

***NORTHROP GRUMMAN***

DEFINING THE FUTURE

# Practical Six Sigma Tools for Systems Engineering

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# Background

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- **Six Sigma has proven to be a powerful enabler for process improvement**
  - CMMI adoption
  - Process improvement for measurable ROI
  - Statistical analysis
- **This presentation will focus on practical tools and techniques for use by systems engineers**

## Agenda

- **What is Six Sigma?**
- **How does it apply to systems engineering?**
- **Strategies and lessons learned**



# Projects Have Historically Suffered from Mistakes

## People-Related Mistakes

1. Undermined motivation
2. Weak personnel
3. Uncontrolled problem employees
4. Heroics
5. Adding people to a late project
6. Noisy, crowded offices
7. Friction between developers and customers
8. Unrealistic expectations
9. Lack of effective project sponsorship
10. Lack of stakeholder buy-in
11. Lack of user input
12. Politics placed over substance
13. Wishful thinking

## Process-Related Mistakes

14. Overly optimistic schedules
15. Insufficient Risk Management
16. Contractor failure Insufficient planning
17. Abandonment of planning under pressure
18. Wasted time during the fuzzy front end
19. Shortchanged upstream activities
20. Inadequate design
21. Shortchanged quality assurance
22. Insufficient management controls
23. Premature or too frequent convergence
25. Omitting necessary tasks from estimates
26. Planning to catch up later
27. Code-like-hell programming

## Product-Related Mistakes

28. Requirements gold-plating
29. Feature creep
30. Developer gold-plating
31. Push me, pull me negotiation
32. Research-oriented development

## Technology-Related Mistakes

33. Silver-bullet syndrome
34. Overestimated savings from new tools or methods
35. Switching tools in the middle of a project
36. Lack of automated source-code control

- Standish Group, 2003  
survey of 13,000 projects
- 34% successes
  - 15% failures
  - 51% overruns

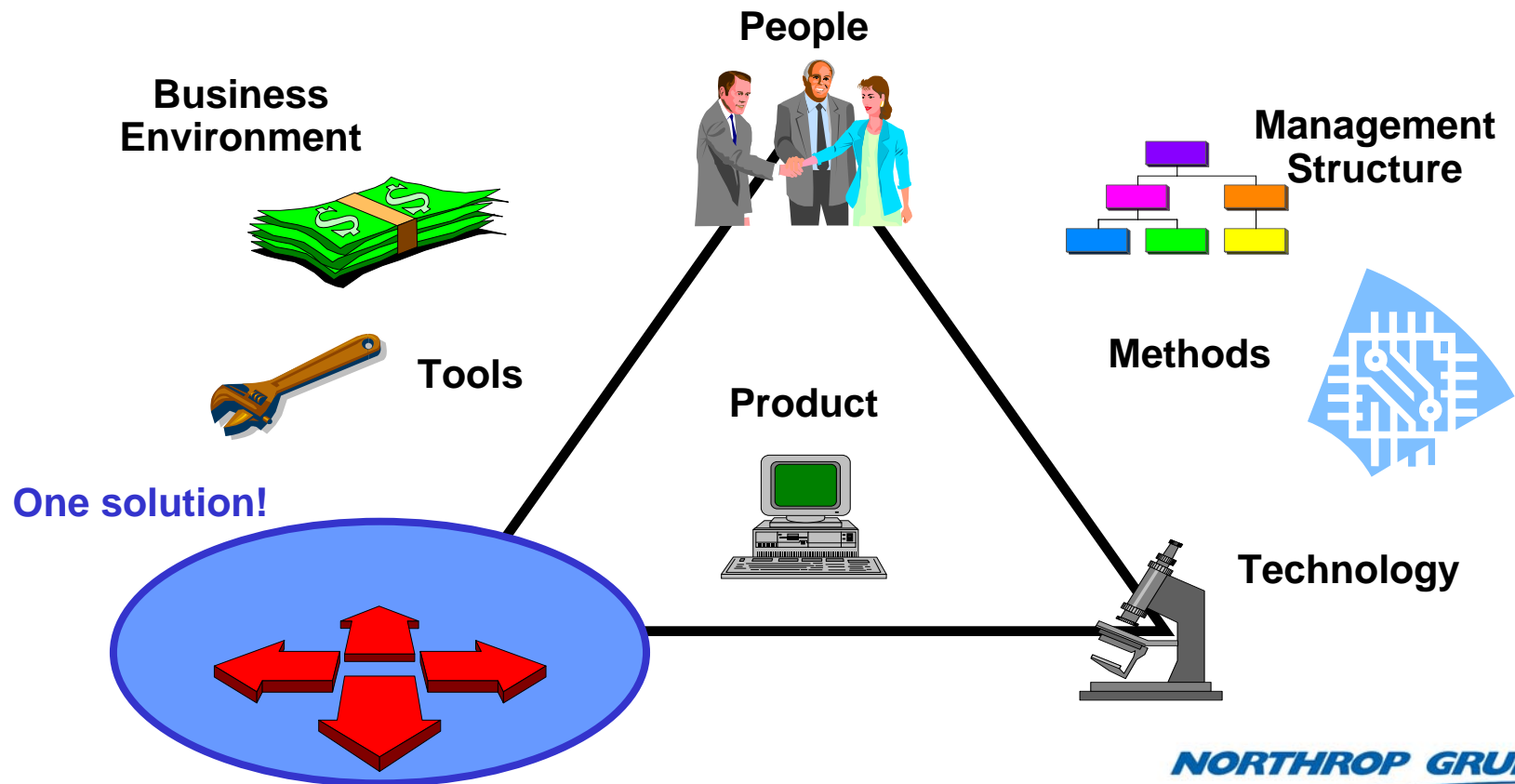
Reference: Steve McConnell, *Rapid Development*

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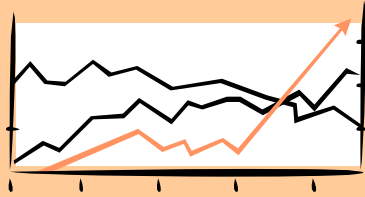
# Many Approaches to Solving the Problems

- Which weaknesses are causing my problems?
- Which strengths may mitigate my problems?
- Which improvement investments offer the best return?



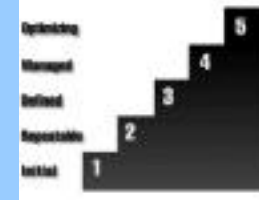
# Approaches to Process Improvement

## 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

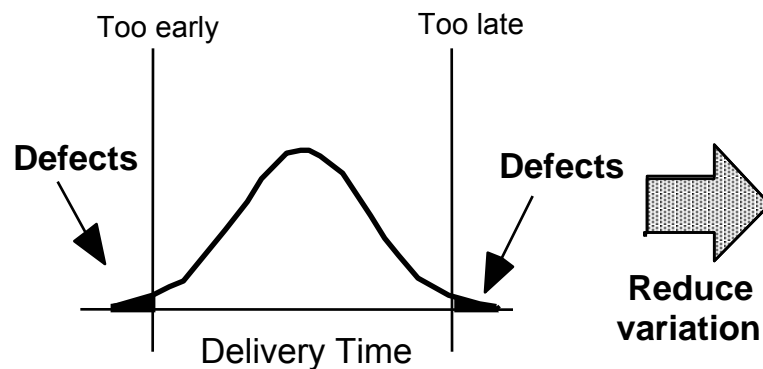
## Model-Driven (e.g., CMM, CMMI)



- **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**

# 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 Typical Six Sigma Project in Systems Engineering

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- 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



# Roles & Responsibilities – Organizational Implementation

- ***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





# Applicability to Engineering

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- **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, ...

# How Six Sigma Helps Process Improvement

- **PI efforts often generate 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-Based Improvement

- **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 in the CMMI**

- 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



# How CMMI Helps Six Sigma Based Improvement

- **CMM/CMMI focuses on organizational change**
  - Provides guidance on many dimensions of the infrastructure

## *Process Areas*

Organizational Process Focus  
Organizational Process Definition  
Organizational Training  
Organizational Process Performance  
Organizational Innovation and Deployment

## *Generic Practices (all process areas)*

GP 2.1 Establish an Organizational Policy  
GP 2.2 Plan the Process  
GP 2.3 Provide Resources  
GP 2.4 Assign Responsibility  
GP 2.5 Train People  
GP 3.1 Establish a Defined Process  
GP 2.6 Manage Configurations  
GP 2.7 Identify and Involve Relevant Stakeholders  
GP 2.8 Monitor and Control the Process  
GP 3.2 Collect Improvement Information  
GP 2.9 Objectively Evaluate Adherence  
GP 2.10 Review Status with Higher-Level Management

# Barriers and Challenges

- **Capturing the first, “low hanging fruit” makes Six Sigma implementation look easy...**
  - Clearer problems, simpler solutions, bigger payoffs
  - Little need for coordination
- **...but later projects are tougher**
  - Keeping projects appraised of similar efforts, past and current
  - Focusing on “the pain”, not the assumed solution
- **Engineering process measurements are often difficult to analyze**
  - Dirty (or no) data, human recording problems
  - May necessitate Define-Measure-Analyze-Measure-Analyze-etc.
- **Must demonstrate the value of quantitative data to managers**
  - Management style - reactive vs. proactive vs. quantitative
  - Less value in a chaotic environment
  - Must engage customers

# Additional Challenges

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- **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
- **Analysis requires that complex SE processes be broken down into small, repeatable tasks**
  - E.g., peer review
- **Repeatable process data requires the project/organization to define (and follow) a detailed process**

