16.660 / 16.853 / ESD.62J Introduction to Lean Six Sigma Methods
January (IAP) 2008

LAI Lean Academy™

Quality Tools and Topics

Learning Objectives

At the end of this module, you will be able to:

- Describe how quality is essential to lean in achieving Customer Satisfaction
- Explain the relationship between product quality and process quality control
- Use seven basic tools of quality
- Explain why Design for Six Sigma (DFSS) and Six Sigma are valuable concepts in achieving customer satisfaction

Why Do We Care About Quality?

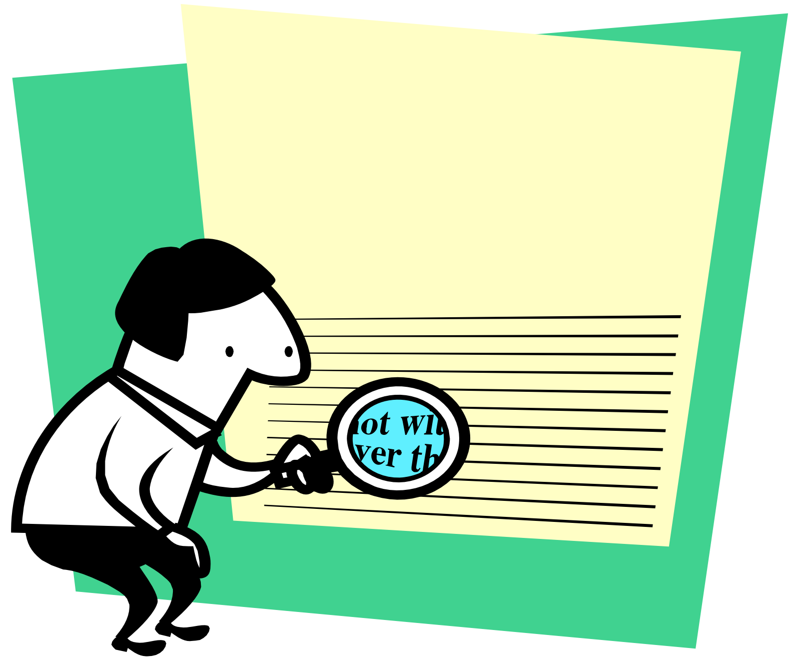
Hidden Costs of Non-Conformance = 6 to 50X Measured Costs

- **Direct Measured Costs:**
- Scrap/rework
- Service calls
- Warranties/concessions

Indirect/Hidden Costs:
- Excess inventory
- Overtime
- Non-value added steps
- Queues and delays
- Reputation/image

Problems with Inspection Based Quality Control

- Inspection does not add value to the customer – it simply screens or detects (most of the time) defective products from leaving the factory.
- Inspection is subject to multiple errors
  - Inspector skill and attention
  - Measurement capability
  - Environment (Human Factors)



Inspection Exercise

1. This exercise will be timed.
2. Task: Circle all of the fs or Fs on a page of text.
3. After 30 seconds – “STOP” and count up the total number of fs and Fs that you found!
4. Take out the “F” Exercise from the student folder
5. When I say “GO” you may begin.

Inspection Exercise Results

Number
(Input Data)

22	*23*	*22*	*15*	*34*	*36*	*21*	*28*	*29*	*23*
28	*29*	*29*	*30*	*32*	*34*	*34*	*31*	*26*	*19*
26	*23*	*34*	*38*	*23*	*34*	*12*	*19*	*22*	*16*

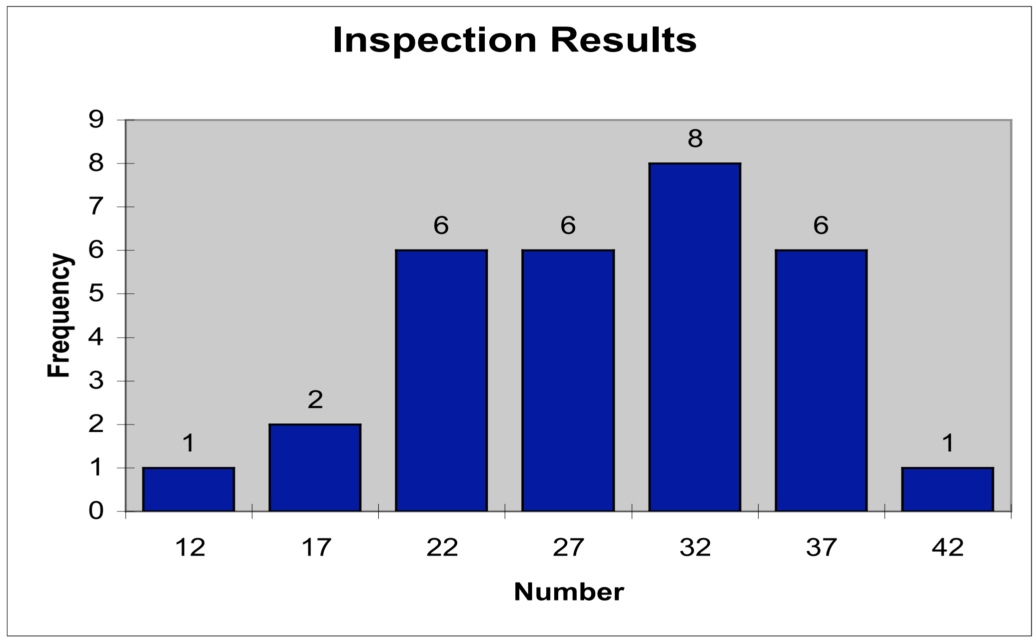
Sorted Data

38	36	34	34	34	34	34	32	31	30
29	29	29	28	28	26	26	23	23	23
23	22	22	22	21	19	19	16	15	12

