Six Sigma & Software Process Improvement

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Scope

- PS&J Software Six Sigma
- Introduction to Six Sigma
- Applying Six Sigma Techniques to Software Process Improvement
- Variation and Statistical Process Control
- Run Charts
- Optimizing and inspection Process
- Controlling Product Quality
- Integrating Six Sigma and the Capability Maturity Model
- PSP and TSP and Six Sigma
- Six Sigma Deployment

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PS&J Software Six Sigma

- Our mission is to provide our customer with the management expertise to
  - Successfully plan and execute their software development projects
  - Systematically improve productivity and cycle time
  - Get the optimum return from their SPI activities

- We
  - Guide our customers through the jungle of conflicting claims about SPI
  - Help them create links between their SPI activities and measurable business results

If you can't measure a positive return on your SPI investment within a year, it's probably not worth doing !

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Experience

- Core team of four professionals with a total of over 100 years experience in software development, management, and process improvement
  - Defense, Aerospace, Industrial Automation & Controls, Medical Instrumentation, Financial Services, Telecommunications
- Moved an organization of 150 software engineers from CMM Level 1 to 4 in less than 5 years – first level 4 organization in AlliedSignal
- Working closely with Watts Humphrey and his SEI team, led the first PSP/TSP projects within AlliedSignal
- Ran Honeywell's corporate level software process improvement organization
  - Six Sigma Software Training and deployment, CMM Based Assessments, PSP/TSP deployment
  - Provided support for 6000 software engineers at 100 sites around the world
- SEI transition partner – more experience with PSP/TSP than anyone other than the SEI team

We offer a unique blend of software management skill and process deployment experience

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PS&J Software Six Sigma Products & Services

- CMM assessments
- SPI planning workshops, ROI analysis, mentoring
- Software project management training and mentoring
- Software 6 Sigma implementation consulting, training, mentoring
- Appraisals & defect prevention training
- PSP training
- TSP launches and mentoring
- Proposal and project red teams

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Starting with Business Results

- Six Sigma is a metrics driven approach to continuous improvement
- Six Sigma starts with quantitative business goals that are of direct value to the customer
- Analysis of process metric data is used to identify specific sub processes with the greatest leverage to affect the business goals
- Critical inputs affecting process performance are identified
- Improvement goals are related to changes in process outputs
- Improvements are implemented on a pilot basis
- If measurements indicate goals have been achieved, improvements are institutionalized
- Process performance is controlled to new performance levels by controlling critical input variables

What are you going to tell your new boss when she asks you to quantify the return on your SPI activities?

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Why continuous process improvement?

- If your process does not include continuous improvement and your competitor's does, you cannot stay in business
- Suppose a competitor systematically improves productivity at a relatively modest annual rate of 7%, year over year, while your productivity remains static. After only 3 years, the productivity differential is $(1.07)^3 = 1.23$, a 23% advantage
- Changing market reality:
  - Old Paradigm: Cost + Profit = Selling Price
  - New Paradigm : Selling Price - Cost = Profit

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Companies

- Six Sigma originated at Motorola
- Early adopters included
  - Texas Instruments
  - AlliedSignal (Honeywell)
  - General Electric
- Many more organizations moved into Six Sigma after General Electric began publicizing its program
  - Nokia, Bombardier, Siebe, Lockheed Martin, Sony, Crane, Polaroid, Avery Dennison, Shimano, Raytheon, Kodak, JP Morgan, Citicorp, TRW, Litton, Boeing
- Initial success in manufacturing and operations, later in services
- Lots of current interest in extending it into product engineering with Design for Six Sigma

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DMAIC – Continuous Improvement Cycle

- **Define process**
- **Measure the process**
- **Analyze the process to identify causal variables**
- **Improve the process**
  - **Modify the process**
  - **Measure the modified process**
  - **Verify the improvement**
  - **Define control mechanism**
- **Control the process to new performance levels**
  - **Monitor performance metrics and take designated action when required**
  - **Perform continuous verification of the stability and capability of the process**

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Why Apply Six Sigma to SPI?

- **Software-dependent businesses have three critical needs**
  - **better cost and schedule management**
  - **better quality management**
  - **cycle time improvement**
- **With conventional CMM based SPI, it is easy to fall into the trap of laying a veneer of process over the same old activities**
  - **adds overhead while having no significant effect**
  - **destroys credibility with the developers**
- **In order to meet business needs, one cannot simply try harder. One must significantly change the engineer's daily activities**
- **Six Sigma increases the likelihood of sustainable success**
  - **linkage to business goals**
  - **objective measurements**
  - **active participation in SPI by the engineers**

One definition of insanity: doing the same thing over and over and expecting a different result

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Software Six Sigma

- Software Six Sigma is an overall strategy to accelerate and sustain continuous improvement in software development process efficiency and in software product quality

- A Six Sigma software development process is characterized by
  - the application of statistical tools to process and product metrics
  - quantitative management of product quality
    - allowing delivery of very high quality product (very few latent defects)
    - reducing time spent in integration and test cutting overall cost and cycle time
    - making the software development process more repeatable and predictable
  - closed loop quantitative process management

- Sigma can also be used as a measurement of product quality
  - Six Sigma processes produce only 3.4 defects per million opportunities - or 99.9997% error-free.
  - Typical software processes operate at between 2.3 and 3.0 sigma
  - The best software processes operate at 4 to 5 sigma

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Software <u>is</u> different, but it is also controllable!

- **Software development is different - it is not like manufacturing**
- **Process variation can never be eliminated or even reduced below a moderate level**
  - **No two modules are alike so process performance always includes an intrinsic degree of variability**
  - **There are very large differences in skills and experience from one developer to another**
- **However, software development processes can be fully characterized by three simple measurements**
  - **Time: the time required to perform a task**
  - **Size: the size of the work product produced**
  - **Defects: the number and type of defects, removal time, point of injection and point of removal**
- **Software measurements are amenable to statistical analysis provided:**
  - **Data is complete, consistent, and accurate**
  - **Data from individuals with widely varying skill levels is not mixed**
- **Statistical Process Control is applicable to software process management**

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Applying the Six Sigma Toolkit to Software

- The majority of elements of the six sigma toolkit are directly applicable to every day software development data analysis
  - Quality Function Deployment (QFD) for prioritizing requirements
  - Process mapping for work flow optimization
  - Correlation Analysis
  - Analysis of Variance (ANOVA)
  - Failure Modes Effect Analysis (FMEA)
  - Statistical Process Control
  - Control Plans
- Design of Experiments (DOE), Measurement System Evaluation (MSE) and LEAN tend to have less applicability to every day software development situations than they do in manufacturing applications

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A control system viewpoint

- The outputs of a process, y, are usually a function, f, of a set of control variables, x, and include a process noise component ε:

$$y = f(x) + \varepsilon$$

  - The y's are not directly controllable, but they can be controlled by the directly controllable x's.
  - Making significant, lasting, and robust improvements, requires identifying, monitoring, and controlling the input variables
  - Statistical measurements are necessary to avoid re-acting to the noise ε

- For a software project, y's include cost and schedule and x's include product quality and time on task.
  - Manage cost and schedule to overall project goals by continuously managing product quality and time on task to appropriate intermediate goals
- For inspections, the y's include yield and defect removal cost and the x's include review rate, checklist content, and team size

- Ideally we would like software process that acts like a responsive, "closed loop" control system driving the x's to planned values and through their relationship to the y's, achieving overall product goals