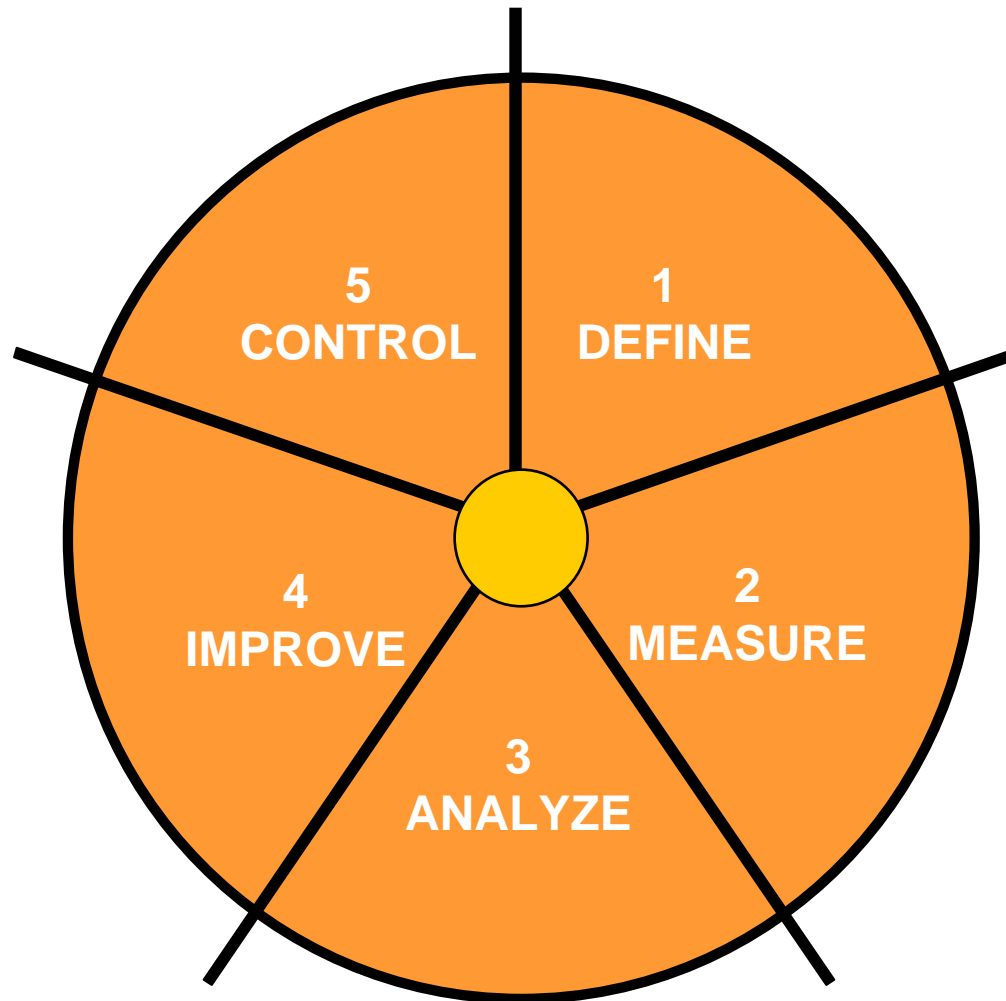




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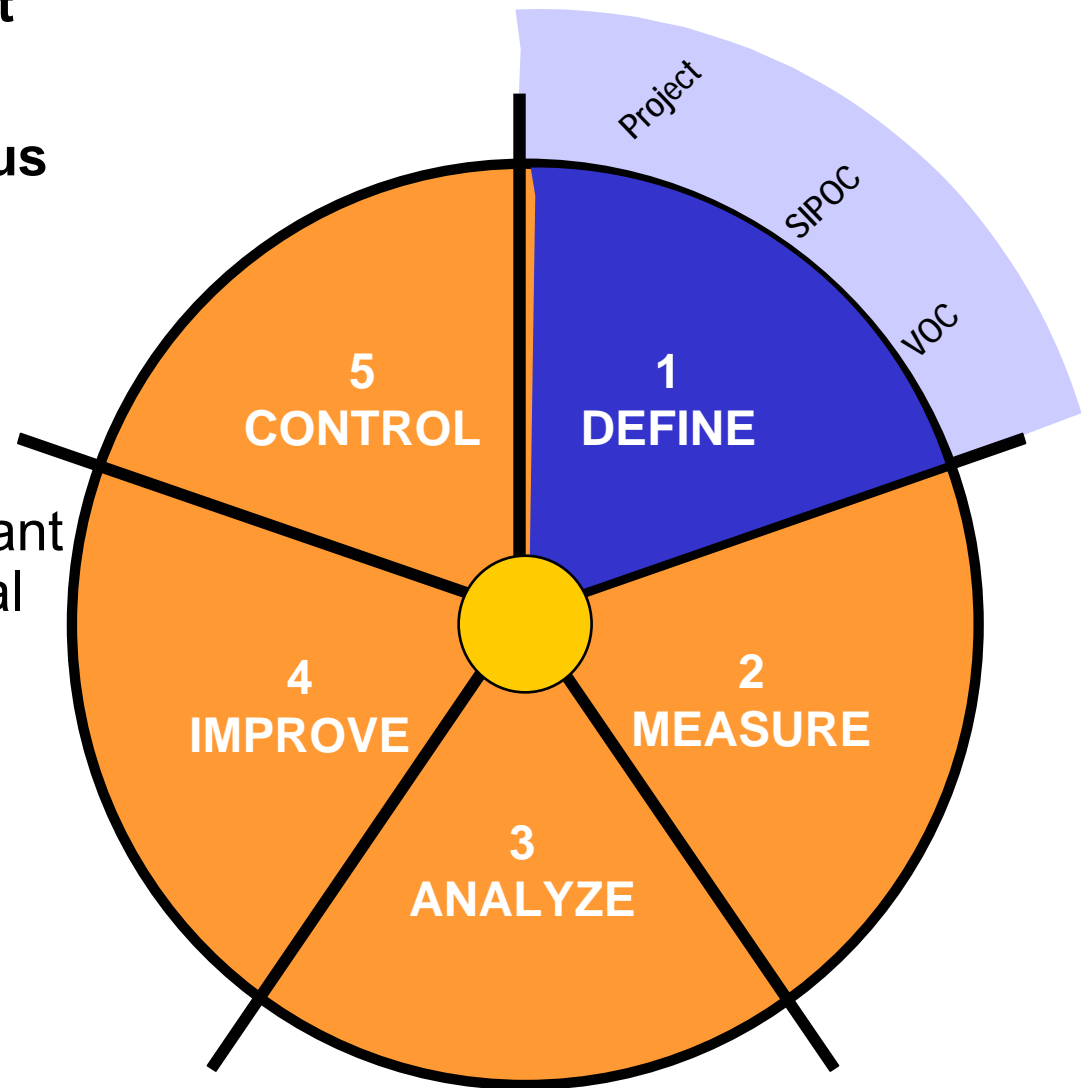
# Tools & Techniques

# DMAIC – A Structured Approach to Improving a Process



# DMAIC – Define

- Purpose is to set project goals and boundaries
- Establishes upfront focus on customer
- Key products
  - Project charter
  - Process map
  - List of what is important to customer -- Critical to Quality factors (CTQs)



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# Identify Key Stakeholders Early On

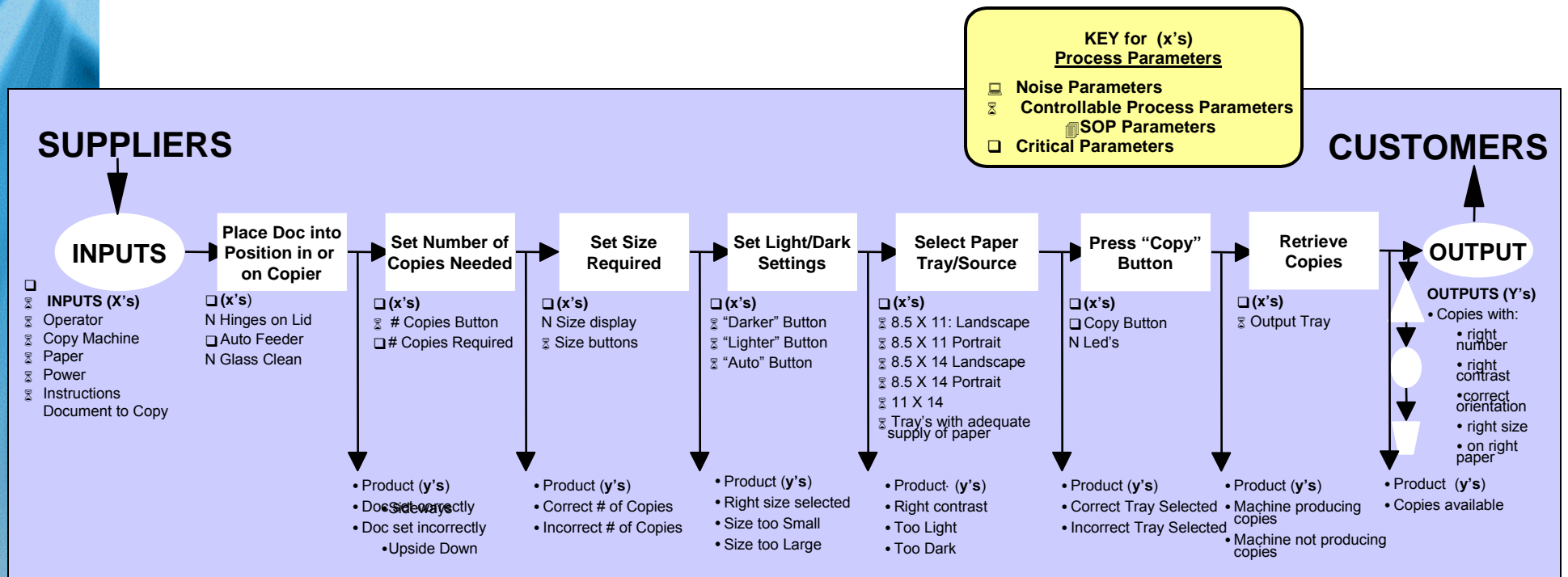
- Develop communication plan based on level of commitment required