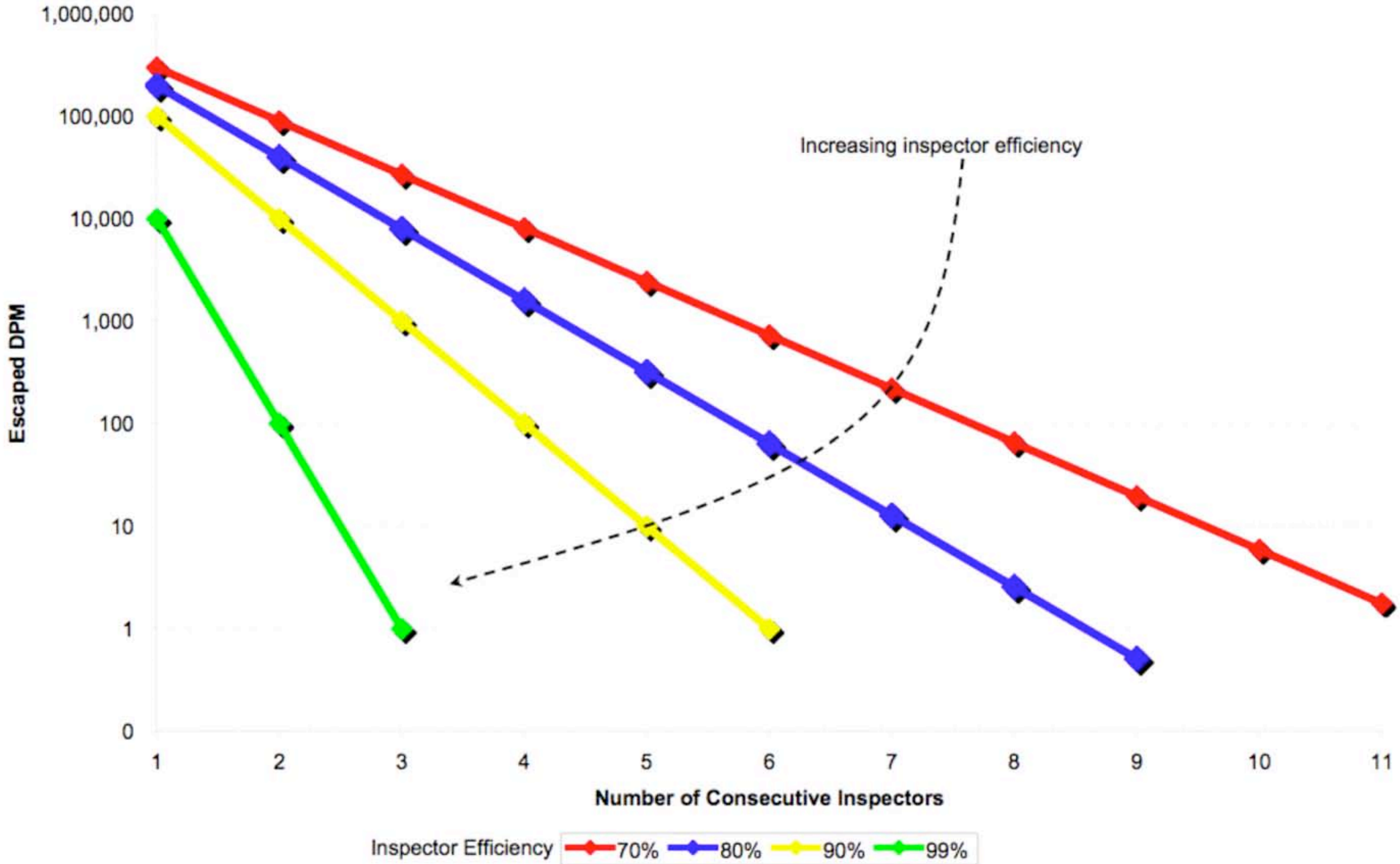
Histogram Data

Qty	Freq
12	1
17	2
22	6
27	6
32	8
37	6
42	1

Number of Inspectors	30
Expected #	99
Total Expected	2970
Total Observed	792
Average Efficiency per Inspector	27%



Impact of Inspector Efficiency on Escaped Quality



Product and Process Quality Defined

- Product Quality is the conformance to customer specifications within a tolerance band
  - *The upper and lower values that the customer is willing to accept are known as upper and lower specification limits (USL and LSL)*
- Process Quality is a measure of the capability of a process to produce to its expected capability
  - *The upper and lower values between which the process must be controlled are known as upper and lower control limits (UCL and LCL)*

How can we assure Process Quality?

The Seven Basic Quality Tools

- Flow Charts
- Check Sheets
- Histograms
- Pareto Charts
- Scatter Diagrams
- Control Charts
- Cause and Effect Diagrams

Photograph of surgical checklist in use removed due to copyright restrictions.
Source: http://seattletimes.nwsource.com/html/localnews/2008018070_checklist26m.html (second photograph).

M&M Demonstration

- The Mars company is very aware of controlling variation
- Open your bag of M&Ms and dump them onto the paper provided
- Don’t eat them; it will “skew” the data
- Count the number of M&Ms in your bag
  - Record the number on your paper
- Sort the colors into a Pareto Diagram
  - Count the number of M&Ms in each group
  - Record on your paper

Class Data: Total Bag Count

Raw Data
(Input Data)

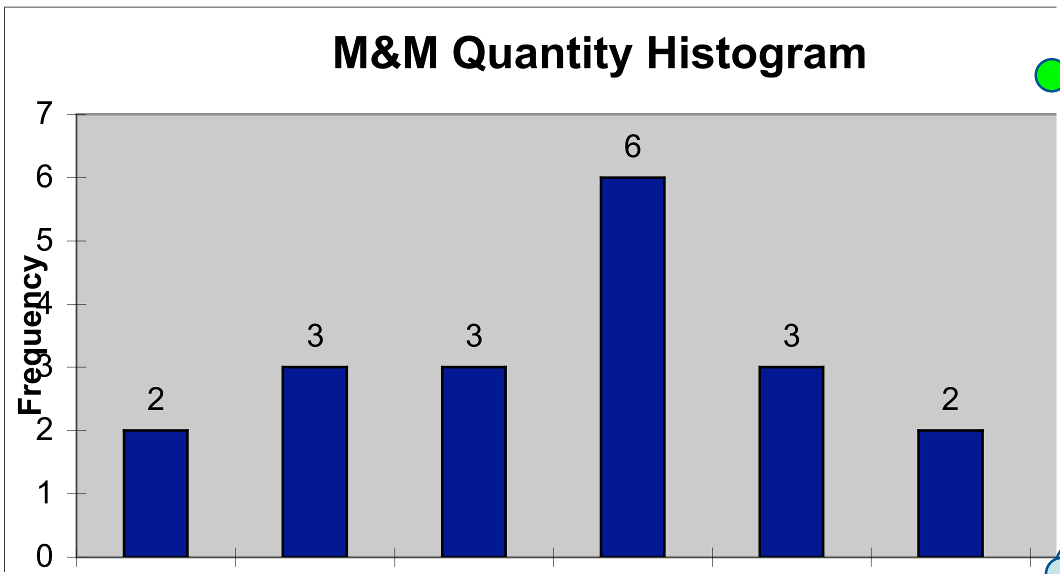
53	*55*	*57*	*57*	*60*	*52*	*61*	*57*	*58*
52	*55*	*54*	*53*	*57*	*58*	*59*	*59*	*61*

Sorted Data

61	61	60	59	59	58	58	57	57
57	56	55	55	54	53	53	52	52

Histogram

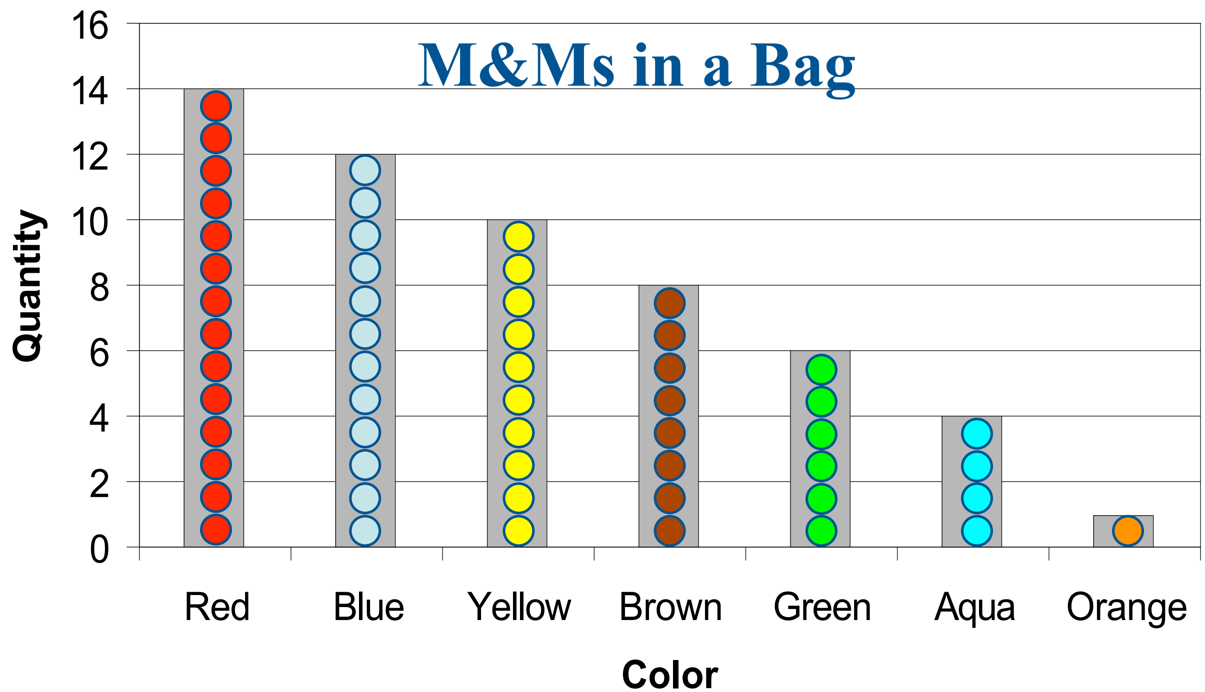
Qty	Freq
52	2
54	3
56	3
58	6
60	3
62	2
64	0
Total	19



Average	56.5

The Pareto Chart

A bar chart whose quantity sums to the total quantity. The bars are sorted by quantity from left to right.

