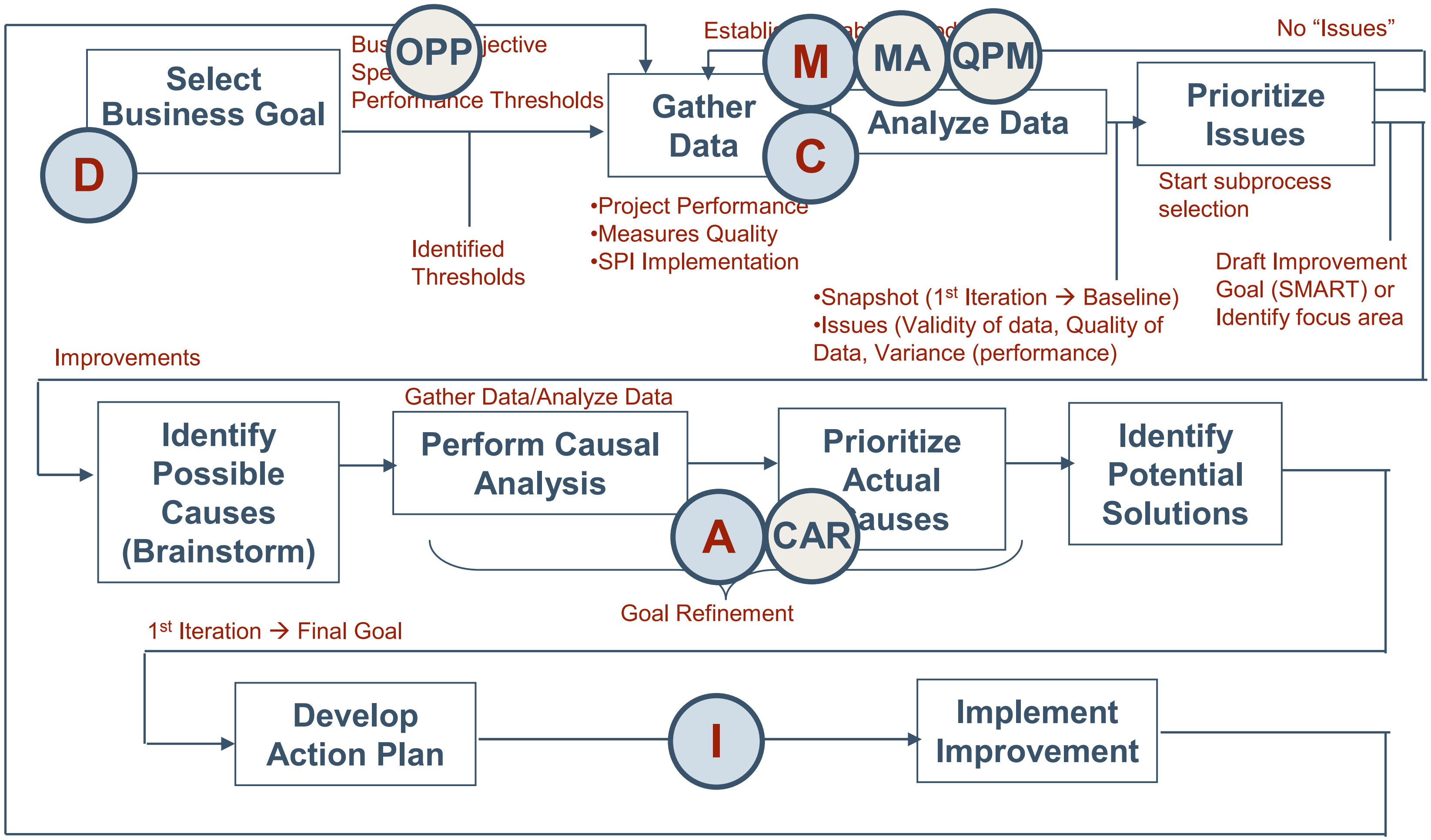
PAs with links to the analytical toolkit include

- Decision Analysis & Resolution
  - e.g., concept selection methods, such as Pugh’s
- Risk Management
  - e.g., Failure Modes & Effects Analysis (FMEA)
- Technical Solution
  - e.g., Design FMEA, Pugh’s



[Siviy 05-1]

Example M&A Process



Strategic Approaches

Observed Patterns in the Joint Implementation of CMMI and Six Sigma

Implement CMMI process areas as “Six Sigma projects”

Use Six Sigma as the tactical engine for high capability and high maturity.