	<i>Stakeholders (Examples)</i>		
<i>Level of Commitment</i>	Testers	Developers	Requirements Leads
Enthusiastic Support		O	O
Help it work	O	↑	↑
Compliant	↑		
Hesitant	X	↑	
Indifferent		X	
Uncooperative			X
Opposed			
Hostile			

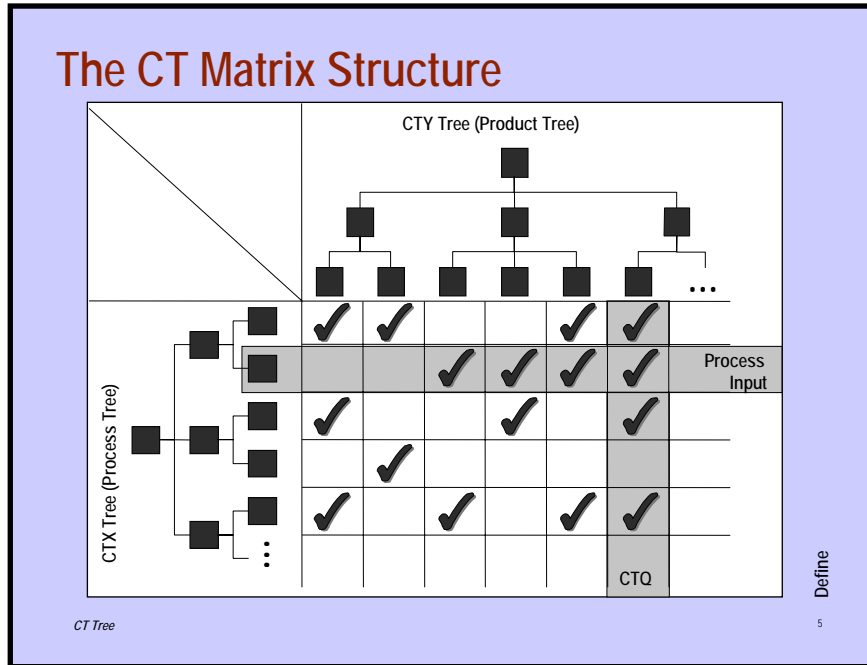
X = Current Level of Commitment  
 O = Level of Commitment Necessary for Success

# Suppliers-Inputs-Process-Outputs-Customers (SIPOC)

- High level “as-is” process map
  - 5 to 7 key steps of main action
  - Used to focus on the fundamental elements of the process



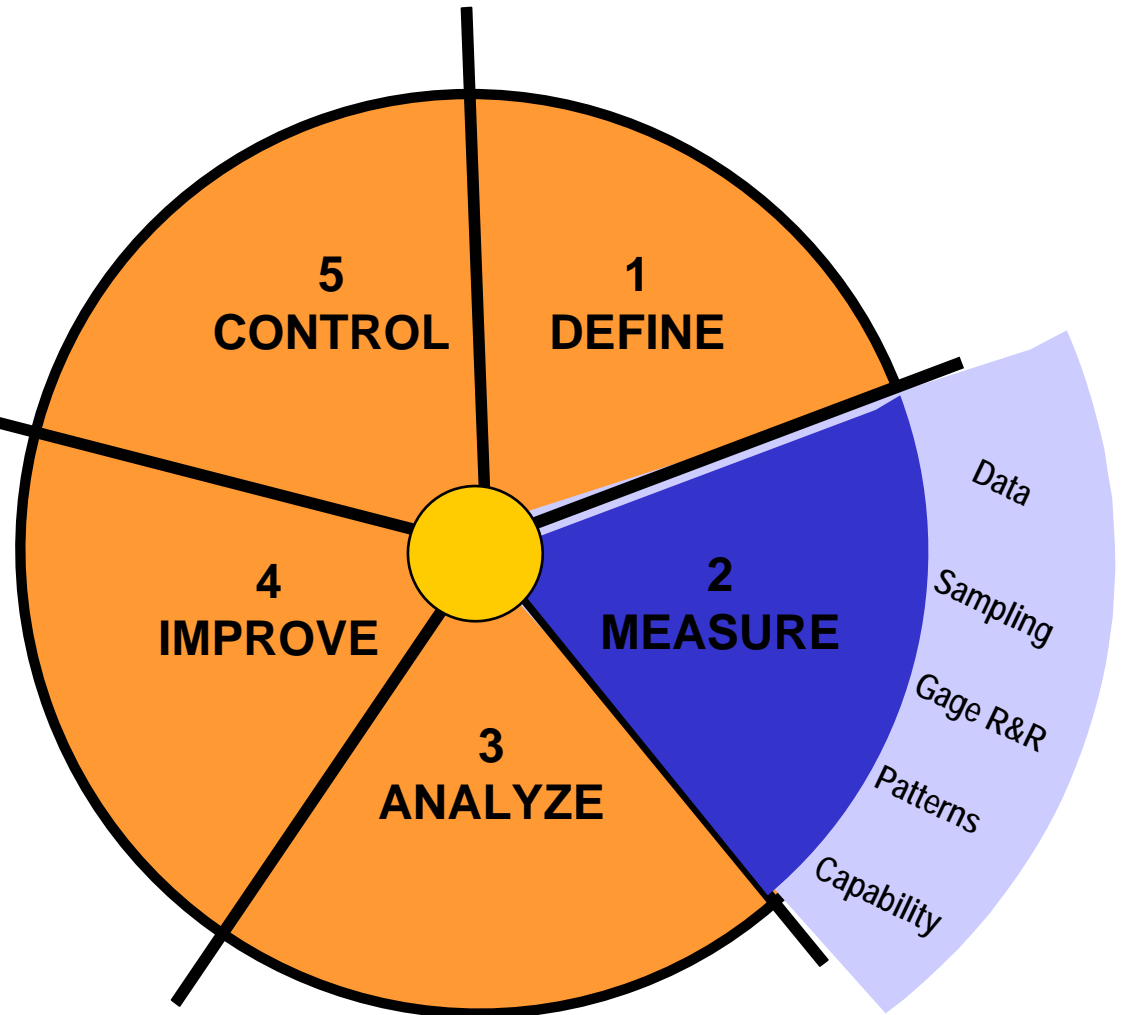
# Voice of the Customer



- CT "critical to" matrix links process or CT tree (columns of the matrix) and product or CTY tree (rows)
  - Critical To Satisfaction (CTS)
  - Critical To Quality (CTQ)
  - Critical To Delivery (CTD)
  - Critical To Cost (CTC)
  - Critical To Process (CTP) - Process parameters which significantly influence a CTQ, CTD, and/or CTC

# DMAIC – Measure

- **Purpose is to narrow range of potential causes and establish a baseline capability level**
  - Identify specific problem(s)
  - Prioritize critical input/process/output measures
  - Validate measurement system
- **Key products**
  - Cause/effect diagrams
  - FMEA
  - Gage R&R
  - Data collection plan
  - Analysis results





# Failure Modes and Effects Analysis

- Used to identify the way in which errors happen; an error mode, the antithesis of function
- Employed as a diagnostic tool in *improvement*
- Used as a prevention tool in *design*
- Deals with the three dimensions of an error mode:
  - Severity
  - Detectability
  - Frequency

Process/Product Failure Modes and Effects Analysis (FMEA)															
Process or Product Name:			Prepared by:			Page ____ of ____			FMEA Date ( Orig ) _____ (Rev) _____						
Responsible:															
Process Step/Part Number	Potential Failure Mode	Potential Failure Effects	S E V	Potential Causes	O C C	Current Controls	D E T	R P N	Actions Recommended	Resp	Actions Taken	S E V	O C C	D E T	R P N