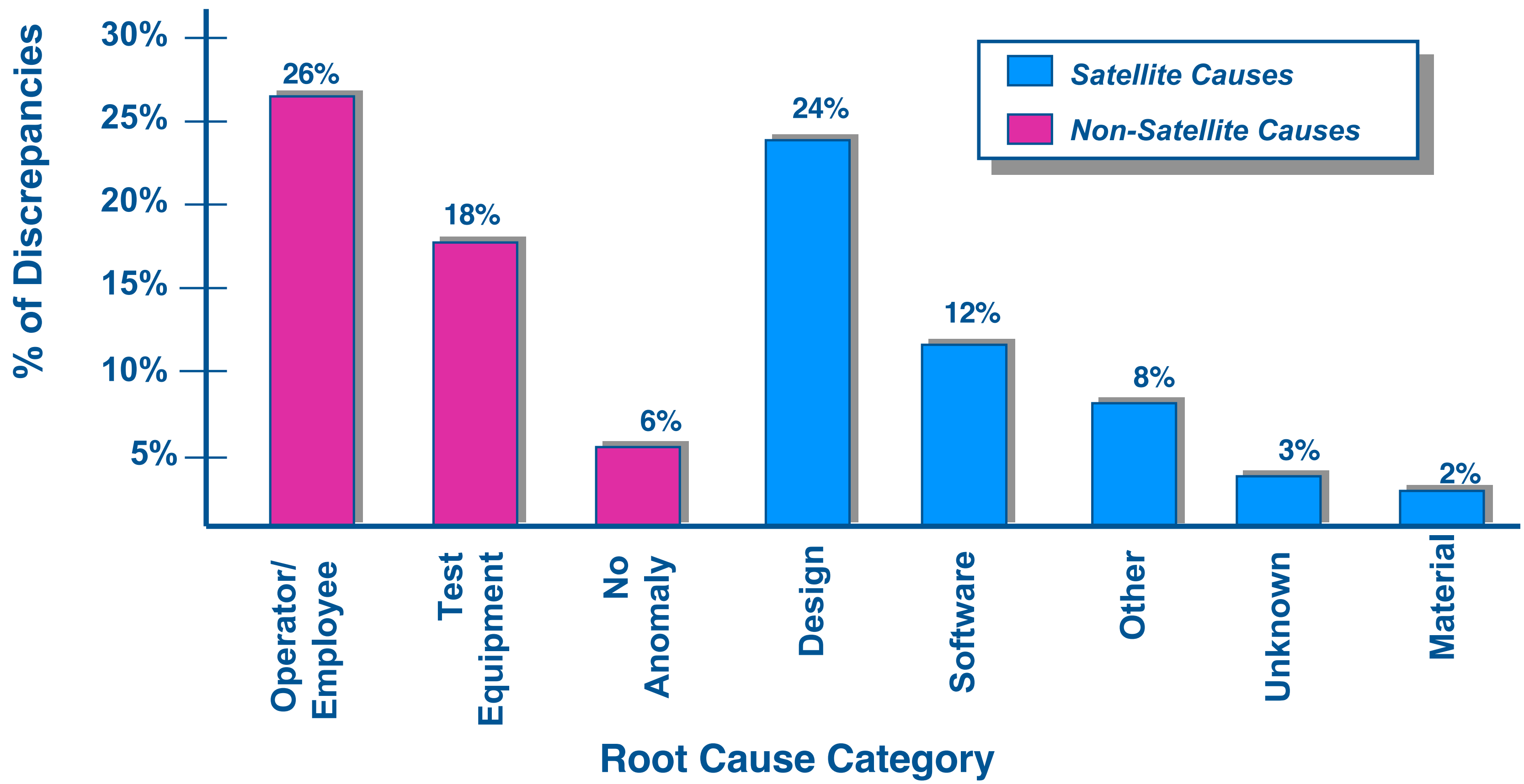


Sorting data and arranging it from highest to lowest is a powerful, visual way to highlight areas of interest.

Suggested by Raytheon Corporation

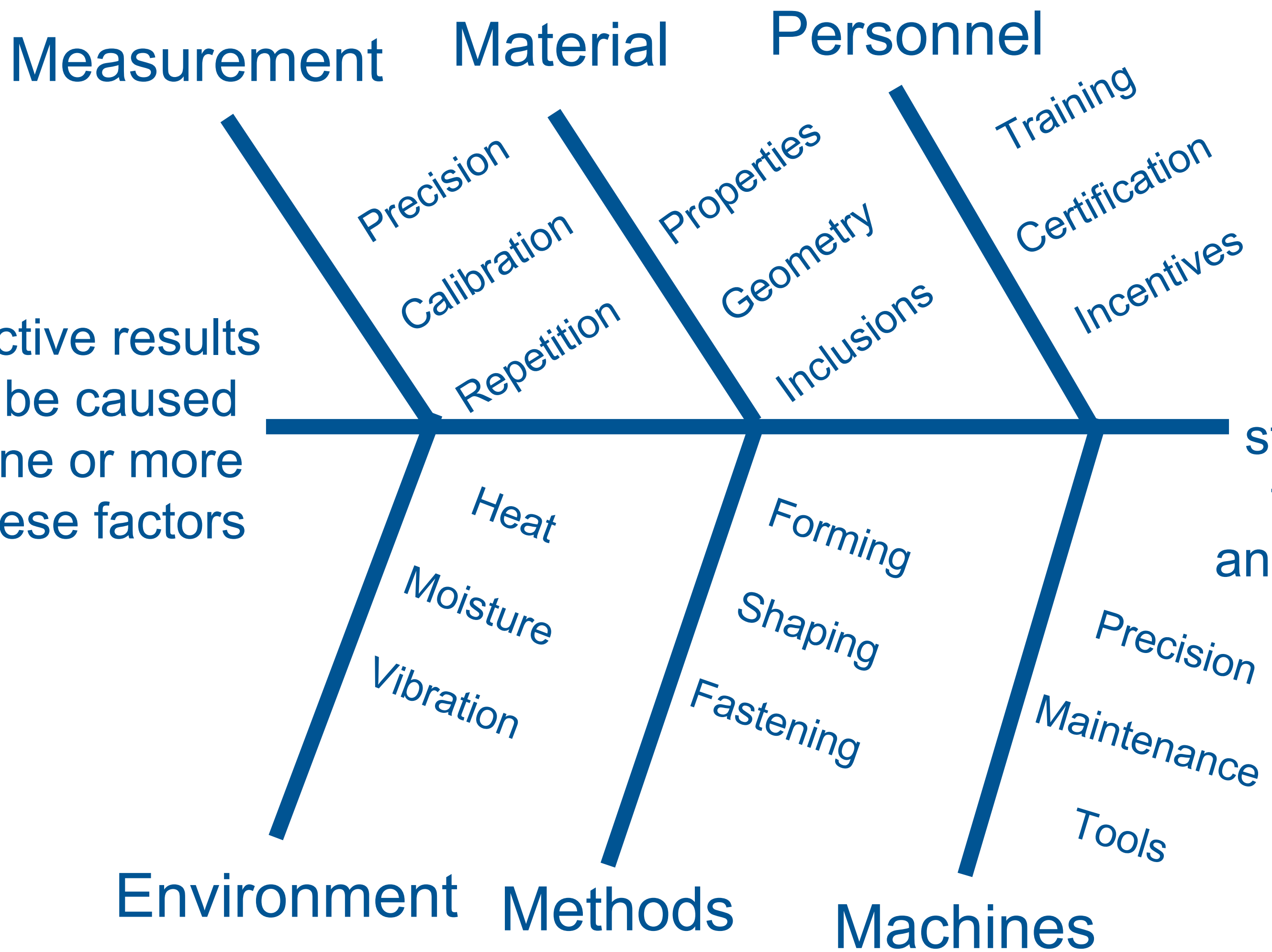
Pareto Example - Discrepancies During Satellite System Integration & Test