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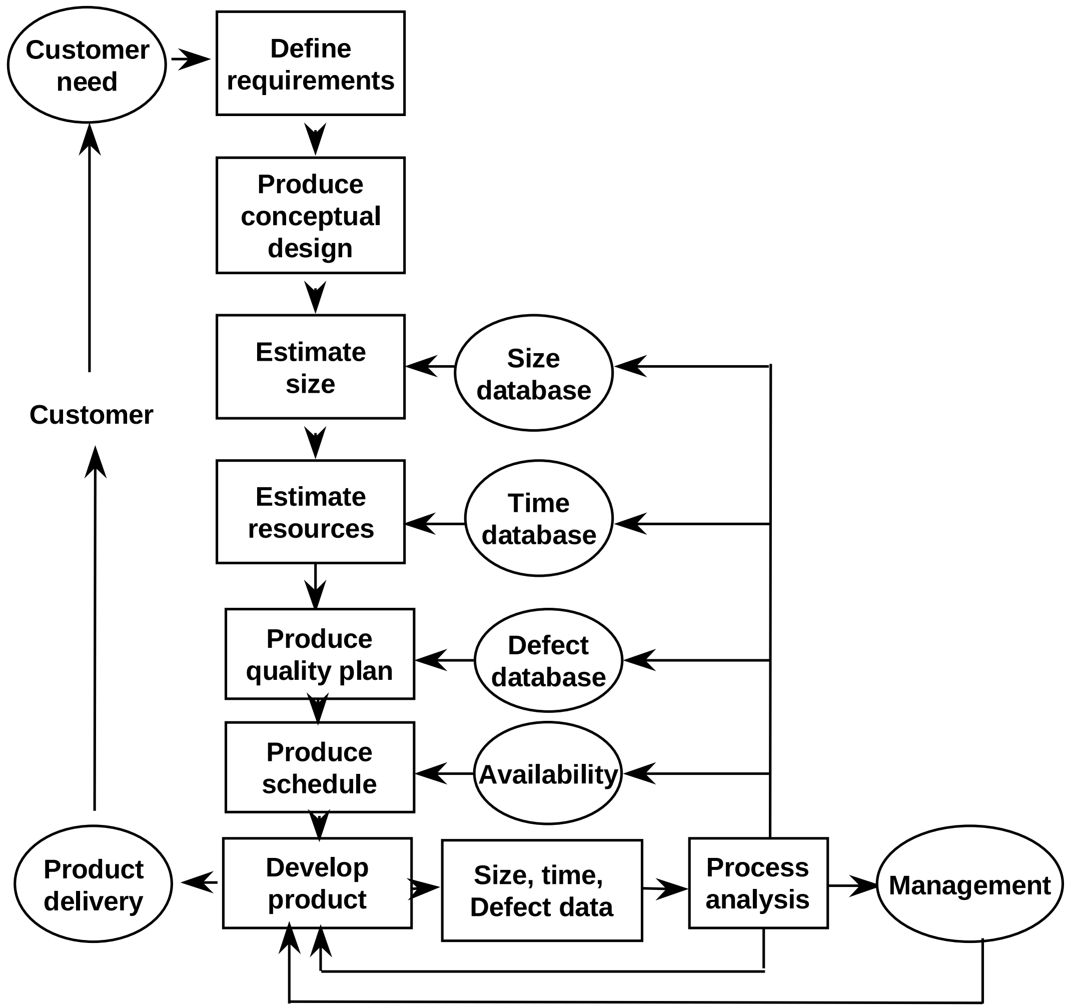
A Closed Loop Process



- Tasks are planned based on historical time, size, and defect data.
- Individuals log time and defect data in process as they perform their tasks
- Individuals manage their own tasks using real-time feedback provided by the difference between planned and actual process metrics
- Activities are driven to planned performance
- Planned performance levels serve as phase exit criteria
- Automated in-process data acquisition and real time analysis is a key enabler

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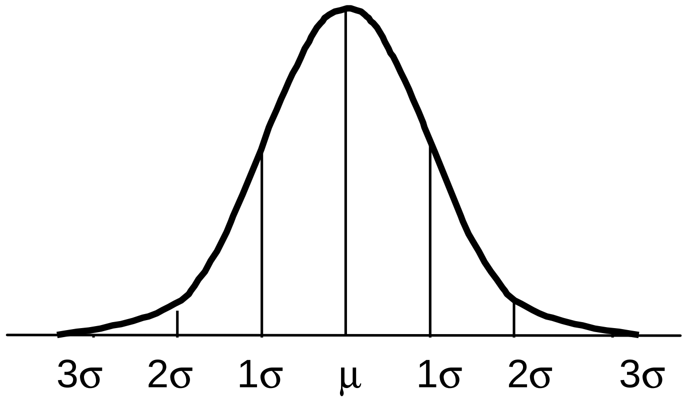
Normal Distribution and Variation

- Most data tends to follow the normal distribution or bell shaped curve.
- One of the key properties of the normal distribution is the relationship between the mean (μ) and the standard deviation (σ).
- σ is a measure of the variation present in the data

$$\sigma = \sqrt{\frac{1}{n-1}\sum (x - x_{avg})^2}$$



- 68.2% of the data lies within 1σ of μ
- 95.4% of the data lies within 2σ of μ
- 99.7% of the data lies within 3σ of μ
- 99.99999975% of the data lies within 6σ of μ

- For data that follows a normal distribution
  - ±3σ is the natural limit of random variation of data produced by a process
  - ±3σ represents 99.7% of all data produced by a process
  - ±3σ are the control limits for natural variation

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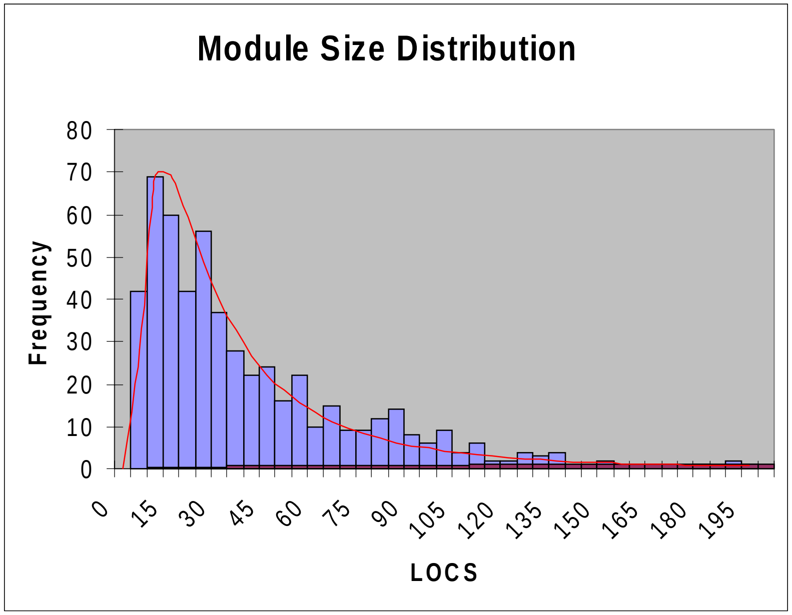
Asymmetric Distributions

- The distributions associated with software process measurements tend to be asymmetric
  - Many variables of interest cannot have negative values, e.g. product size, effort, and defect density.
    - In general these quantities have more “room to vary” up than down since they are constrained to be non-negative.
    - This causes an asymmetric distribution of values.
  - Unlike the normal distribution, the mean, median, and mode are not coincident.
    - The mean will not be the most likely value of the random variable and that there will be a higher likelihood of a random variable being on one side of the mean than on the other.
- The empirical rule allows us to treat non-normal data as if it were normal for the purposes of statistical process control



- Given a homogenous set of data
  - Roughly 60%-75% of the data will be located within 1σ of μ
  - Roughly 90%-98% of the data will be located within 2σ of μ
  - Roughly 99%-100% of the data will be located within 3σ of μ

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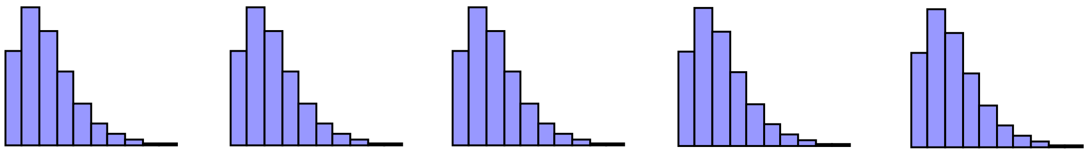
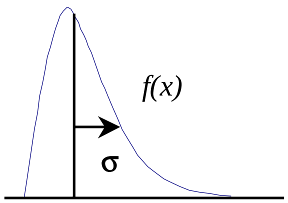
Statistical Control