# Data Collection Plan

## Measurement Consistency and Accuracy

### Data Collection Plan

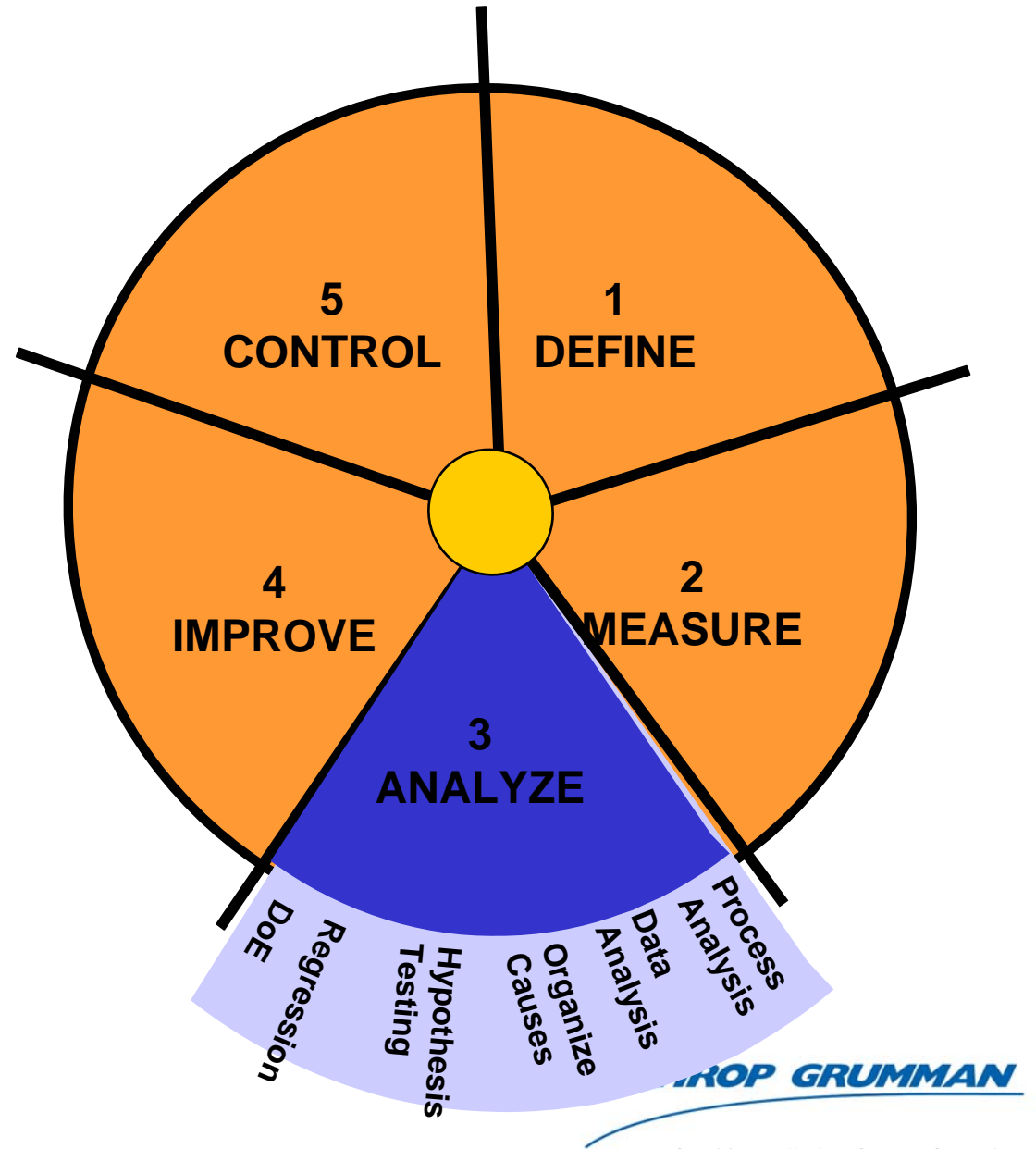
*What questions do you want to answer?*

Data		Operational Definition and Procedures			
What	Measure type/ Data type	How measured	Related conditions	Sampling notes	How/ where
How will you ensure consistency and stability?		What is your plan for starting data collection? How will the data be displayed?			

- **Meaning of measurement in relation to project, process, or product**
- **What is counted into or excluded**
- **Measurement validation method**
  - Regular validation during collection
  - Periodic validation of samples or aggregates independent of collection tools and methods
- **Frequency of measurement collection**
- **Calculations used to derive an indirect, aggregated, or accumulated value**
- **How and where measurements are stored and accessed**
- **Tools, methods, resources, and assignments required**

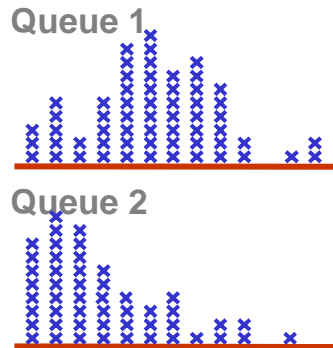
# DMAIC – Analyze

- Purpose is to evaluate data/information for trends, patterns, causal relationships and "root causes"
- Key products
  - Quantitative analysis results
  - Theory that has been tested

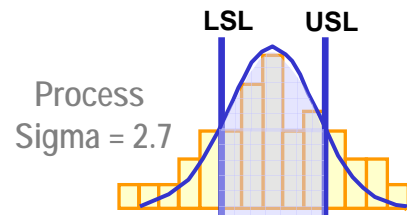


# Six Sigma Tool Kit

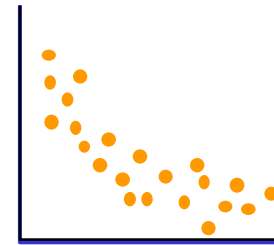
## Stratification



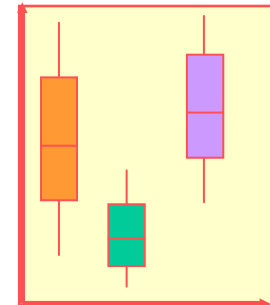
## Capability Analysis



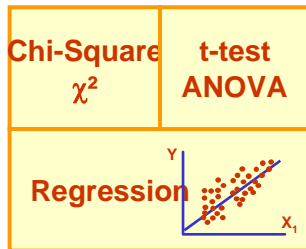
## Regression Analysis



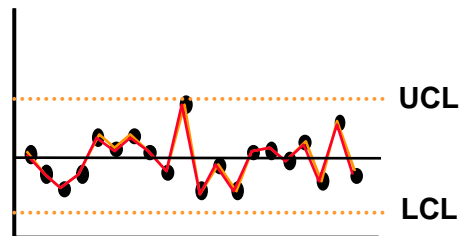
## Boxplot ANOVAs



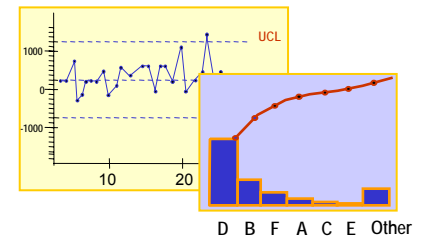
## Hypothesis Testing



## Control Charts



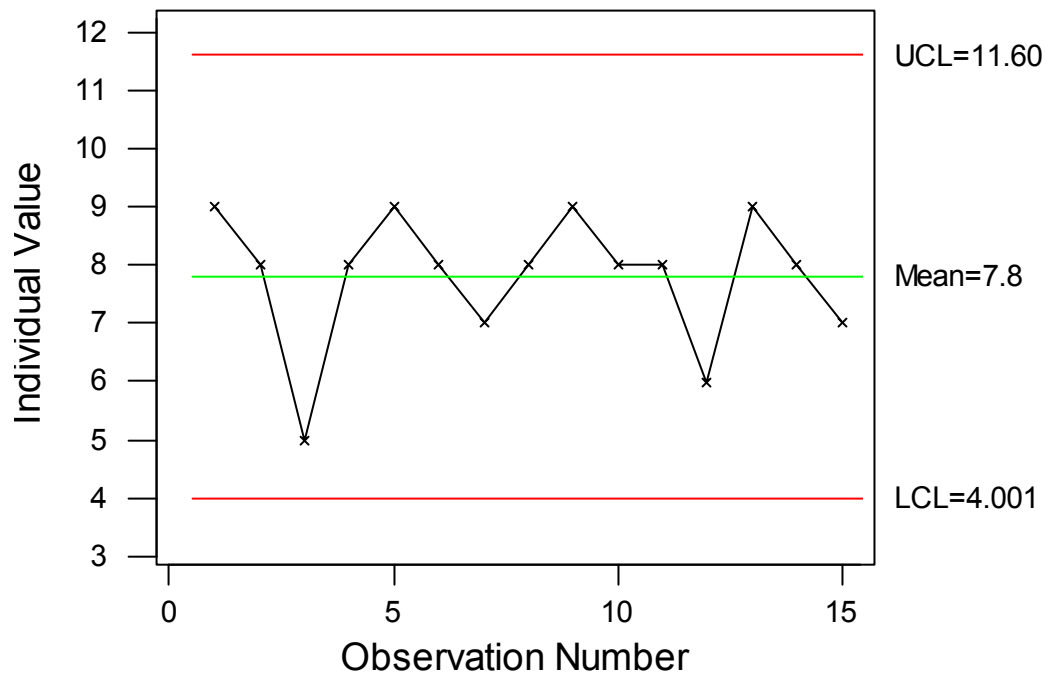
## Data Analysis





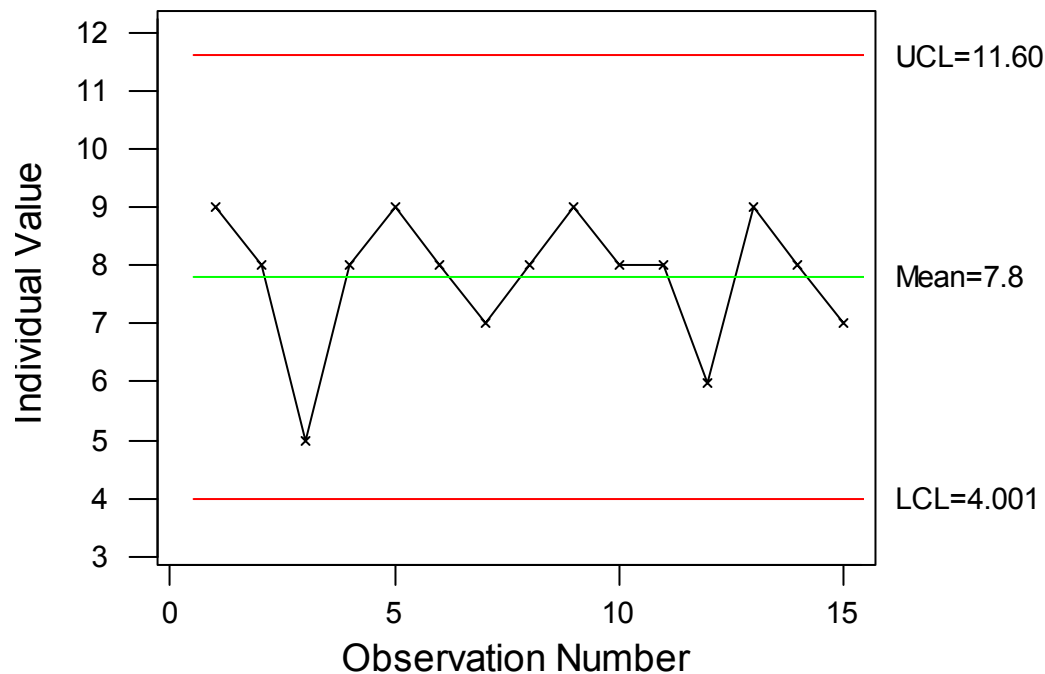
# Exercise – What is Quantitative Management?