Root Cause of Discrepancies for 229 Satellites tested from 1970-1999



Source: Weigel A. and Warmkessel, J., “Seeing The Spacecraft Testing Value Stream”, LAI Executive Board Briefing, June 2000
Ref: Weigel, A., “Spacecraft System Level Test Discrepancies: Characterizing Distributions and Costs”, MIT SM Thesis, May 2000

Cause and Effect Diagram



Defective results can be caused by one or more of these factors

The diagram provides a structured method for identification and corrective action

Statistical Process Control

- Control charting is the primary tool of SPC
- Control charts provide information about the stability/predictability of the process, specifically with regard to its:
  - Central Tendency (to target value)
  - Variation
- SPC charts are time-sequence charts of important process or product characteristics

Quality Tools and Topics Part II

Statistical Process Control

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  - Variation
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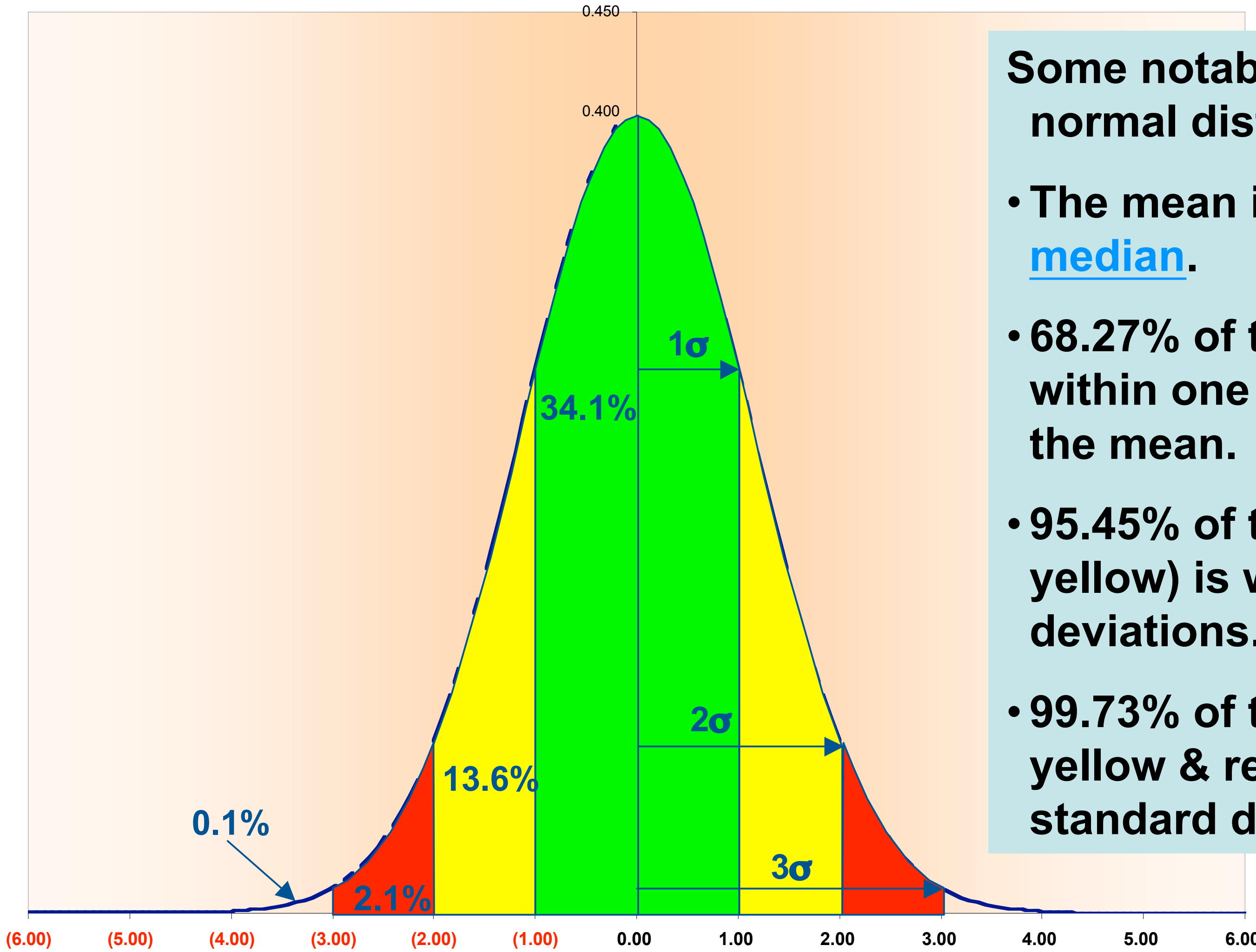
Types of Process Variation

- Common Cause Variation is the sum of many 'chances causes,' none traceable to a single major cause. Common cause variation is essentially the noise in the system. When a process is operating subject to common cause variation it is in a state of statistical control.

- Special Cause Variation is due to differences between people, machines, materials, methods, etc. The occurrence of a special (or assignable) cause results in an out of control condition.

Control Charts provide a means for distinguishing between common cause variability and special cause variability