- When a process displays statistical control, a sequence of measurements x_1, x_2, x_3,,…x_n,… will display a consistent and predictable amount of variation

- Periodic histograms of the measurements will exhibit a consistent pattern of variation, so that it is possible to represent this pattern of variation by a stationary density function f(x)





- It is possible to make statistically valid predictions about processes that exhibit statistical control
- When a process does not exhibit statistical control, the distribution function changes over time destroying the ability to make statistically based predictions

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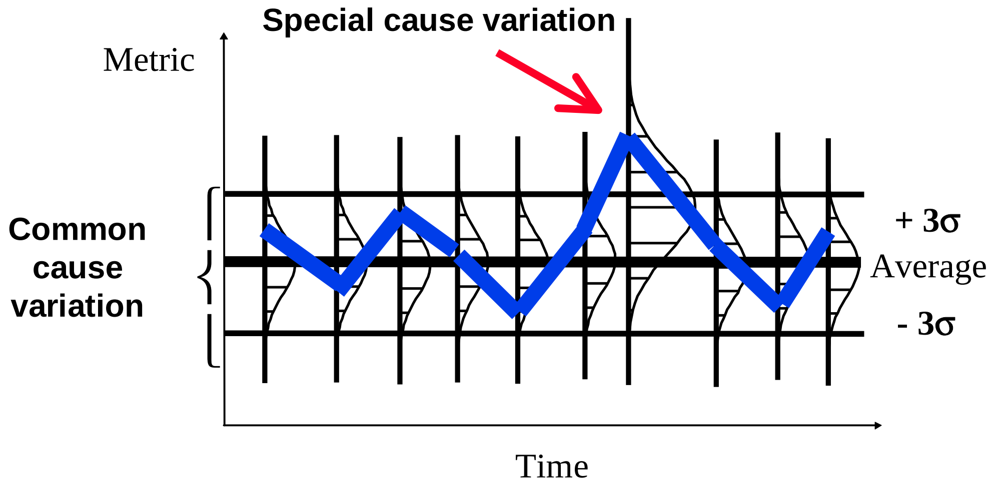
Control Charts



- Control charts are a graphical depiction of the normal range of variation of a stable process.
- Common cause variation is normal random variation in process performance
  - Reduction requires a process change
- Special cause variation represents an exception to the process
  - Actions to correct special cause variation must eliminate the specific assignable cause
  - Special cause action eliminates a specific isolated event; does not necessarily involve a process change

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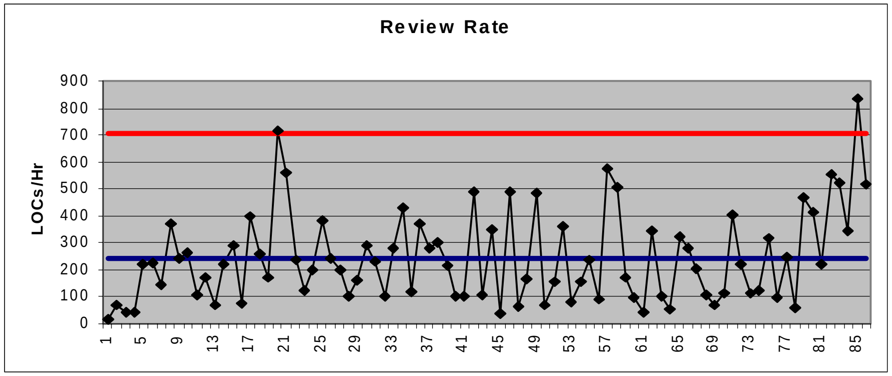
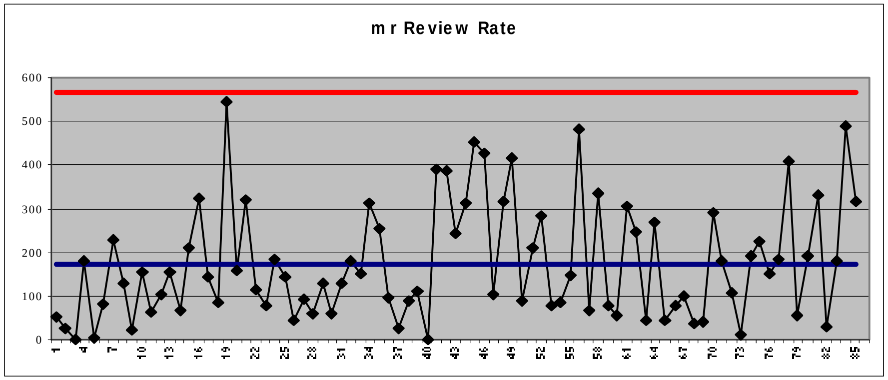
XmR Charts

- X is time series of variables x_i, i = 1,2,...
- R is time series for range of X from measurement to measurement, i.e. $r_i = |x_i - x_{i-1}|$

- x_{avg} is average value of X
- mR is average value of R

- X chart shows
  - x_i vs. time
  - X_{avg}
  - $CL_x = X_{avg} \pm 2.660$ mR
- R chart shows
  - r_i vs time
  - mR
  - $CL_r = 3.628$ mR





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Detecting Assignable Causes

- X is out of control whenever
  - a single point x_i falls outside the three sigma control limits CL_X
  - at least two out of three successive x_i's fall on the same side of, and more than two sigma units away from, the central line
  - at least four out of five successive x_i's fall on the same side of, and more than one sigma unit away from, the central line
  - at least 8 successive x_i's fall on the same side of the central line
- R is out of control when
  - 8 or more successive r_i's fall on same side of median
  - or 12 or more successive r_i's fall on same side of mR
- A trend is any upward or downward movement of 5 or more consecutive points
- Use of control charts to quantify normal variation and to identify the presence of assignable causes is called Statistical Process Control (SPC)

Never attempt to interpret the X chart when the mR chart is out of control !

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Always Take Appropriate Action

Avoid taking special cause action, designed as a one time event to correct an isolated incident, on a common cause problem that is inherent to the process

Don't over react to common cause variation in process performance

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Inspections

INSPECTION PROCESS

INPUTS → **INSPECTION Process** → **OUTPUTS**

INPUTS

- Code
- Checklists
- Scripts
- Team

OUTPUTS

- prep time
- meeting time
- closeout time
- defects
- defects/inspector
- product size
- review rate
- defects/KLOC
- completed checklists

- **Optimizing the inspection process is a good place for an organization to try out a six sigma approach**

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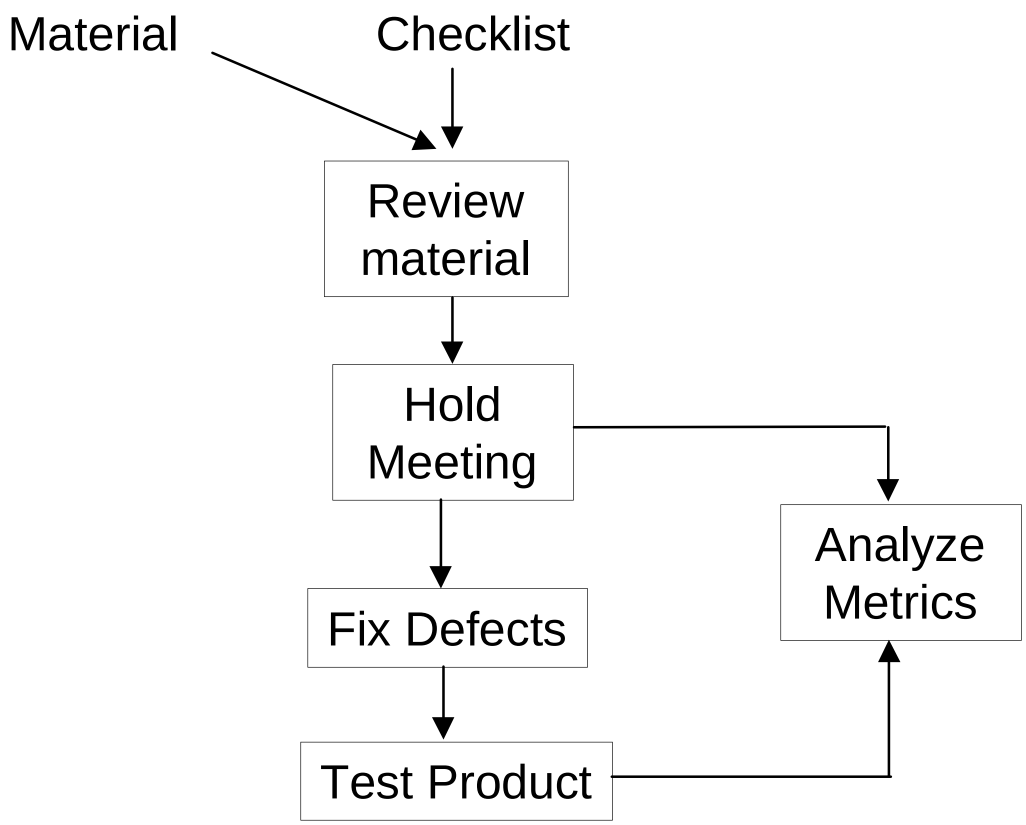
Open Loop Inspection Process - Tracking