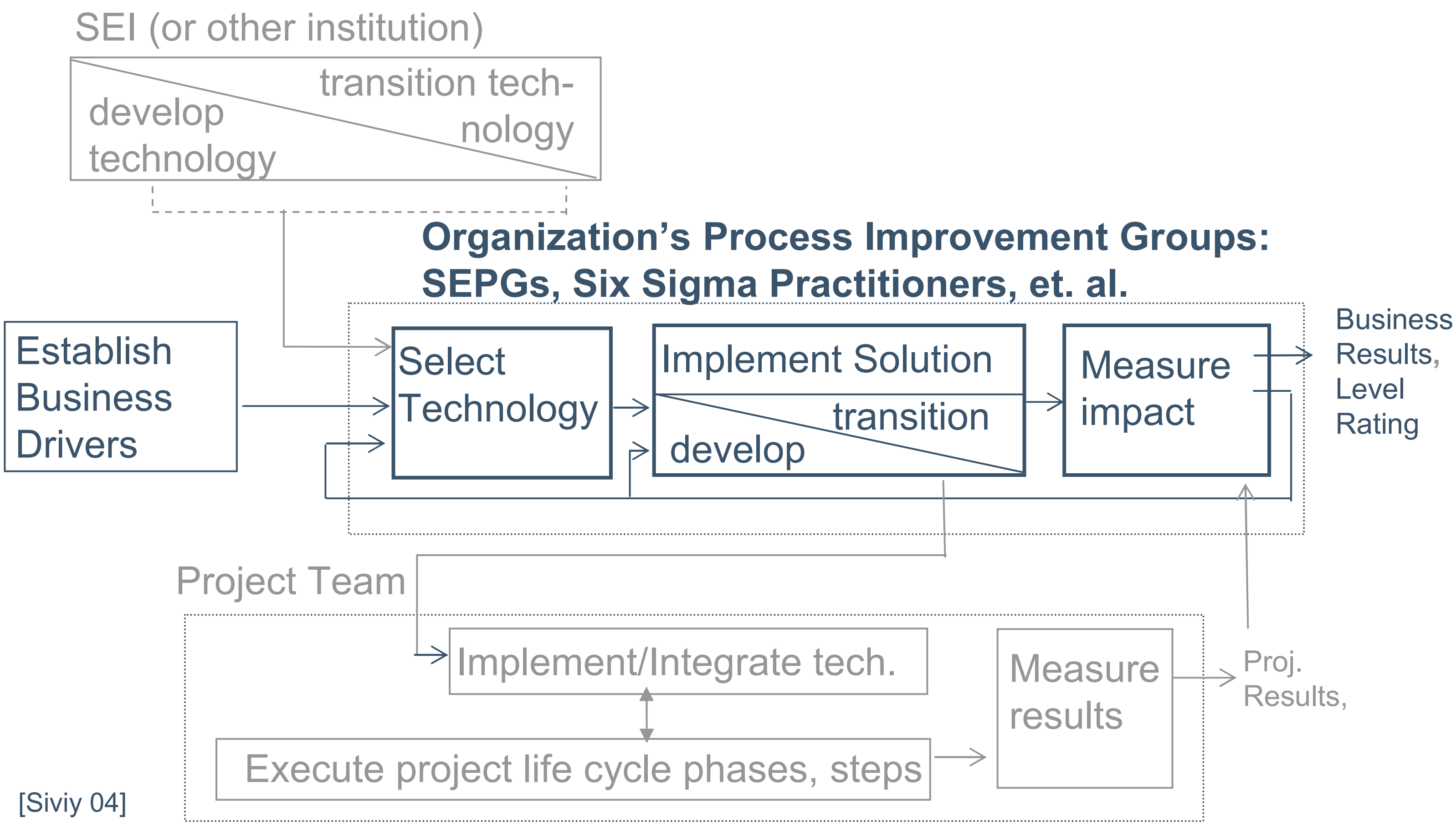
Apply Six Sigma to improve or optimize an organization’s improvement strategy and processes.