- Suppose your project conducted several peer reviews of similar code, and analyzed the results
  - Mean = 7.8 defects/KSLOC
  - $+3\sigma$  = 11.60 defects/KSLOC
  - $-3\sigma$  = 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?



# Exercise – What is Required for Quantitative Management?

- What is needed to develop the statistical characterization of a process?



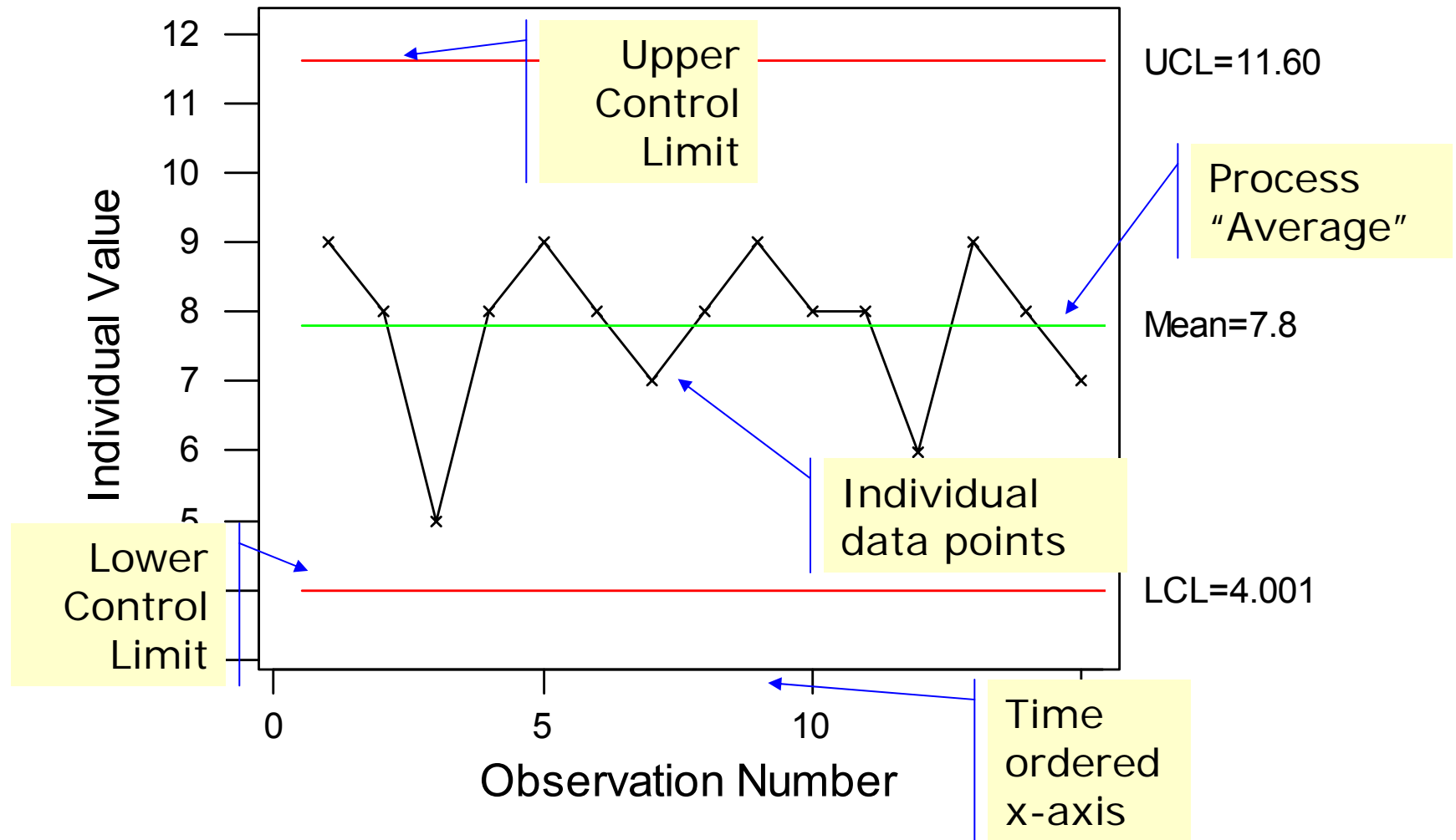
- The process has to be stable (predictable)
  - Process must be consistently performed
  - Complex processes may need to be stratified (separated into simpler processes)
- There has to be enough data points to statistically characterize the process
  - Processes must occur frequently within a similar context (project or organization)

# What Is a Control Chart?



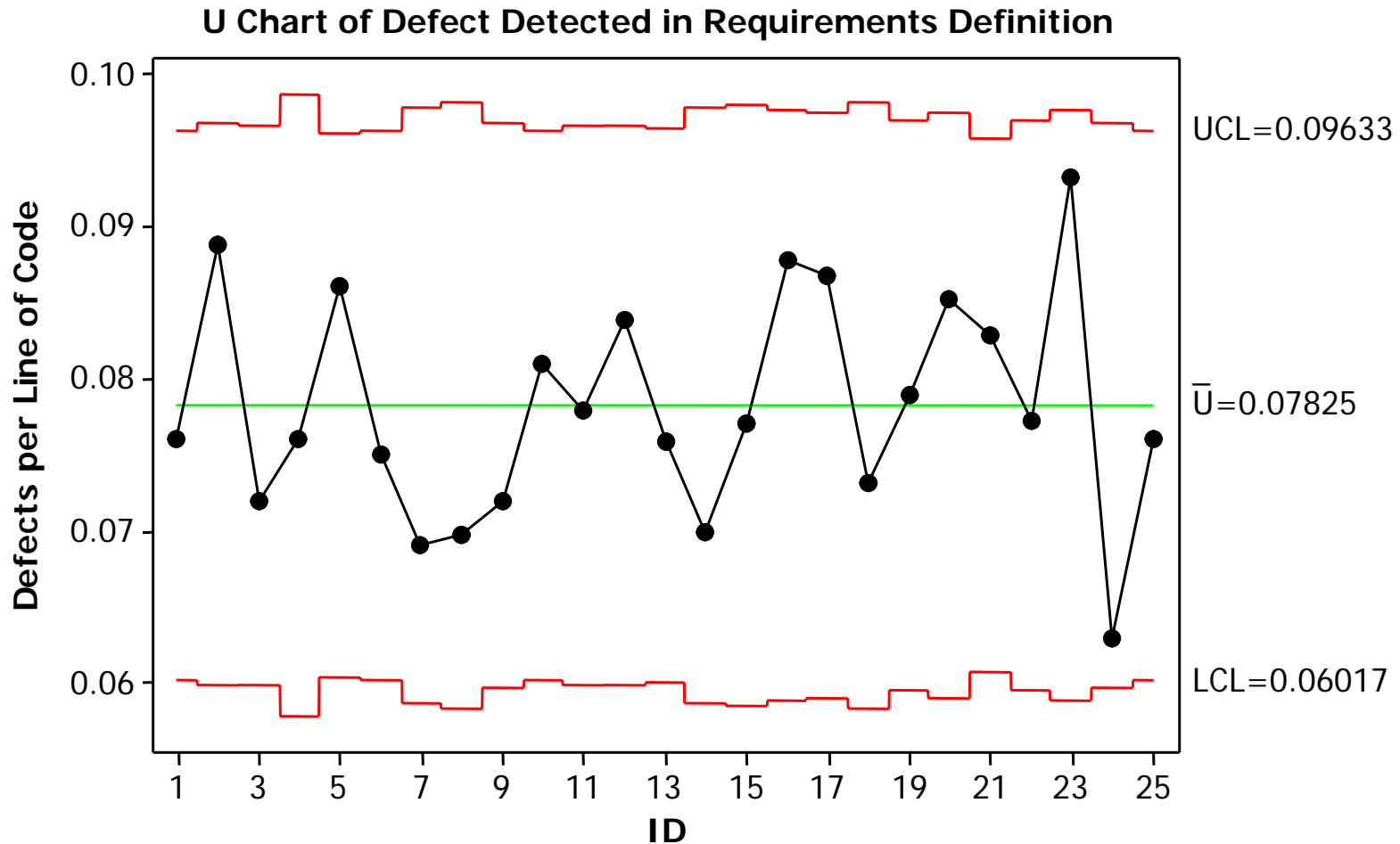
- A time-ordered plot of process data points with a centerline based on the average and control limits that bound the expected range of variation
- Control charts are one of the most useful quantitative tools for understanding variation