- Track process metrics:
  - rate vs yield

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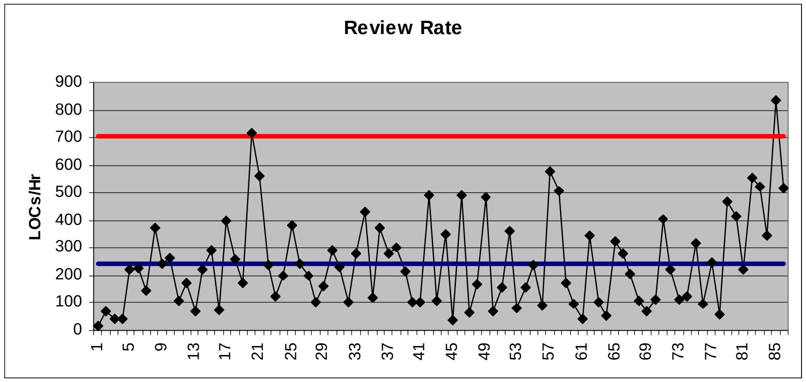
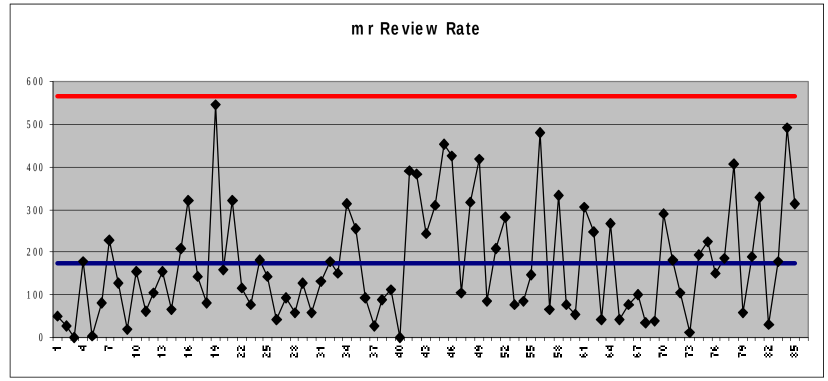
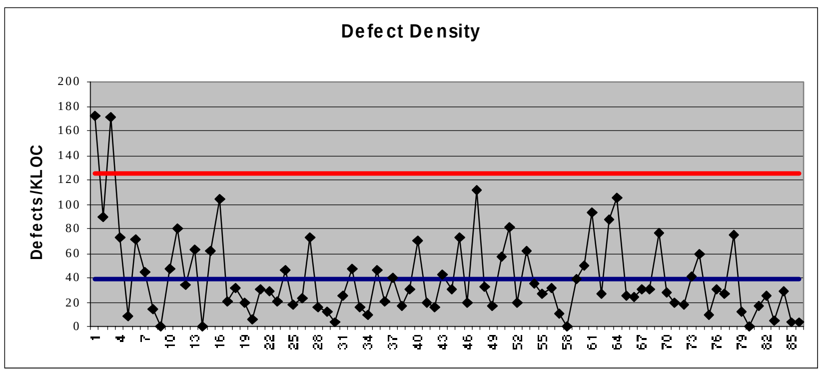
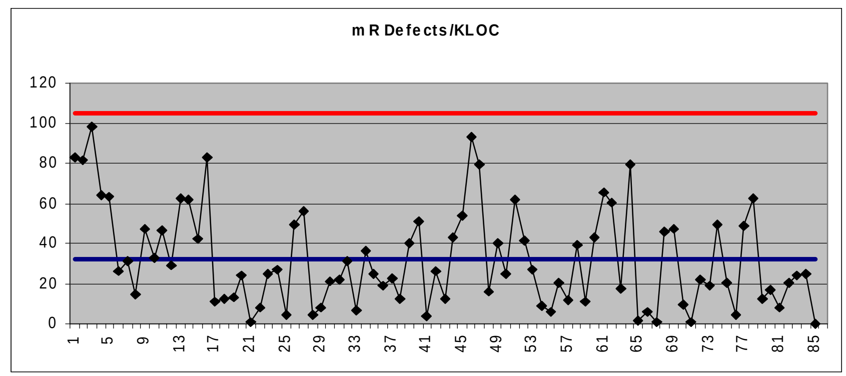
Open Loop Process Run Charts









- **Average review rate 244 LOCs/Hr**
- **Average defect density 39 Defects/KLOC**
- **Average removal rate 6/Hr**

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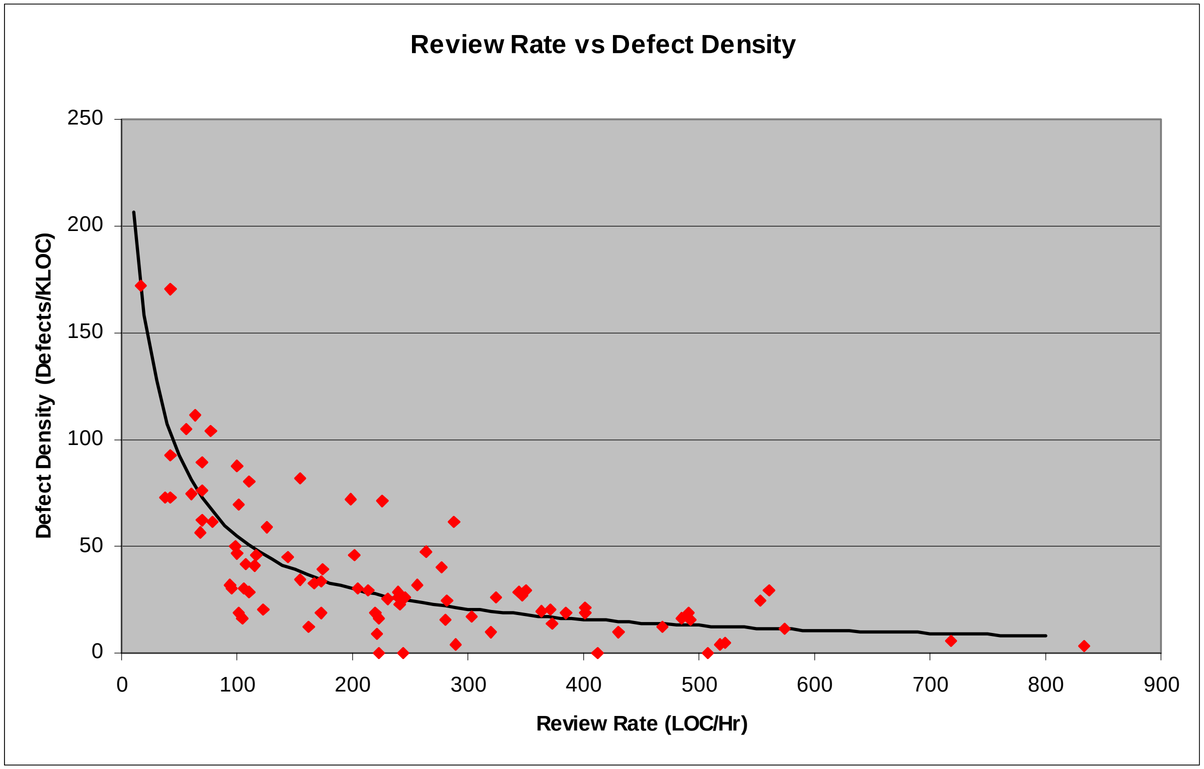
Correlation Analysis