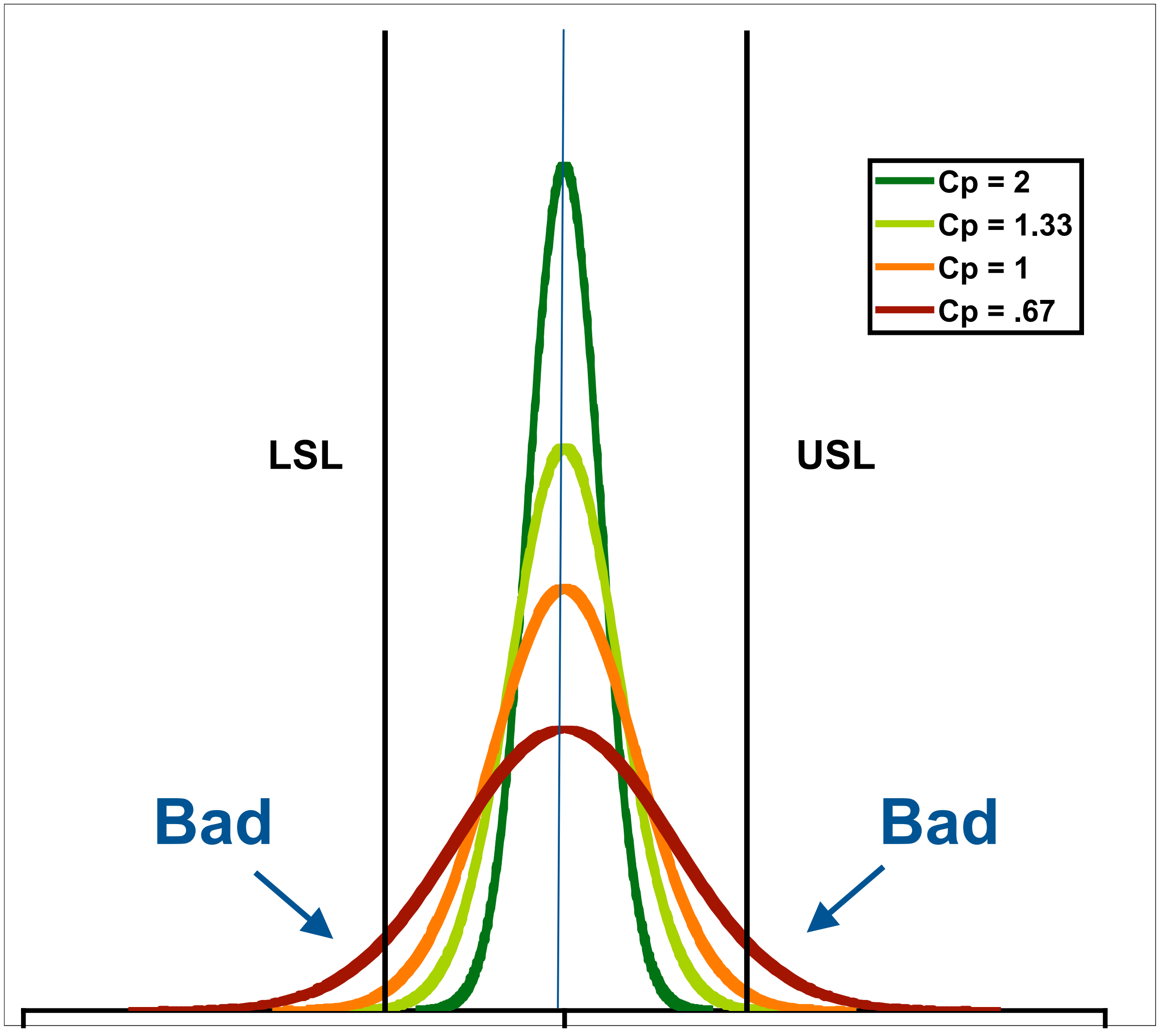
Standard Normal Distribution Curve



Some notable qualities of the normal distribution:

- The mean is also its mode and median.
- 68.27% of the area (green) is within one standard deviation of the mean.
- 95.45% of the area (green & yellow) is w/in two standard deviations.
- 99.73% of the area(green & yellow & red) is w/in three standard deviations

Assessing Process Capability

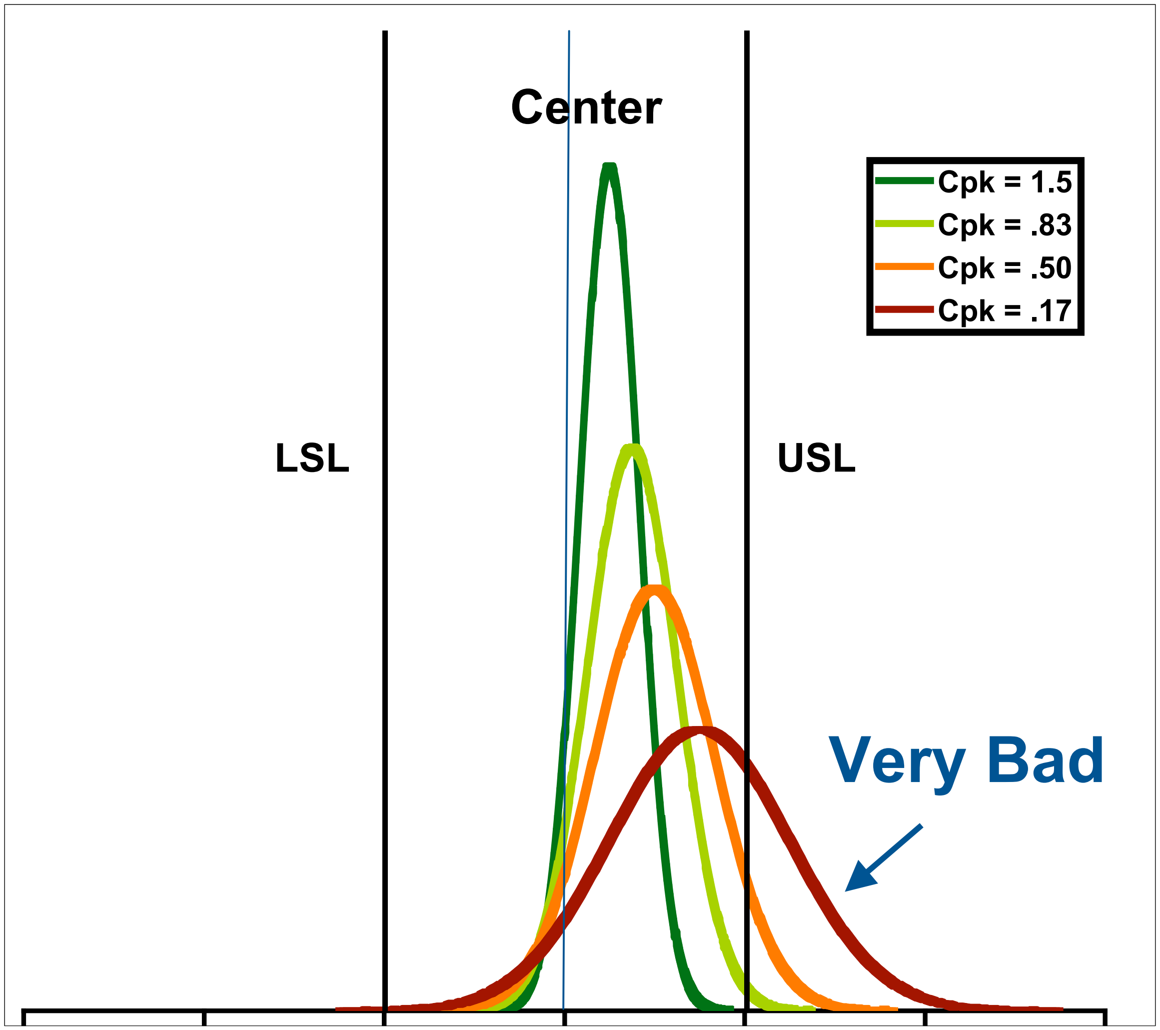


C_p, a term used to define process capability, is mathematically expressed by:

$$C_p = \frac{USL - LSL}{6\sigma}$$

The figure shows centered distributions with various C_p levels. Note C_ps less than two have visible tails outside the acceptable limits.

Non-Centered Distributions



If the distribution is off center, the probability of a bad result drastically increases. In this case C_{pk} is used. It is the smaller of

$$C_{pk} = \frac{USL - Mean}{3\sigma}$$

or

$$C_{pk} = \frac{Mean - LSL}{3\sigma}$$

This figure shows the same distributions off-center by 1.5σ. The C_{pk}s are smaller than the corresponding C_ps. This illustrates the need to both control variation and accurately hit the desired mean.

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Cp versus Cpk

In this case, the shooter (archer) has a bad eye – the shots are widely dispersed and slightly off-center

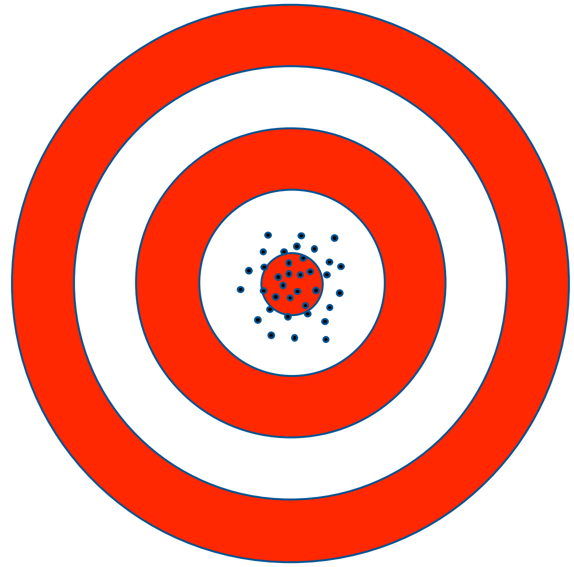
C_p is low

C_{pk} is low

In this case, the shooter (archer) has a good eye, but all the shots are off-center