# What Are the Key Features of a Control Chart?



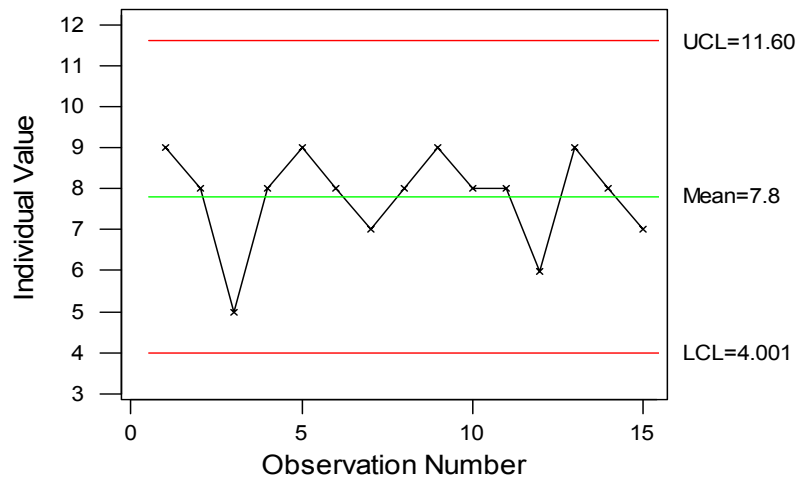


# There are Many Types of Control Charts



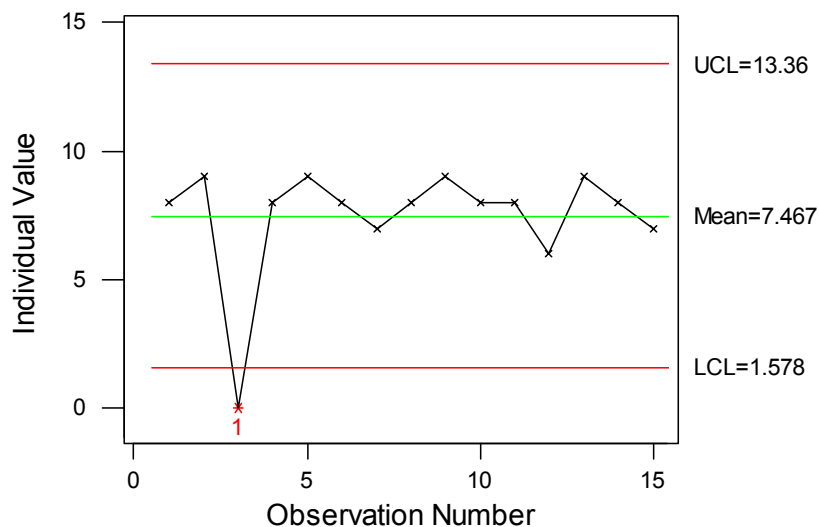
Tests performed with unequal sample sizes

# What is *Special Cause* and *Common Cause* Variation?



## ■ Common Cause Variation

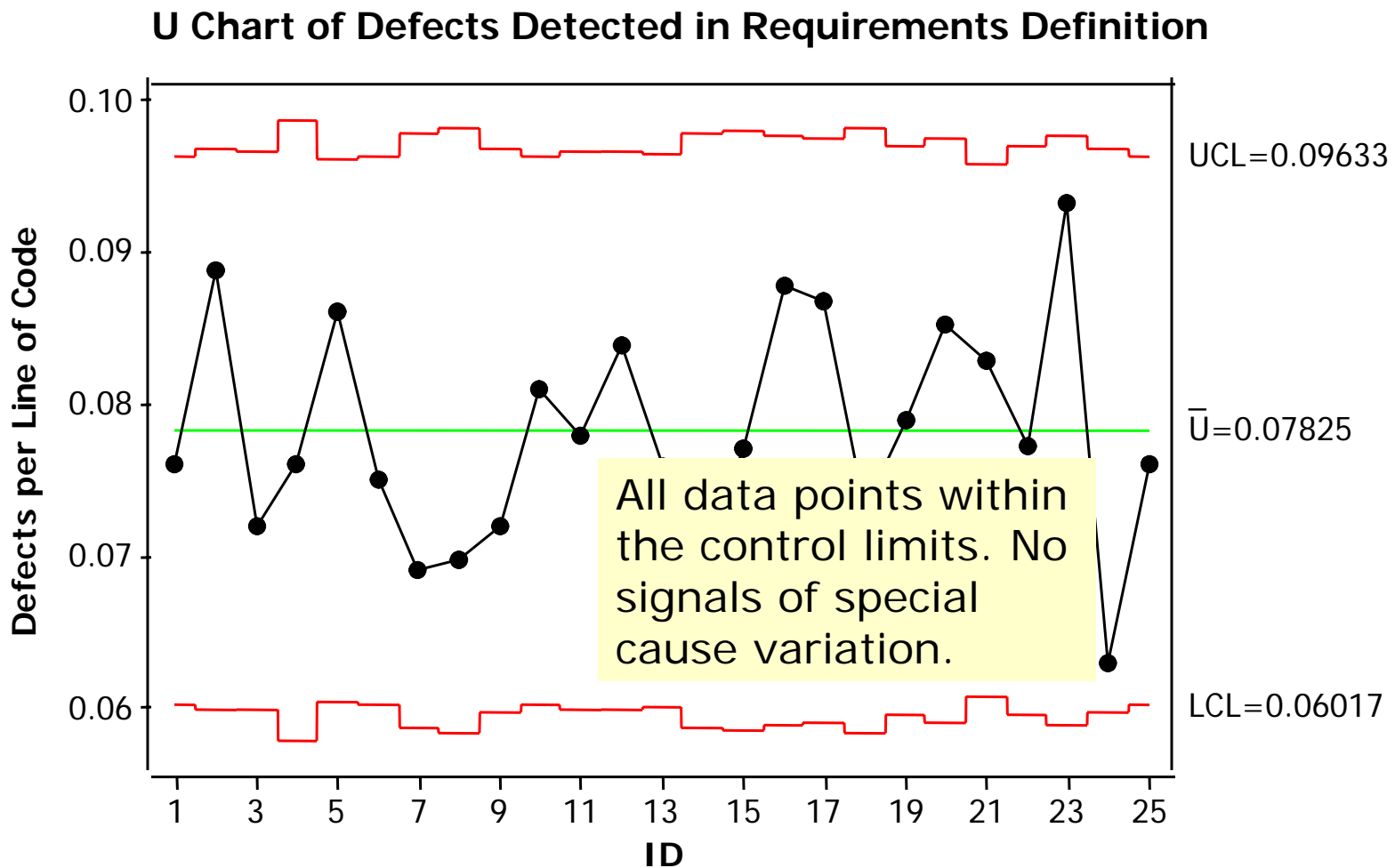
- *Routine* variation that comes from within the process
- Caused by the natural variation in the process
- Predictable (stable) within a range



## ■ Special Cause Variation

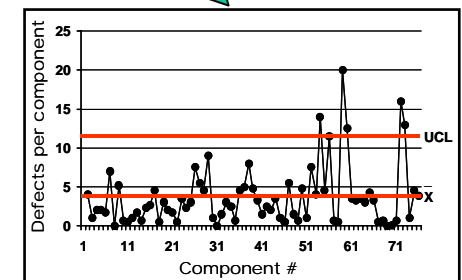
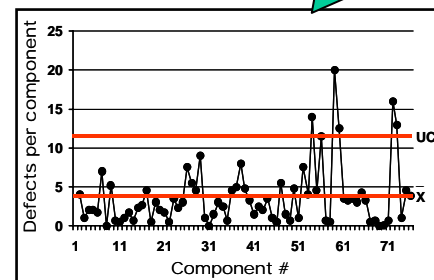
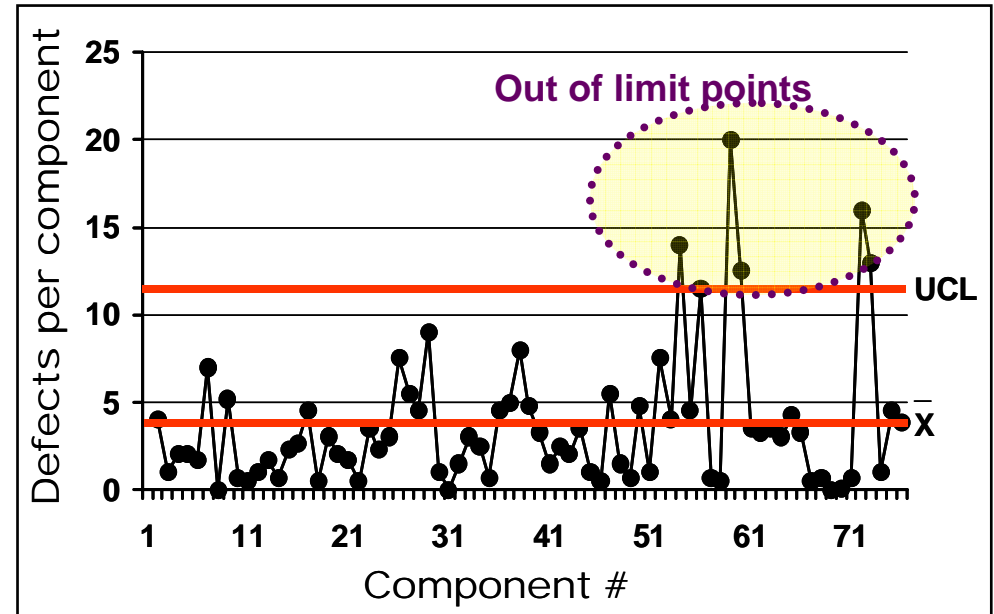
- *Assignable* variation that comes from outside the process
- Caused by a unexpected variation in the process
- Unpredictable

# What Is a *Stable* (Predictable) Process?



# 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 stratify 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





# Hearing Voices

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- **Voice of the process**  
= the natural bounds of process performance
- **Voice of the customer**  
= the goals established for the product/process performance
- **Voice of the business**  
= process performance needed to be competitive
  
- **Process capability may be determined for the**
  - Organization
  - Product line
  - Project
  - Individual
  