Integrate CMMI, Six Sigma, and other improvement models/references into a process standard to be used by every project throughout its life cycle

[Siviy 05-1]

Determining YOUR Approach

First Remember: Everything is a Process!



[Siviy 04]

Determining YOUR Approach

Key Questions

- What is your mission? What are your goals?
- Are you achieving your goals? What stands in your way?
- What process features are needed to support your goals?
  - What technologies provide or enable these features?
- What is the design of a cohesive (integrated), internal standard process that is
  - rapidly and effectively deployed
  - easily updated
  - compliant to models of choice

Considerations & Success Factors

- Process architecture & process architects
- Technology and organization readiness
- Technology adoption scenarios and strategy patterns
- Measurement as integrating platform

[Siviy 05-2]

Determining YOUR Approach - Reminders

Focus on mission success

When speaking with managers about your plan

- Talk in the language of business
- Invest the effort it takes to be succinct

Design an integrated, ***yet simple***, process architecture

Everything should be made as simple as possible, but not one bit simpler

- Albert Einstein

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➡ Summary

Cheap Sources of Information and Tools

MSE Addendum

Summary

Mission Focus

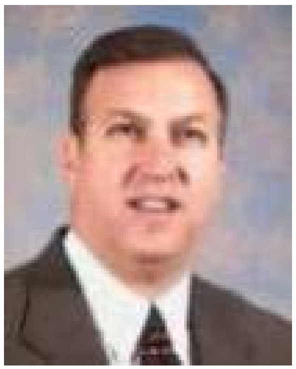
Performance Driven Improvement

CMMI & Six Sigma Synergy

Arsenal of Tools

- Basic charting methods
- And, don't forget "measurement system evaluation"

Contact Information



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Addenda

- Cheap Sources of Information and Tools
- MSE Details
- DMAIC Roadmap – Guidance Questions

Additional Readings 1

[A-M 99] Abdel-Malek, Nabil and Anthony Hutchings, Applying Six Sigma Methodology to CMM for Performance Improvement, JP Morgan, European SEPG 1999, (slides available to SEIR contributors at http://seir.sei.cmu.edu)

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[BPD] Process Maturity / Capability Maturity, http://www.betterproductdesign.net/maturity.htm, a resource site for the Good Design Practice program, a joint initiative between the Institute for Manufacturing and the Engineering Design Centre at the University of Cambridge, and the Department of Industrial Design Engineering at the Royal College of Art (RCA) in London.

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[Forrester] Forrester, Eileen, Transition Basics

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[Harrold 99] Harrold, Dave, Designing for Six Sigma Capability, Control Engineering Online, January 1999, http://www.controleng.com/archives/1999/ctl0101.99/01a103.htm

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

[Hefner 02] Hefner, Rick and Michael Sturgeon, Optimize Your Solution: Integrating Six Sigma and CMM/CMMI-Based Process Improvement, Software Technology Conference, 29 April – 2 May 2002

[isixsigma] From http://isixsigma.com

Online Statistical Textbooks

Computer-Assisted Statistics Teaching - http://cast.massey.ac.nz

DAU Stat Refresher- http://www.cne.gmu.edu/modules/dau/stat/dau2_frm.html

Electronic Statistics Textbook - http://davidmlane.com/hyperstat/index.html

Statistics Every Writer Should Know - http://nilesonline.com/stats/

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Addenda

- **Cheap Sources of Information and Tools**
- MSE Details
- DMAIC Roadmap – Guidance Questions

MSE Metrics-Precision

%Gauge Repeatability & Reproducibility (%GR&R):

The fraction of total variation consumed by measurement system variation.

$$\%GRR^{*} = \frac{\sigma_{MS}}{\sigma_{Total}} x100\ \%$$

* Automotive Industry Action Group (AIAG) MSA Reference Manual, 3rd edition

How Much Variation is Tolerable?