C_p is high

C_{pk} is low



C_p is high

C_{pk} is high

In this case, the shooter (archer) has a good eye, and has now adjusted the gun (bow) sight to bring the shots on target

Process Capability

- Once we have a process in control then we can answer the question of whether the process is capable of meeting the customer's specifications.
- *"Process Capability* is broadly defined as the ability of a process to meet customer expectations" (Bothe, 1997)

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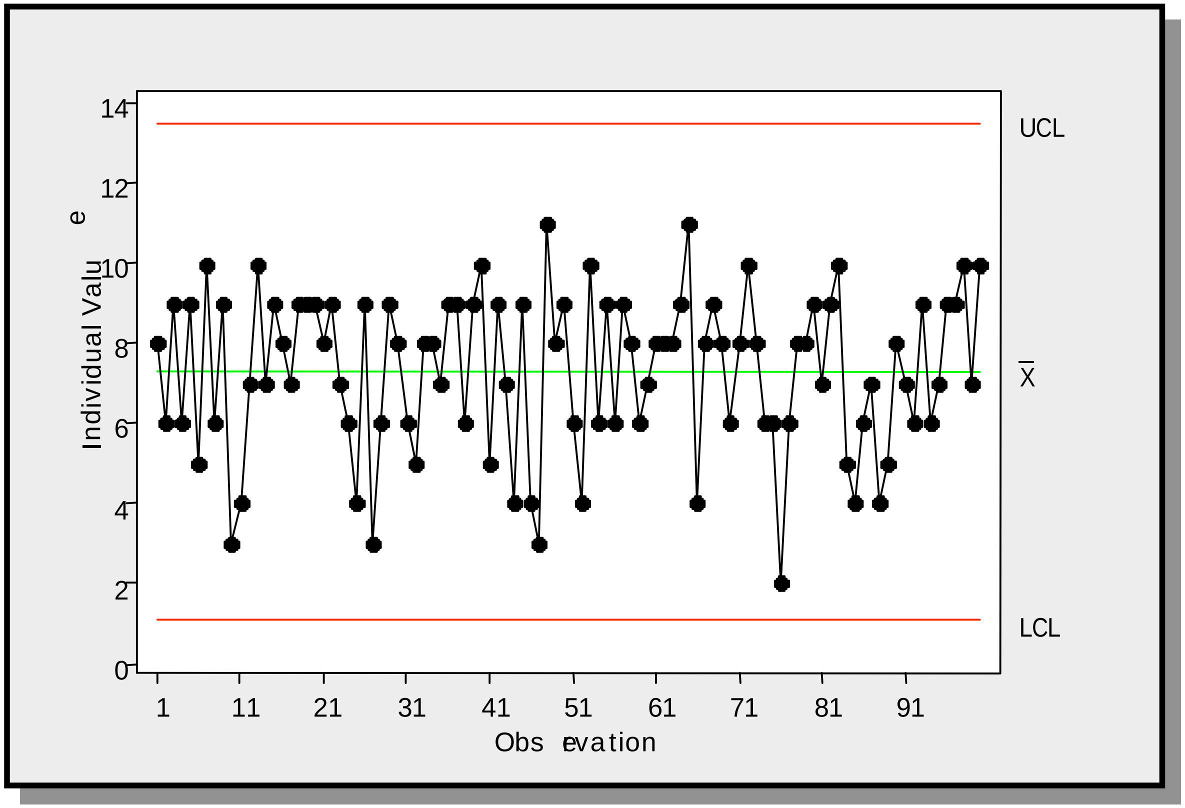
SPC Exercise



Sample Outcome

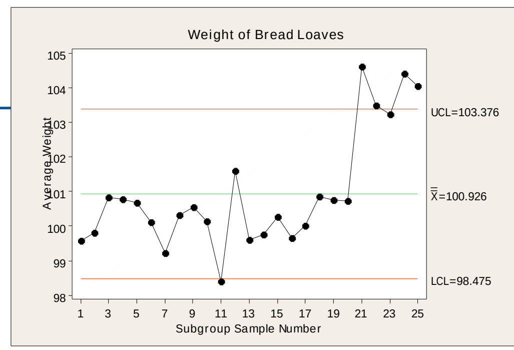
Process Improvement and Control Charts

Input

Process

Output

Measurement System

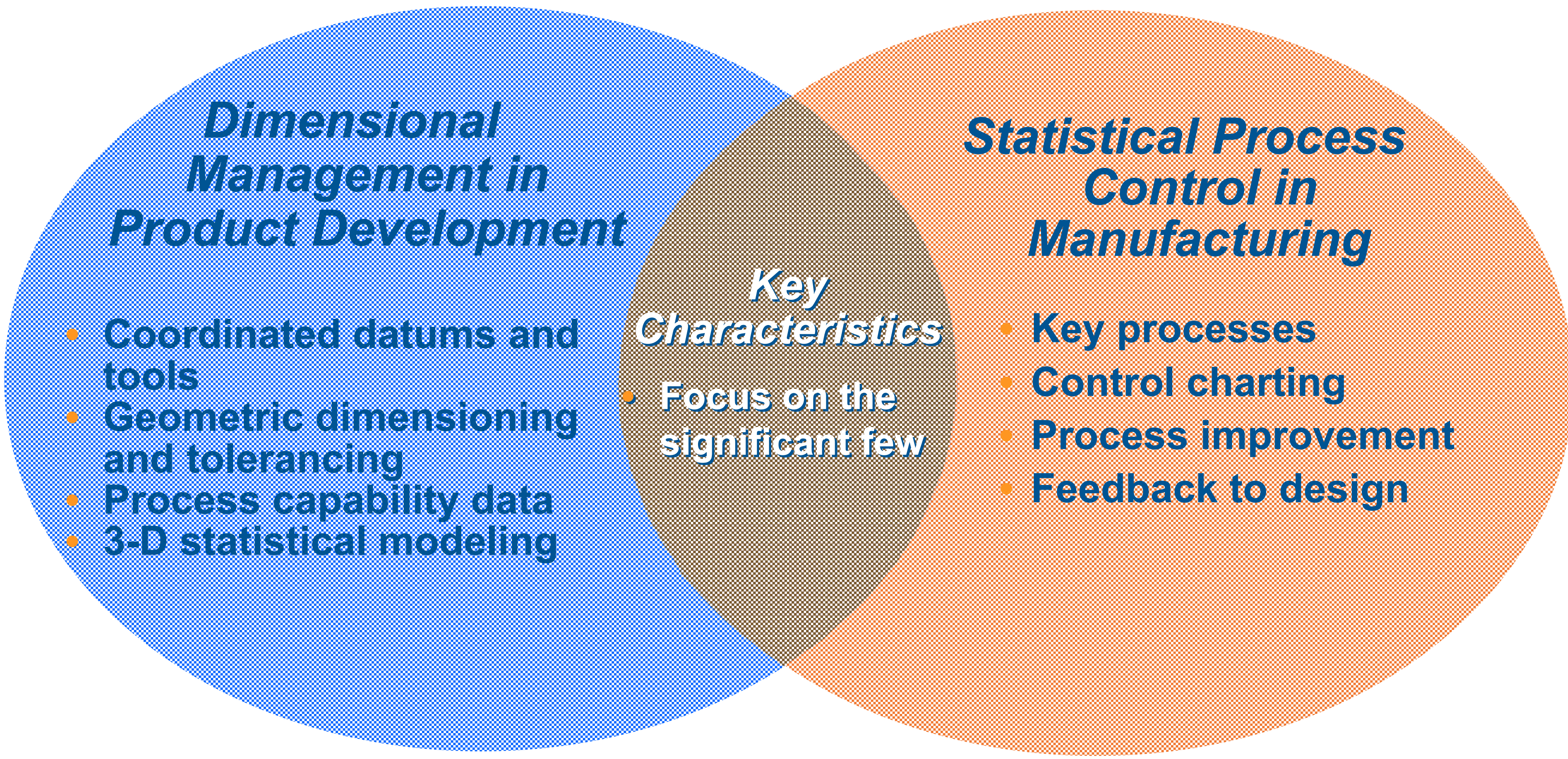


1. Identify opportunities and measure inputs and outputs (Define & Measure)
2. Identify Root Cause (Analyze)
3. Implement Corrective Action (Improve)
4. Verify and Monitor (Control)

Strategy for Using Control Charts

- In early stages, control charts (usually on output variables) are used to understand the behavior of the process
- After corrective actions, place charts on critical *input* variables
- If a chart has been implemented, remove it if it is not providing valuable and actionable information
- The goal: Monitor and control *inputs* and, over time, eliminate the need for SPC charts by having preventative measures in place

Variability Reduction Spans The Enterprise



A lean enterprise requires robust engineering designs and capable manufacturing processes!