- **To evaluate review rate for suitability as a control variable use correlation analysis**
- **$r^2 = 0.67$ – moderately good fit by hyperbola**
- **Chart suggests targeting review rate in the 100 – 200 LOCs hour range**

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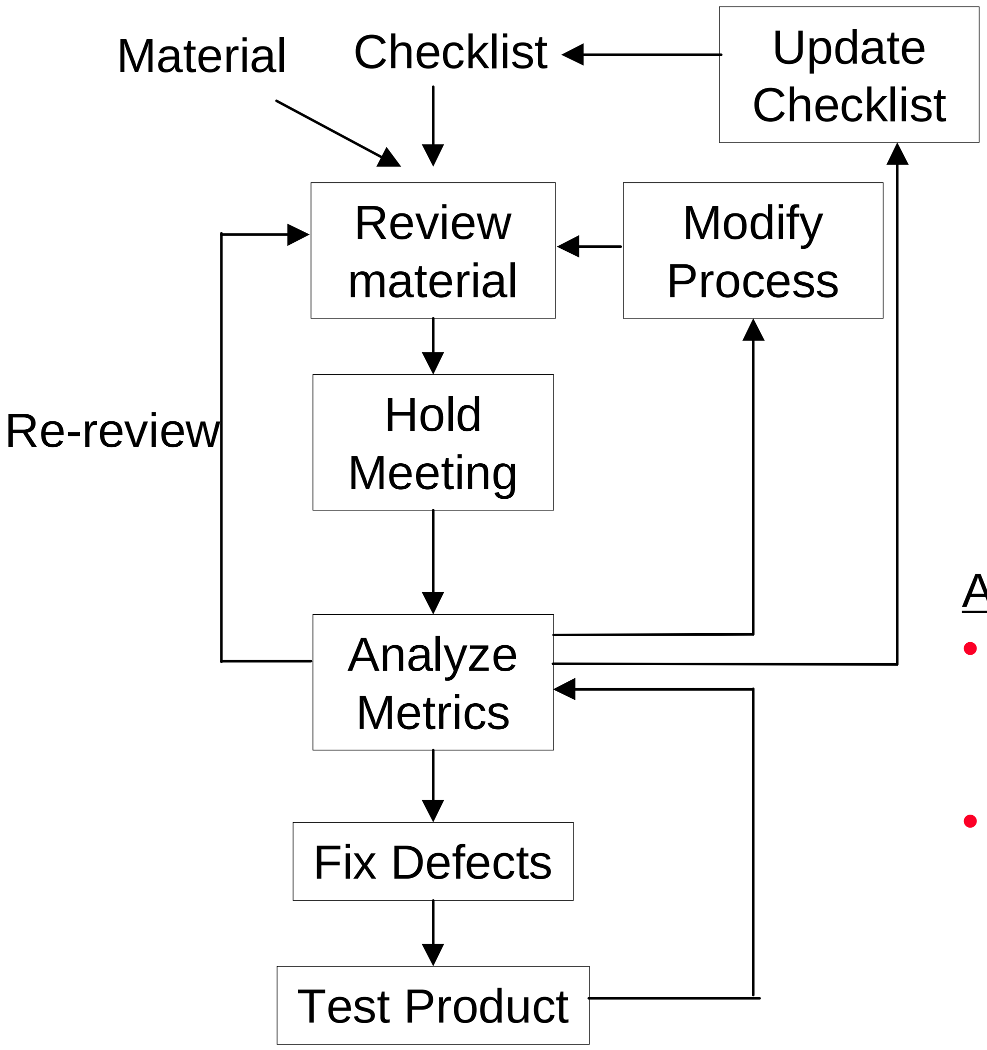
Closed Loop Inspection Process - Managing



Update Checklist

- Remove questions that are not catching defects.
- Add questions to catch defects that are leaking out to test.

Modify Process

- Modify review rate
- Vary size of material reviewed
- Include test cases

Analyze Metrics

- Process metrics:
  - Rate vs Yield
  - Effectiveness of checklist questions
- Product metrics:
  - Compare yields to quality plan
  - Consider re-review of products that fall outside quality thresholds
  - Buggiest products list

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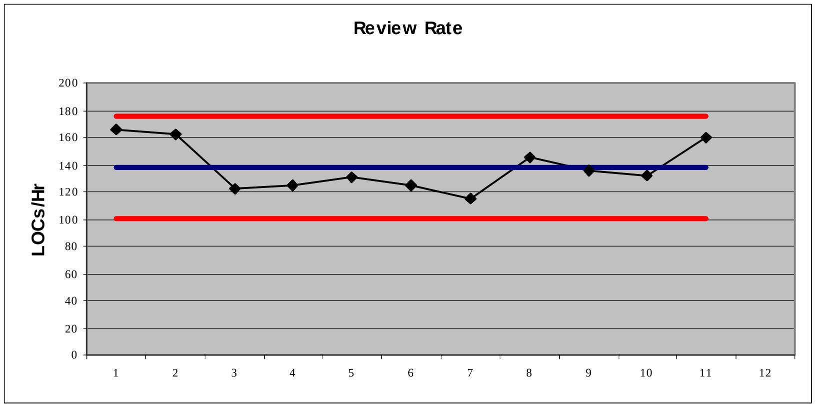
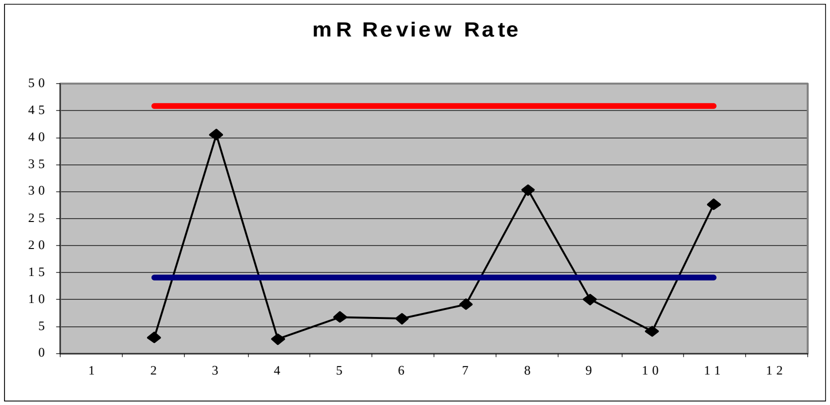
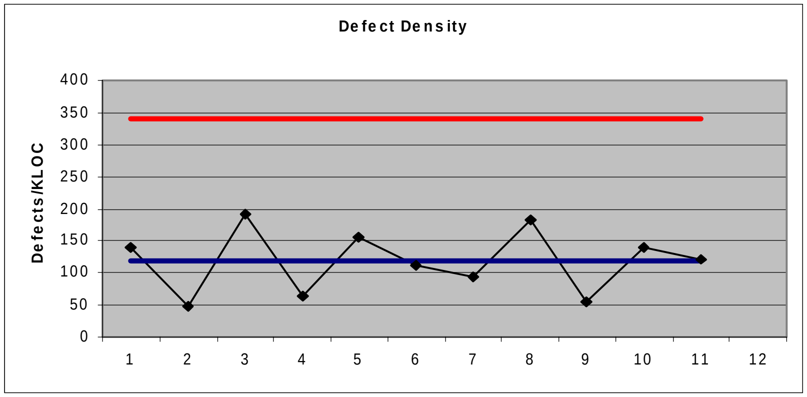
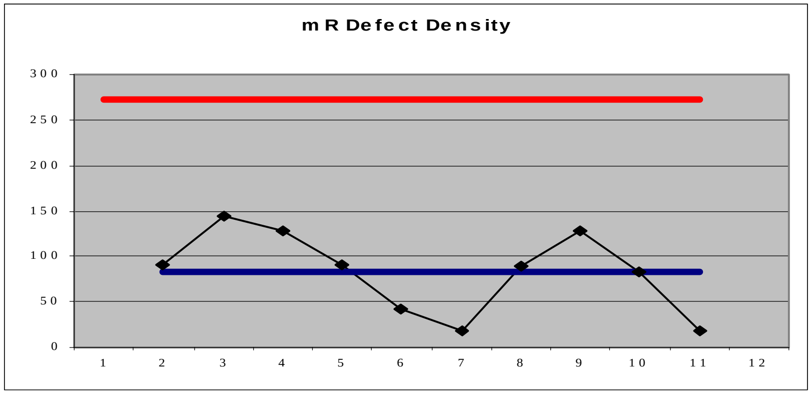
Closed Loop Run Charts