- **Typically, the higher the level of analysis, the greater the variation**

# Common Challenges for Engineering



- Data are often discrete rather than continuous, e.g., defects
- Observations often are scarce
- Processes are aperiodic
- Size of the the object often varies, e.g., software module
- Data distributions may not be normal

# How Do I Address These Challenges?

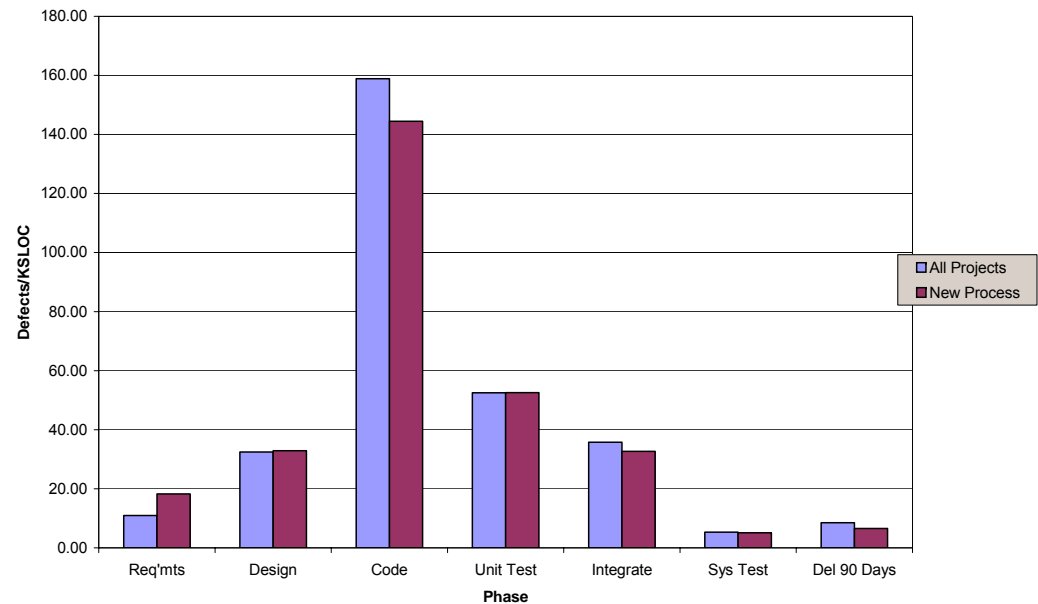


- Employ control chart types that specifically deal with discrete data distributions, e.g.,  $u$ -charts and  $p$ -charts
- Use control charts that compensate for widely variable areas of opportunity
- Transform non-normal continuous data to normal data before constructing a control chart
- Cross check control charts with hypothesis tests where few data points exist

# 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)

Defect Detection Profile

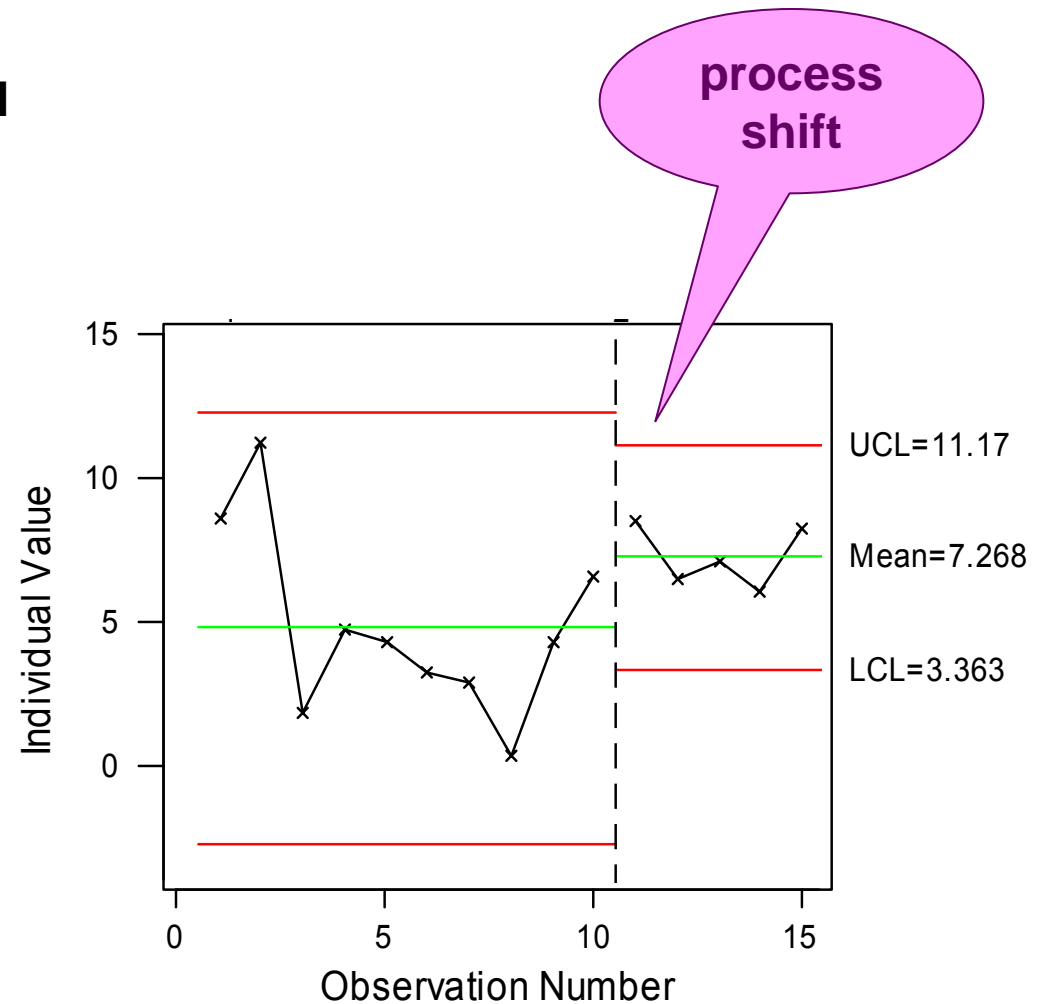


## Process performance

- **Process measures** (e.g., effectiveness, efficiency, speed)
- **Product measures** (e.g., quality, defect density).

# How Can Quantitative Management Help?

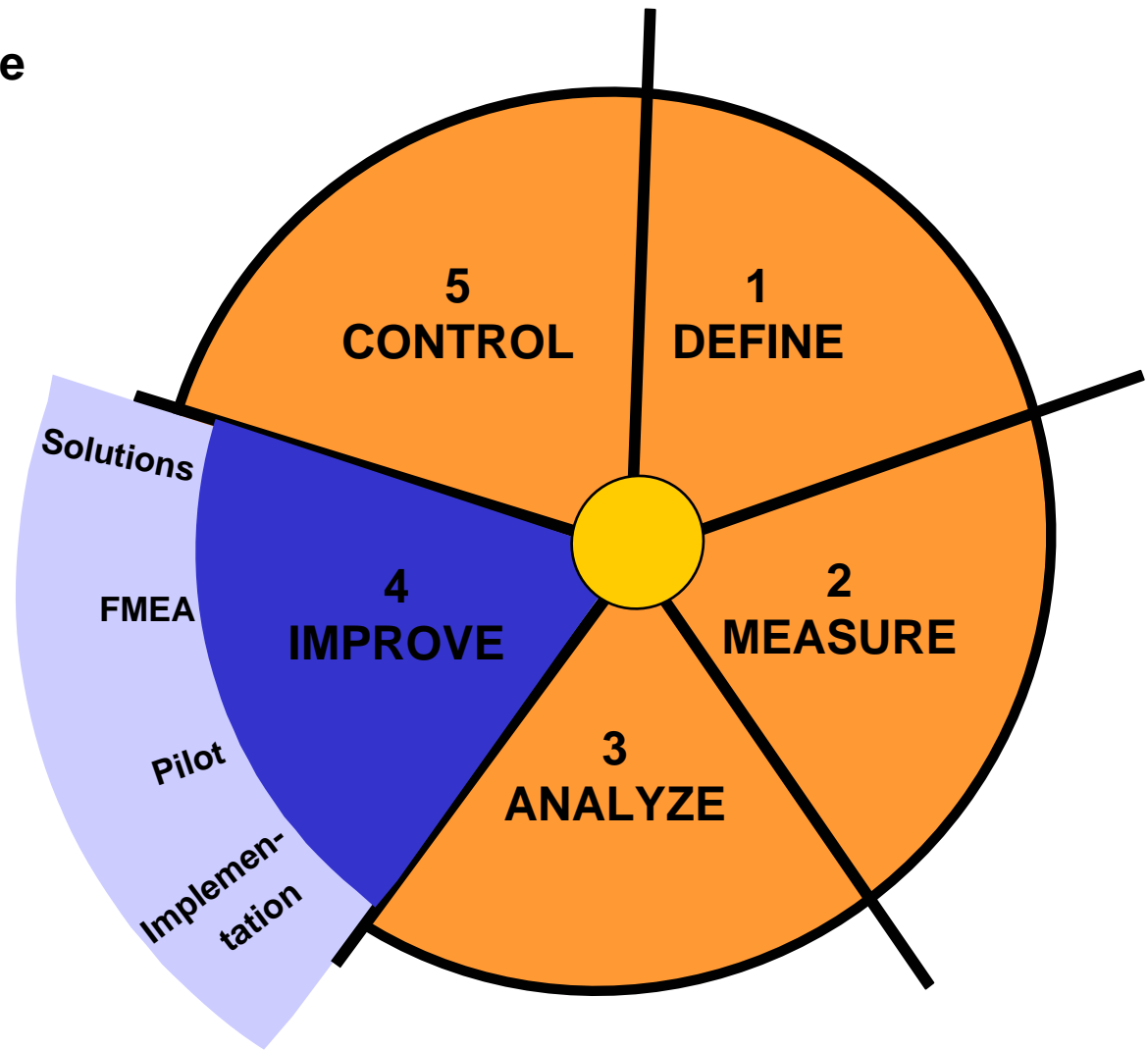
- By measuring both the mean and variation, the project/ organization can assess the full impact of an “improvement”
- Can focus on reducing the variation (making the process more predictable)
  - Train people on the process
  - Create procedures/checklists
  - Strengthen process audits
- Can focus on increasing the mean (e.g., increase effectiveness, efficiency, etc.)
  - Train people
  - Create checklists
  - Reduce waste and re-work
  - Replicate best practices from other projects
- Can do both