	If the %GRR is…	Then measurement error is…
(green)	**<10%**	**Acceptable**
(yellow)	between **10% & 30%**	**Unacceptable for "critical" measurements** (You should improve the measurement process.)
(red)	**>30%**	**Unacceptable**

* Reference Automotive Industry Action Group (AIAG) MSA Reference Manual, 3rd edition

Simple MSE for Continuous Data—1

- Have **10 objects** to measure (projects to forecast, modules of code to inspect, tests to run, etc…; variables data involved!).
- Have **3 appraisers** (different forecasters, inspectors, testers, etc…).
- Have **each person repeat the measurement at least 2 times for each object**.
- Measurements should be made independently and in random order.
- **Calculate the %GRR metric** to determine acceptability of the measurement system (see output next page).

Simple MSE for Continuous Data—2

Gage R&R

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.09143	7.76
Repeatability	0.03997	3.39
Reproducibility	0.05146	4.37
Operator	0.05146	4.37
Part-To-Part	1.08645	92.24
Total Variation	1.17788	100.00

Source	StdDev (SD)	Study Var (6 * SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.30237	1.81423	27.86	22.68
Repeatability	0.19993	1.19960	18.42	14.99
Reproducibility	0.22684	1.36103	20.90	17.01
Operator	0.22684	1.36103	20.90	17.01
Part-To-Part	1.04233	6.25396	96.04	78.17
Total Variation	1.08530	6.51180	100.00	81.40

MSE Calculations for Attribute Data—3

Formal Statistical Approach

1. Use Minitab Attribute Agreement Analysis to measure error:
   - within appraisers
   - between appraisers
   - against a known rating standard
2. Select at least **20 items** to measure.
3. **Identify at least 2 appraisers who will measure each item at least twice**.
4. View 95% Confidence Intervals on % accurate ratings (want to see 90% accuracy).
5. **Use Fleiss' Kappa statistic <u>or</u> Kendall's coefficients** to conduct hypothesis tests for agreement.

MSE Calculations for Attribute Data—4

When should each formal statistical approach be used?

Attribute data is on Nominal scale → **Fleiss' Kappa statistic**

e.g. Types of Inspection Defects,
Types of Test Defects,
ODC Types, Priorities assigned to defects, Most categorical inputs to project forecasting tools, Most human decisions among alternatives

Attribute data is on Ordinal scale → **Kendall's coefficients**
(each item has at least 3 levels)

e.g. Number of major inspection defects found,
Number of test defects found,
Estimated size of code to nearest 10 KSLOC,
Estimated size of needed staff,
Complexity and other measures used to evaluate architecture, design & code

MSE Calculations for Attribute Data—5

Interpreting results of Kappa’s or Kendall’s coefficients

Green	When Result = 1.0	perfect agreement
Green	When Result > 0.9	very low measurement error
Yellow	When 0.70 < Result < 0.9	marginal measurement error
Red	When Result < 0.7	too much measurement error
Red	When Result = 0	agreement only by chance

Interpreting the accompanying p value

Null Hypothesis: Consistency by chance; no association

Alternative Hypothesis: Significant consistency & association

Thus, a p value < 0.05 indicates significant and believable consistency or association.

MSE Calculations for Attribute Data—6

How do you interpret these **Kappa values** and p values for this nominal measurement system?

Fleiss' Kappa Statistics

Appraiser	Response	Kappa	Kappa	Z	P(vs > 0)
1	Architecture	*	*	*	*
	Code	0.780220	0.316228	2.46727	0.0068
	Design	0.523810	0.316228	1.65643	0.0488
	Reqt	0.780220	0.316228	2.46727	0.0068
	Overall	0.699248	0.223916	3.12281	0.0009
2	Architecture	*	*	*	*
	Code	0.780220	0.316228	2.46727	0.0068
	Design	0.393939	0.316228	1.24575	0.1064
	Reqt	0.375000	0.316228	1.18585	0.1178
	Overall	0.527559	0.230495	2.28881	0.0110
3	Architecture	-0.052632	0.316228	-0.16644	0.5661
	Code	0.797980	0.316228	2.52343	0.0058
	Design	0.583333	0.316228	1.84466	0.0325
	Reqt	*	*	*	*
	Overall	0.626168	0.277383	2.25742	0.0120

MSE Calculations for Attribute Data—7

Response is an ordinal rating. Thus, appraisers get credit for coming close to the correct answer!