- **Targeting rate yielded major decrease in variation**
- **Closed loop process achieved significant improvements**
  - **Average Review Rate 138 LOCs/hr**
  - **Average Defect Density 118 Defects/KLOC**
  - **Average Defect Removal Rate 15/hr**

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Yield and the Hidden Factory

Traditional View

"The Hidden Factory"

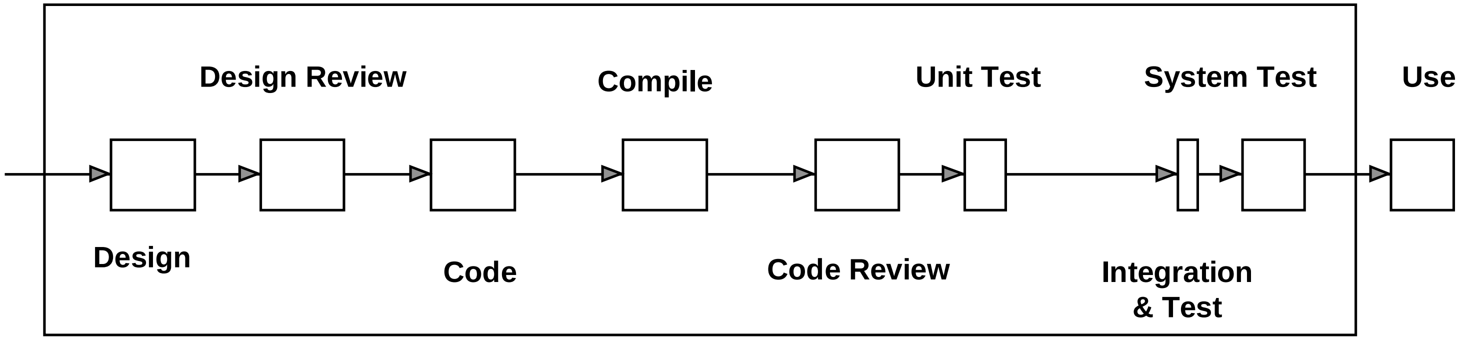
Defects are not recorded prior to system test.

Yield = $n_{system}/(n_{system} + n_{escapes})$.

The <u>true</u> yield for the development process must include all defects injected during the development process.

Yield = $n_{developmen}t/(n_{development} + n_{escapes})$.

6σ View



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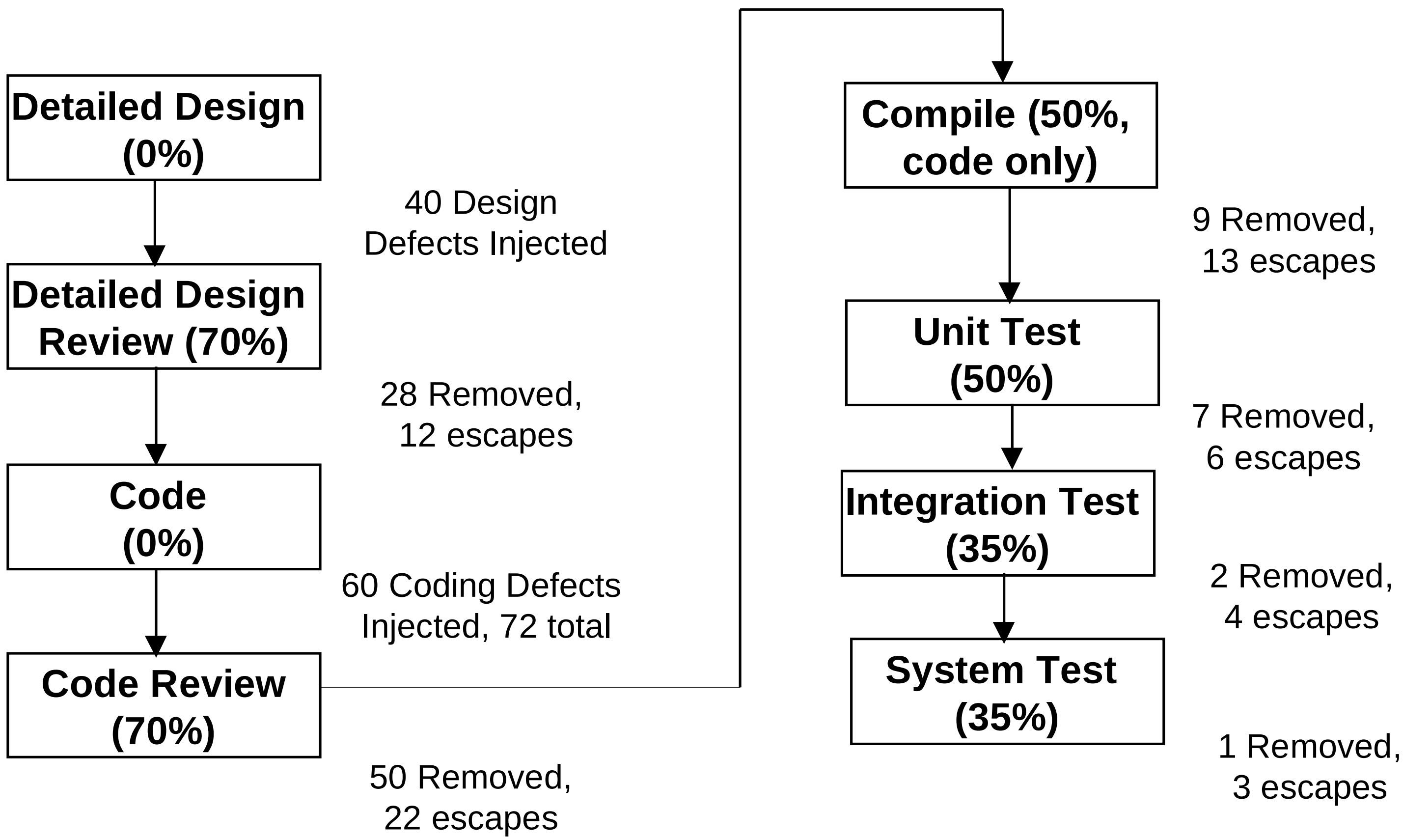
Process Yield



What's the yield of this process? **97/(40 + 60) = 97%**

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Control Plan for Product Quality

- **Inspection process can be characterized by its yield**
- **Historical yields allow you to plan the number of defects that will be removed**
- **Manage to the plan by taking planned corrective actions when actual Defects Contained diverge from planned by an amount that exceeds a threshold**
  - **If a module has too many defects in integration, pull it and inspect it**

	Defects leaked from prev phase	New Defects Injected	Phase Yield	Defects Contained	Defects Leaked	Defect Removal Cost	Total Removal Cost (hrs)
Design	0.0	40	0%	0.0	40.0	n/a	0.00
Design Bench Check	40.0	0	50%	20.0	20.0	10 mins	3.33
Design Inspection	20.0	0	50%	10.0	10.0	30 mins	5.00
Code	10.0	60	0%	0.0	70.0	n/a	0.00
Code Bench Check	70.0	0	70%	49.0	21.0	5 mins	4.08
Compile	21.0	0	50%	10.5	10.5	1 min	0.18
Code Inspection	10.5	0	60%	6.3	4.2	15 mins	1.58
Unit Test	4.2	0	50%	2.1	2.1	15 mins	0.53
Integration Test	2.1	0	35%	0.7	1.4	18 hrs	13.23
System Test	1.4	0	35%	0.5	0.9	18 hrs	8.60
CUSTOMER	0.9						37