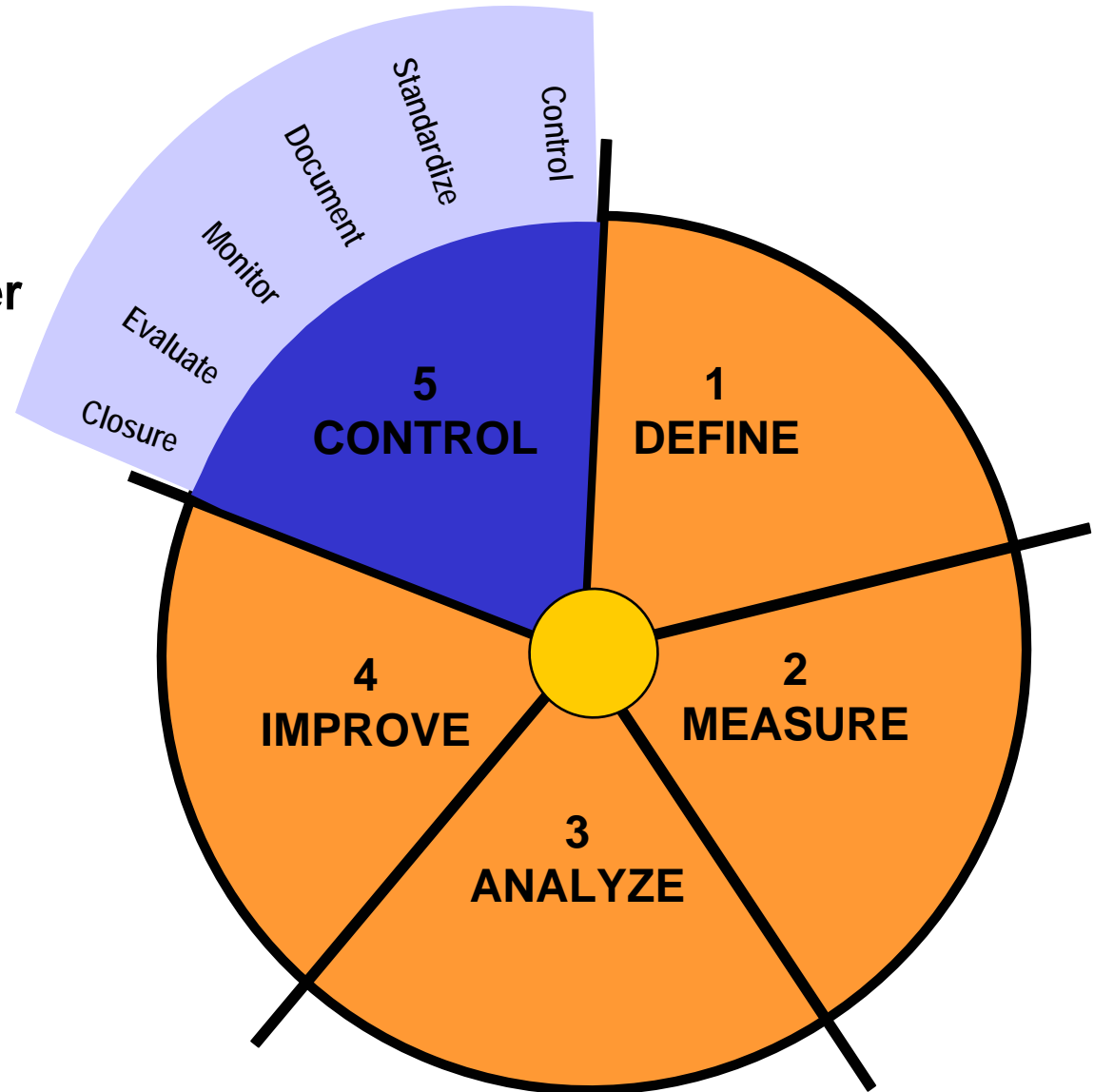
# DMAIC – Improve

- Purpose is to develop, implement and evaluate solutions targeted at identified root causes
- Key products
  - Candidate solutions
  - Pilot results
  - Risk assessment
  - Implementation plan



# DMAIC – Control

- Purpose is to make sure problem stays fixed and new methods can be further improved over time
- Products
  - Control plan
  - Process documentation
  - Key learnings



# The Control Plan

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- **Systematic tool for identifying and correcting root causes of out-of-control conditions**
- **Focus is on prevention -- not a “triggering” system**
- **Questions that must be answered**
  - Who owns the process?
  - How will we transition responsibility from the Black Belt to the process owner?
  - How do we ensure we maintain the gains?
  - How do we track our results (performance and financial)?

# Institutionalize Key Learnings

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- **Capture knowledge gained from Six Sigma project**
  - Results
  - Key learnings
  - Potential future projects
- **Communicate to rest of organization for knowledge sharing and transfer**
- **Archive in knowledge management repositories**

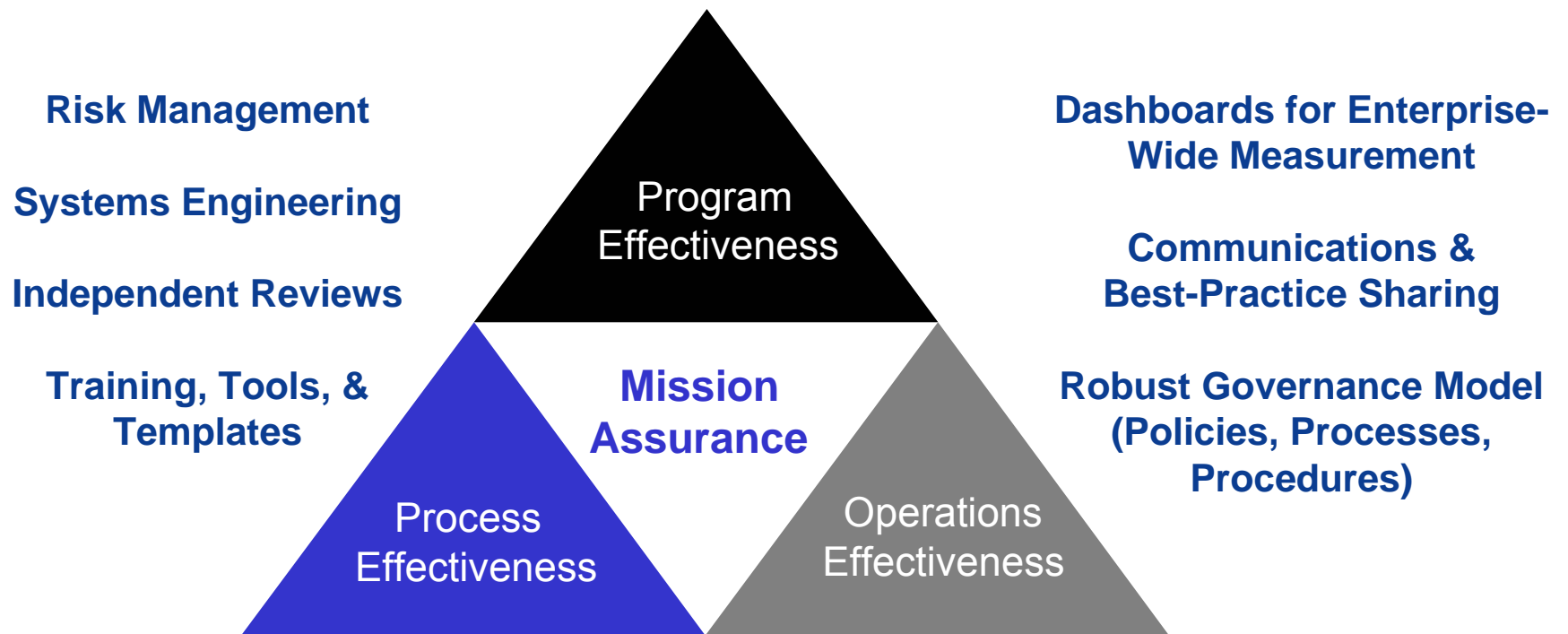


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# Lessons Learned



# Mission Success Requires Multiple Approaches



**CMMI Level 5 for Software, Systems, and Services**

**ISO 9001 and AS-9100 Certification**

**Six Sigma**

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# Benefits

## *Based on 18 Northrop Grumman CMMI Level 5 organizations*

- **Having multiple improvement initiatives helps encourage a change in behavior as opposed to “achieving a level”**
  - Reinforces that change (improvement) is a way of life
- **The real ROI comes in institutionalizing local improvements across the wider organization**
  - CMMI establishes the needed mechanisms
- **CMMI and Six Sigma compliment each other**
  - CMMI can yield behaviors without benefit
  - Six Sigma improvements based solely on data may miss innovative improvements (assumes a local optimum)
- **Training over half the staff has resulted in a change of language and culture**
  - Voice of Customer, data-driven decisions, causal analysis, etc.
  - Better to understand and use the tools in everyday work than to adopt the “religion”

# Contact Information

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