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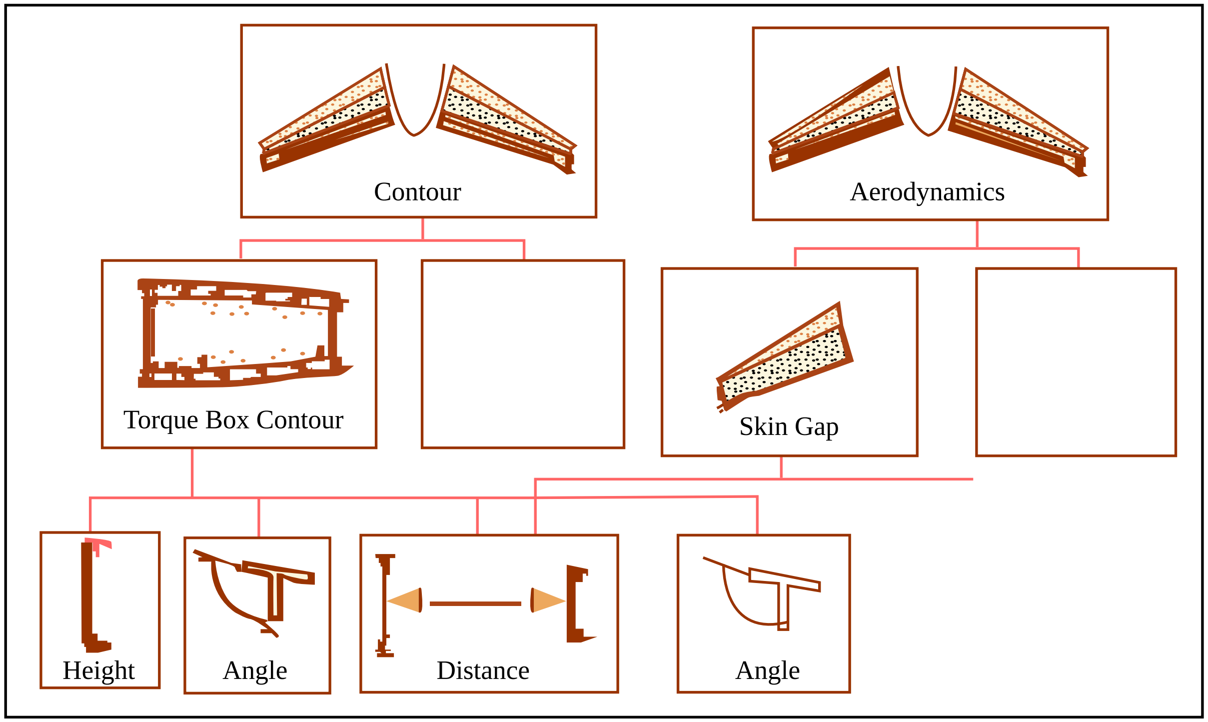
Dimensional Management Enabled by Key Characteristics

Key Characteristics: Critical few product features that significantly affect quality, performance, or cost



System KCs

Subassembly KCs

Feature KCs

Figure by MIT OpenCourseWare.

Concentrate Dimensional Management effort where it matters - on KC's

Source: Dr. Anna C.Thornton,
Ref: Anna C.Thornton, Variation Risk Management, John Wiley & Sons, Inc. 2004

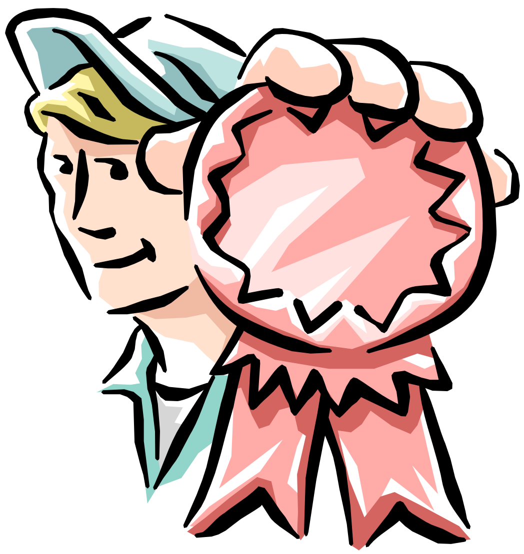
Benefits of Variability Reduction: Floor Beams for Commercial Aircraft

Courtesy of Boeing. Used with permission.

	747	777
Assembly strategy	Tooling	Toolless
Hard tools	28	0
Soft tools	2/part #	1/part #
Major assembly steps	10	5
Assembly hrs	100%	47%
Process capability	$C_{pk}<1$ (3.0σ)	$C_{pk}>1.5$ (4.5σ)
Number of shims	18	0

Refs:J.P. Koonmen, "Implementing Precision Assembly Techniques in the Commercial Aircraft Industry", Master's thesis, MIT (1994), and J.C.Hopps, "Lean Manufacturing Practices in the Defense Aircraft Industry", Master's Thesis, MIT (1994)

What is Six Sigma?



Strategy… *a data driven philosophy and process* resulting in dramatic shifts in way a company behaves, treats its customers, and produces products/services. Measurement… *Measurement of the variation* of a process…standard deviation. Translates into process performance…defects per million (DPM).

The goal of Six Sigma is to reduce process variation

Defects

- **Improving quality means reducing the defects per million opportunities (DPMO). There are two attributes to this metric that can be controlled:**
  - ***Opportunities* – reducing the number of parts, joints, fasteners, and other "opportunities" will help improve quality – lean engineering**
  - ***Defects* – reducing the number of defects by reducing the amount of process variation – Six Sigma**

Implications of a Six Sigma Process

Six Sigma is defined as 3.4 defects per million opportunities, or a first pass yield of 99.9997%

Process Mean On-Target			Process Mean Shifted 1.5σ	
Cp	DPMO		Cpk	DPMO
2.00	0.00197		1.50	3.40
1.67	0.57330		1.17	233
1.33	63		0.83	6,210
1.00	2,700		0.50	66,811
0.67	45,500		0.17	308,770
0.33	317,311		-0.17	697,672

With a Six Sigma process even a significant shift in the process mean results in very few defects

Six Sigma – Practical Meaning

99% GOOD (3.8 Sigma)

- 20,000 lost articles of mail per hour
- Unsafe drinking water for almost 15 minutes per day
- 5,000 incorrect surgical operations per week
- Two short or long landings at most major airports each day
- 200,000 wrong drug prescriptions each year
- No electricity for almost seven hours each month

99.99966% GOOD (6 Sigma)

- Seven articles of mail lost per hour
- One unsafe minute every seven months
- 1.7 incorrect operations per week
- One short or long landing every five years
- 68 wrong prescriptions each year
- One hour without electricity every 34 years

When Can Six Sigma Be Used?