How do you interpret these **Kendall coefficients** and p values?

Kendall's Correlation Coefficient

Appraiser	Coef	SE Coef	Z	P
Duncan	0.89779	0.192450	4.61554	0.0000
Hayes	0.96014	0.192450	4.93955	0.0000
Holmes	1.00000	0.192450	5.14667	0.0000
Montgomery	1.00000	0.192450	5.14667	0.0000
Simpson	0.93258	0.192450	4.79636	0.0000

Addenda

Cheap Sources of Information and Tools

MSE Details

DMAIC Roadmap – Guidance Questions

Define Guidance Questions

Define → Measure → Analyze → Improve → Control

Define project scope

- What is the current problem to be solved?
- What are the goals, improvement targets, & success criteria?
- What is the business case, potential savings, or benefit that will be realized when the problem is solved?
- Who are the stakeholders? The customers?
- What are the relevant processes and who owns them?

Establish formal project

- Have stakeholders agreed to the project charter or contract?
- What is the project plan, including the resource plan and progress tracking?
- How will the project progress be communicated?

Measure Guidance Questions

Define → **Measure**

Define

- Does the measurement system yield accurate, precise, and reproducible data?
- Are urgently needed improvements revealed?
- Has the risk of proceeding in the absence of 100% valid data been articulated?

Identify needed data

- What are the process outputs and performance measures?
- What are the process inputs?
- What info is needed to understand relationships between inputs and outputs? Among inputs?
- What information is needed to monitor the progress of this improvement project?

Obtain data set

- Is the needed measurement infrastructure in place?
- Are the data being collected and stored?

Evaluate data quality

Summarize & baseline data

- What does the data look like upon initial assessment? Is it what we expected?
- What is the overall performance of the process?
- Do we have measures for all significant factors, as best we know them?
- Are there data to be added to the process map?
- Are any urgently needed improvements revealed?
- What assumptions have been made about the process and data?

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Analyze Guidance Questions

- Are there any hypotheses that need to be tested?
- What causal factors are driving or limiting the capability of this process?
- What process map updates are needed?
- Are there any immediate issues to address? Any urgent and obvious needs for problem containment?

Analyze

Explore data

- What do the data look like?
- What is driving the variation?
- What is the new baseline?
- What are associated risks and assumptions associated with revised data set and baseline?

Characterize process and problem

Update improvement project scope and scale

- Should the improvement goal be updated?
- Is additional data exploration, data decomposition, and/or process decomposition needed? Is additional data needed?
- Can I take action? Are there evident improvements and corrections to make?
- Have I updated the project tracking and communication mechanisms?

solutions

method

Evaluate data quality

Summarize, baseline data

Improve Guidance Questions

Improve

Identify possible solutions

- What type of improvement is needed?
- What are solution alternatives to address urgent issues and root causes of identified problems?
- What are the process factors to be adjusted?
- What is the viability of each potential solution?
- What is the projected impact or effect of each viable solution?

Select solution

- What are the relative impacts and benefits?
- What are relevant technical and logistical factors?
- What are potential risks, issues, and unintended consequences?

Implement (pilot as needed)

- What is the action plan with roles, responsibilities, timeline and estimated benefit?
- Is piloting needed prior to widespread implementation?

Evaluate

- Did the solution yield the desired impact?
- Has the goal been achieved?
- If piloted, are adjustments needed to the solution prior to widespread rollout? Is additional piloting needed?
- How will baselines, dashboards, and other analyses change?

Control Guidance Questions

Define → M… → … → … → **Control**

- Should data be compared to a range? If so, which range?
- Does procedural adherence need to be monitored?

Define control method

- What updates are needed in the measurement infrastructure?
- What process documentation needs to be updated?
- What new processes or procedures need to be established?
- Who is the process or measurement owner who will be taking responsibility for maintaining the control scheme?

Implement

- Have we documented improvement projects for verification, sustainment, and organizational learning?
- What are the realized benefits?
- Is the project documented or archived in the organization asset library?
- Have documentation and responsibility been transferred to process or measurement owner?

Document