Quality Plan for 1 KLOC Embedded Code

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Calculating Return on Investment - 1

- Without inspections, the cost of defect removal is 267 hrs per KLOC
- Savings require estimating the difference in cost between finding a defect in review and finding it later in the process

	Defects leaked from prev phase	New Defects Injected	Phase Yield	Defects Contained	Defects Leaked	Defect Removal Cost	Total Removal Cost (hrs)
Design	0.0	40	0%	0.0	40.0	n/a	0.00
Design Bench Check	40.0	0	0%	0.0	40.0	10 mins	0.00
Design Inspection	40.0	0	0%	0.0	40.0	30 mins	0.00
Code	40.0	60	0%	0.0	100.0	n/a	0.00
Code Bench Check	100.0	0	0%	0.0	100.0	5 mins	0.00
Compile	100.0	0	50%	50.0	50.0	1 min	0.83
Code Inspection	50.0	0	0%	0.0	50.0	15 mins	0.00
Unit Test	50.0	0	50%	25.0	25.0	15 mins	6.25
Integration Test	25.0	0	35%	8.8	16.3	18 hrs	157
System Test	16.3	0	35%	5.7	10.6	18 hrs	102
CUSTOMER	10.6						267

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Calculating Return on Investment - 2

	Defects leaked from prev phase	New Defects Injected	Phase Yield	Defects Contained	Defects Leaked	Defect Removal Cost	Total Removal Cost (hrs)
Design	0.0	40	0%	0.0	40.0	n/a	0.00
Design Bench Check	40.0	0	50%	20.0	20.0	10 mins	3.33
Design Inspection	20.0	0	50%	10.0	10.0	30 mins	5.00
Code	10.0	60	0%	0.0	70.0	n/a	0.00
Code Bench Check	70.0	0	70%	49.0	21.0	5 mins	4.08
Compile	21.0	0	50%	10.5	10.5	1 min	0.18
Code Inspection	10.5	0	60%	6.3	4.2	15 mins	1.58
Unit Test	4.2	0	50%	2.1	2.1	15 mins	0.53
Integration Test	2.1	0	35%	0.7	1.4	18 hrs	13.23
System Test	1.4	0	35%	0.5	0.9	18 hrs	8.60
CUSTOMER	0.9						37

- **With inspections, the cost of defect removal drops to 37 hours, a savings of 230 = 267 – 37 hours**
- **The cost of holding the inspections is about 80 hours (at 100 LOC/hr), so the net savings is 150 hours**

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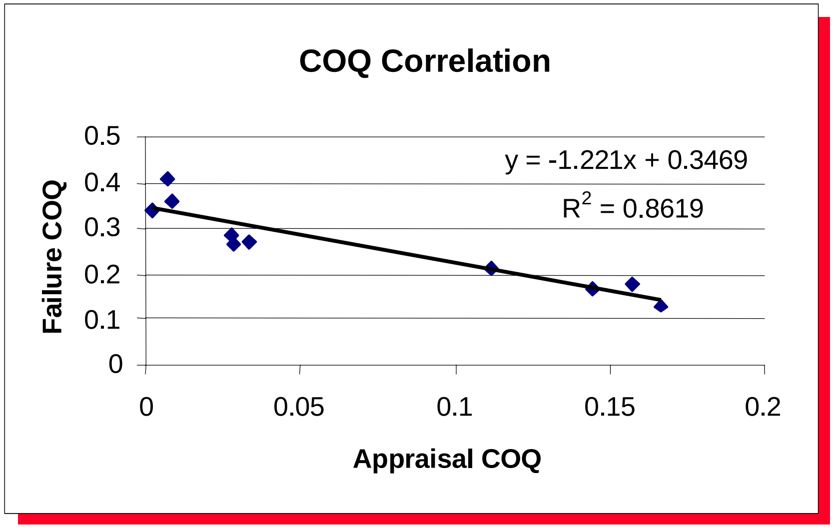
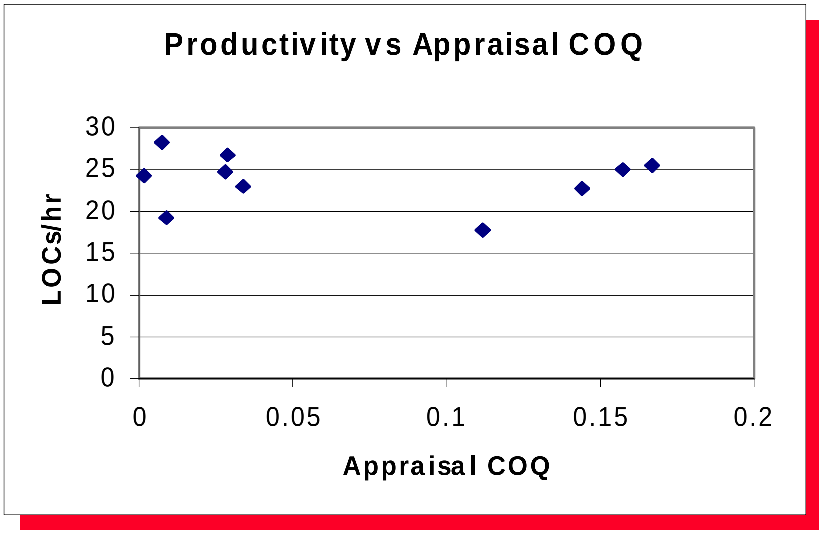
Quality is Free





- **As appraisal cost increases**
  - **Failure costs decrease**
  - **Overall COQ remains constant**
  - **Productivity remains constant**
- **No net cost to performing appraisals**
- **Appraisal cost is more controllable than failure cost**
- **Results in more accurate estimates, fewer defects to integration and system test**

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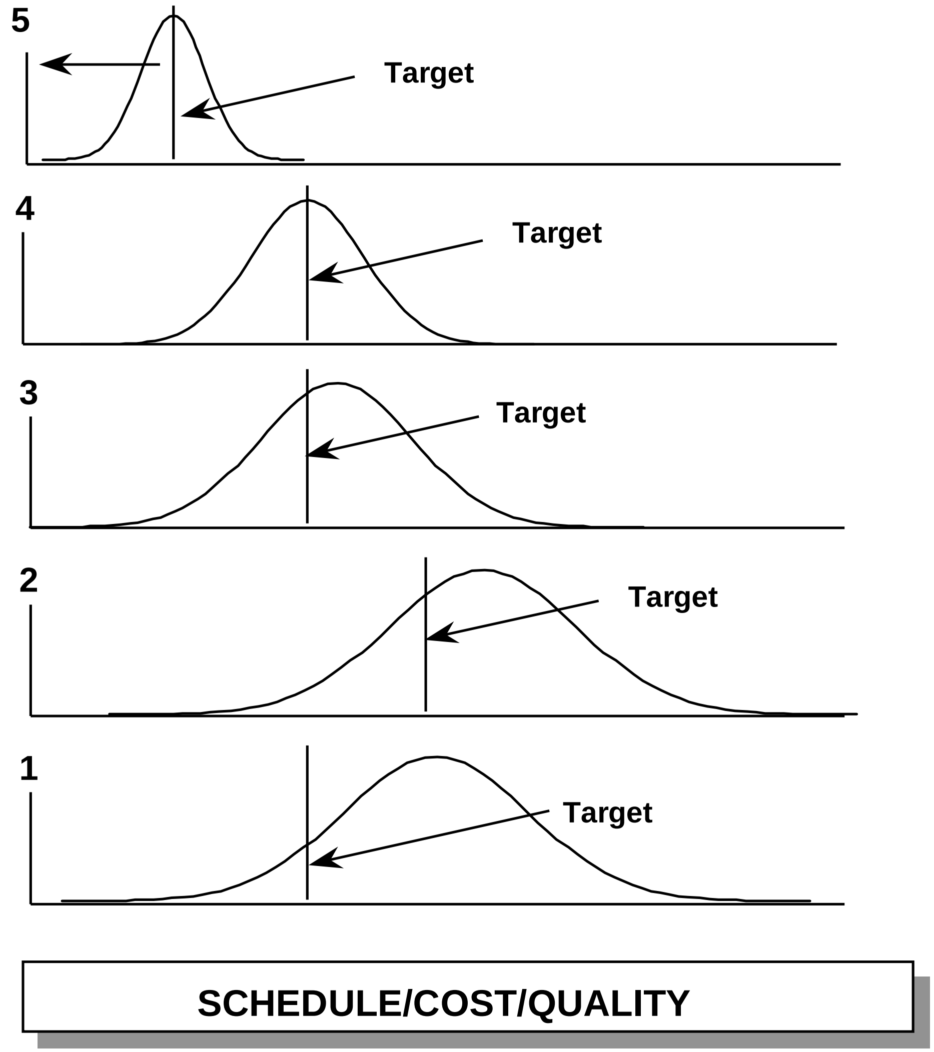
CMM – A Six Sigma Perspective