- There are two major forms of Six Sigma, each of which apply to specific phases within a product's lifecycle:
  - Design for Six Sigma (DFSS)
    - Used to analyze and improve a product's (or service's) key quality characteristics and to develop robust processes to produce the product (or service)
  - "Traditional" Six Sigma Methodology
    - Typically used throughout the production stages of a product's lifecycle

Six Sigma Methodology

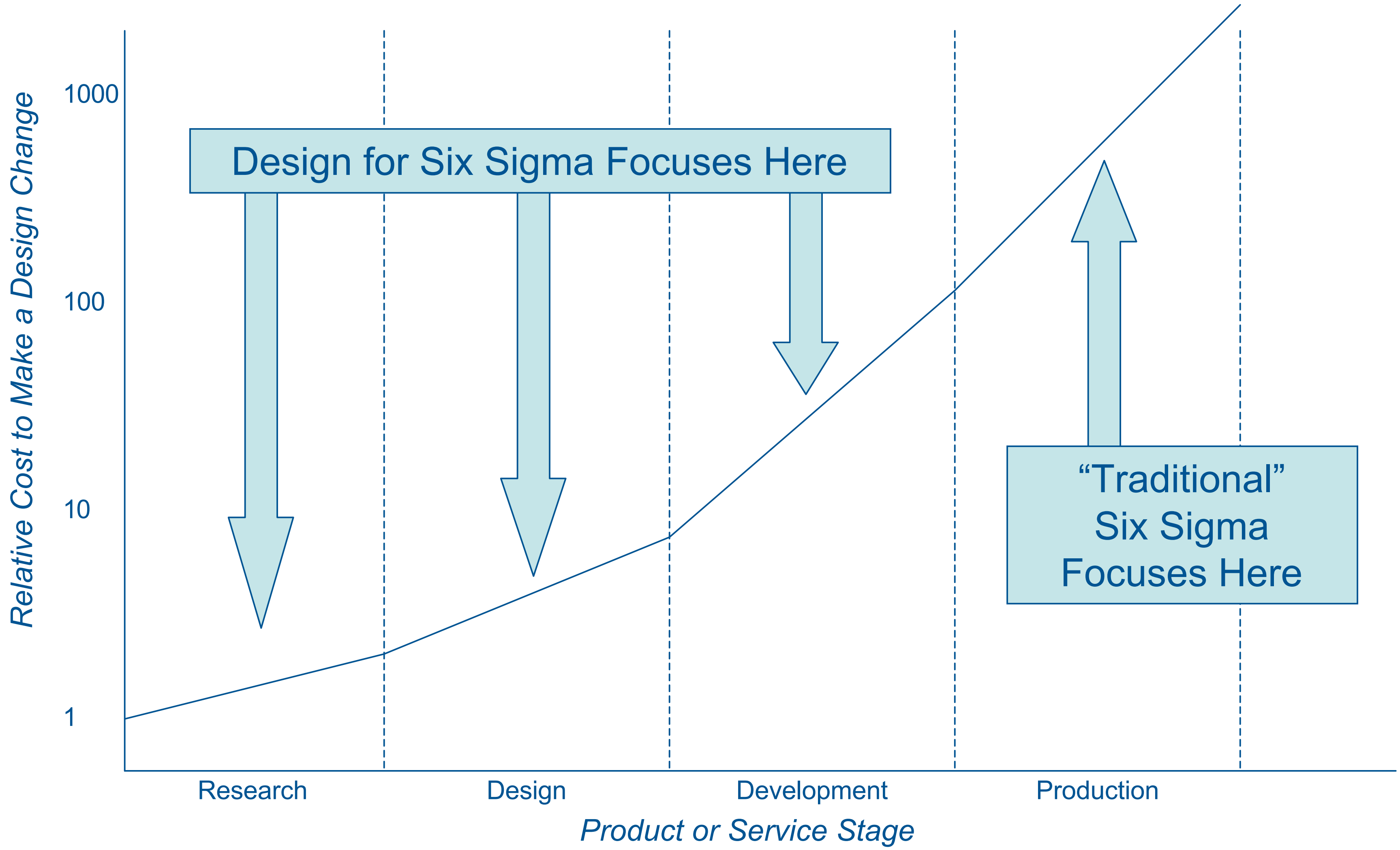
- There are five fundamental steps in the Six Sigma DMAIC process:
  - Define –
    - Who are the customers and what are their problems?
    - Identify key characteristics important to the customer.
  - Measure –
    - Categorize key input and output characteristics, verify measurement systems
    - Collect data and establish the baseline performance
  - Analyze –
    - Convert raw data into information to provide insights into the process
  - Improve –
    - Develop solutions to the problem and compare the results to the baseline performance
  - Control –
    - Monitor the process to assure no unexpected changes occur

What is DFSS?

*D*esign *f*or *S*ix *S*igma

- A methodology for designing new products and/or processes
- A methodology for re-designing existing products and/or processes
- A way to implement Six Sigma methodology as early in the product or service life cycle
- A way to “design in” quality when costs are lowest

Timing of DFSS vs. Six Sigma



Adapted from: "Using the Design for Six Sigma (DFSS) Approach to Design, Test, and Evaluate to Reduce Program Risk." Dr. Mark J. Kiemele, Air Academy Associates. NDIA Test and Evaluation Summit, Victoria, British Columbia February 24-27, 2003.

DFSS Process & Tools

***I**dentify*	***D**esign*	***O**ptimize*	***V**alidate*
• Integrated Product Team • Team Charter • Voice of the Customer • Benchmarking • Business Case • Critical-to-Quality Variables	• Cause & Effect Analysis • Computer Aided Design • Computer Aided Engineering • Pareto Analysis	• Histogram • Design for Manufacturing and Assembly • Error-Proofing	• Integrated product team • Cause & Effect Analysis • Capable process and product (C_p, C_{pk})
Leadership **Communication** **Conflict resolution and consensus building** **Organization**			

Note the overlap between Lean tools and Six Sigma tools!

Comparison of Lean & Six Sigma Approaches

Program	Six Sigma	Lean
Theory	Reduce variation	Remove waste
Application Guidelines	1. Define 2. Measure 3. Analyze 4. Improve 5. Control	1. Identify Value 2. Identify Value Stream 3. Flow 4. Pull 5. Perfection
Focus	Problem focused	Flow focused
Assumptions	• A problem exists • Figures and numbers are valued • System output improves if variation in all processes inputs is reduced	• Waste removal will improve business performance • Many small improvements are better than system analysis

Ref: Nave, Dave. "How to Compare Six Sigma, Lean, and the Theory of Constraints." Quality Progress. March 2002

Lean and Six Sigma…

Merging Process Improvement Approaches

- **Lean And Six Sigma are merging into a unified framework for enterprise change**
- **Lean optimizes flow, reduces cycle time, and eliminates waste (including the waste of poor quality)**
- **Six Sigma provides a means for *measuring* quality**
  - **for improving individual processes**
  - **for measuring performance improvement across the enterprise**
- **Lean strives for speed through continuous "drum-beat" flow… Six Sigma strives for quality through elimination of variation**

Continuous flow cannot be achieved without high quality processes

Discussion and Take Aways

- Quality is essential to lean – not a competitor

  Why?
- Process and product quality are linked

  How?
- A variety of tools are available for determining and improving quality

  What are some?
- Six sigma is a valuable concept in achieving customer satisfaction

  Why?

Reading List

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Acknowledgements

- Tom Callarman – Arizona State University
- Phil Farrington – University of Alabama in Huntsville
- Al Haggerty - MIT, Boeing (ret.)
- Trent Hancock – Rockwell Collins
- Dick Lewis – Rolls-Royce (ret.)
- Jose Macedo – Cal Poly, San Luis Obispo
- Jan Martinson - Boeing, IDS
- Hugh McManus, Metis Design
- Earll Murman, MIT
- Bo Oppenheim - Loyola Marymount University
- Jack Reismiller – Rolls-Royce Six Sigma Master Black Belt
- Steve Shade - Purdue University
- Sue Siferd - ASU
- Alexis Stanke - MIT
- Barrett Thomas –University of Iowa
- Ed Thoms - Boeing, IDS

Notes