- **From a business perspective, predictable process performance is a key aspect of process capability**
- **Predictable performance requires a stable process**
- **First step to a stable process is a "defined process"**
- **Moving up the CMM levels corresponds to first stabilizing the process, then reducing variation, and finally centering the process on target performance**

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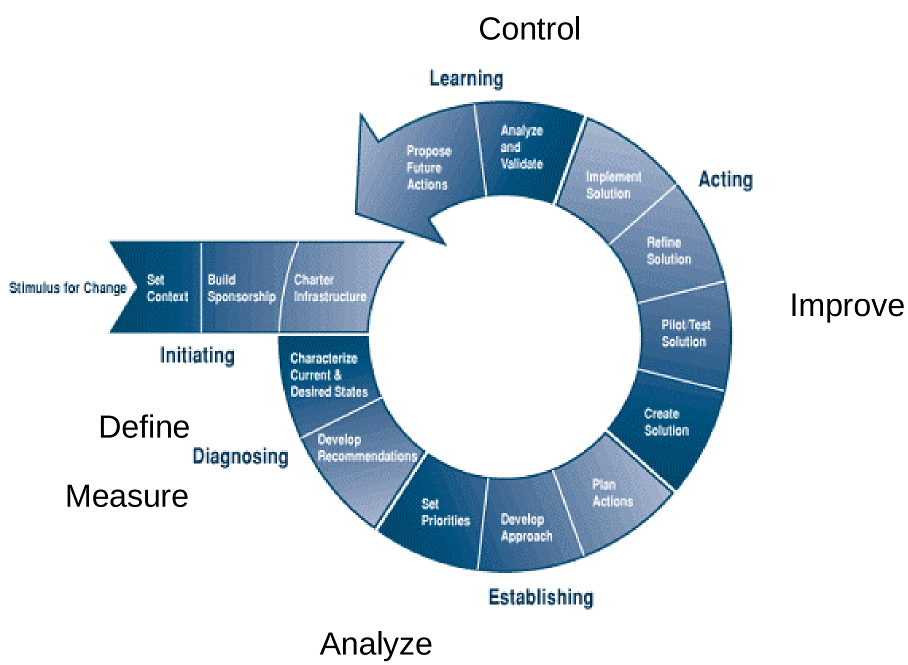
Driving CMM Based SPI With Six Sigma

- **Six Sigma can be used to drive CMM based SPI in a bottoms-up fashion**
- **Emphasis on direct coupling to business results and measurable improvements**
  - **allows easy quantification SPI ROI**
  - **moves organization away from level oriented goals – levels become a by-product of SPI, not the primary goal of SPI**
  - **sustains executive sponsorship**
- **Metrics driven bottoms up approach more likely to result in real measurable improvements than top down process deployment driven by level goals**
- **Apply DMAIC to one or two processes at a time as part of an SPI action plan**
- **Look at process metrics and success at achieving business goals in assessing process effectiveness**

IDEAL and DMAIC



- **Track SPI ROI using relationships to business goals**
- **If your organization has a six sigma initiative, integrate your CMM activities with it**

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PSP

- PSP is a lightweight level 5 process
- It is based on six sigma concepts
  - fact based
  - data driven
  - closed loop
- It is designed to be introduced bottoms up in an organization, one team at a time
- It doesn't require a high level of process maturity for introduction, basic configuration management and quality assurance are the only pre-requisites
- Data recording overhead is exceptionally low – typically less than 5 minutes per day
- Engineers are provided with real-time data analysis for decision support in the course of doing their task and performing a task post-mortem

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TSP

- **Team oriented approach to project planning and tracking**
- **Launch meeting kicks off a project**
  - **Three to four day team building experience**
  - **Data driven, emphasizes individual ownership, focuses on attaining overarching business goals**
  - **Detailed plan features 0-100 milestones with 2 /person/week granularity that provides EV tracking with extraordinary fidelity**
  - **Everyone comes out with a clear understanding of roles, responsibilities, and tasks**
  - **Detailed quality plan that projects defects injected and removed by phase, establishes phase exit criteria, defines corrective action plans**
- **Structured weekly status meeting are used to manage the project**
  - **Each person briefs performance relative to plan, risk and action item status**
  - **Lead briefs overall status, sets goals for next week**
- **Quarterly re-launches create new detailed plans**
  - **Due to extraordinary high level of task granularity, detailed planning is only done one quarter out**

In 4 days, 5 people will generate a far better plan than one person working alone for 20 days.
They'll do it faster. They'll own it. They'll use it.

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PSP, TSP, and Six Sigma

- PSP and TSP directly address
  - Large data variation normally seen due to the wide range of individual skills
  - Process noise caused by inadequate measurements
  - Credibility of process improvement with team members
    - The PSP training course is based on each individual using the process, making measurements, and observing their own performance improvements as the course progresses
  - Willingness of individual engineers to take data and use it for continuous improvement
    - PSP is structured so that all data is used by the person who collected it within a short time after collection.
    - Results of data driven process improvement are immediately apparent to each practitioner
  - Support structure to change individual behavior through use of TSP team building, status meetings, and use of post mortems
- PSP and TSP are well-defined fully instrumented processes, generally applicable "out of the box", supported by excellent training material, and has extensive performance data available
- For all these reasons, PSP and TSP make a great platform for the deployment of six sigma technique
  - Six Sigma techniques easily integrate into and extend PSP/TSP's management, design, inspection, and post-mortem processes

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Six Sigma Deployment

- Many organizations have had significant success deploying six sigma in manufacturing, but have had very little or no success in penetrating software engineering
- Some barriers to successful application in software that must be addressed are
  - Too many competing initiatives
    - TQ, ISO, CMM, Six Sigma
  - Rigid application of the CMM staged model
    - SPC is for level 4 and 5 organizations
  - Standard six sigma training does not directly relate to software development
    - Software is different
    - Software developers can't bridge gap on their own
    - "One size fits all" generates resistance
  - Business as usual after training
    - No time for continuous improvement
    - Six Sigma Projects are not considered integral to software development
    - Deployment process fails to change engineers daily behavior, not just managers, process people, etc.
  - Poor alignment of sponsorship
    - Divided responsibilities for productivity improvement and product development
- Once you have addressed the barriers
  - Set SMART goals
  - Train project oriented teams
  - Put them to work using the six sigma toolkit to focus on achieving the goal immediately
  - Provide them with adequate mentoring and visible sponsorship

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Why Should You Use Six Sigma?

- You can’t manage what you don’t measure
- If you don’t manage a process it is unlikely to perform as well as it could
- Closed loop processes outperform open loop ones
- If you don’t couple an SPI effort to measurable business results, it is unlikely to survive a change in executive sponsorship
- CMM Levels do not equate to business results
- Combining a Six Sigma approach to process improvements at the tactical level with a CMM approach at the strategic level, addresses all of these issues
- You only need to measure three things: size, time, and defects, but you need to measure them well
- Metrics can and should be taken at every CMM level and should be used to manage and evaluate process effectiveness
- Metrics need to be put into a statistical context before being used to make decisions
- Once you know how, you’ll find most elements of the Six Sigma tool kit have broad applicability to software development

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