SIX SIGMA

M Sc Statistics

Sem III

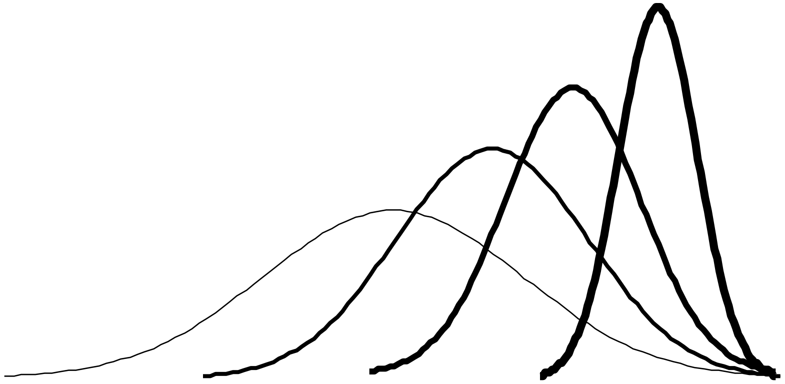
Paper IV - Industrial Process and Quality Control

Unit III – SIX SIGMA

Dr Sandhya Dhabe

Associate Professor,Dept of Statistics, Institute of Science ,Nagpur

SIX SIGMA

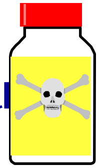


A STRATEGY FOR PERFORMANCE EXCELLENCE

How good is good enough?

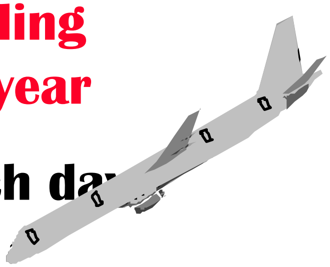
99.9% is already VERY GOOD

But what could happen at a quality level of 99.9% (i.e., 1000 ppm), in our everyday lives (about 4.6σ)?

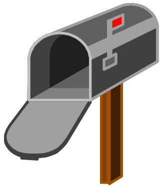


- **4000 wrong medical prescriptions each year**

- **More than 3000 newborns accidentally falling from the hands of nurses or doctors each year**



- **Two long or short landings at American airports each day**



- **400 letters per hour which never arrive at their destination**

How can we get these results

- 13 wrong drug prescriptions per year
- 10 newborn babies dropped by doctors/nurses per year
- Two short or long landings per year in all the airports in the U.S.
- One lost article of mail per hour

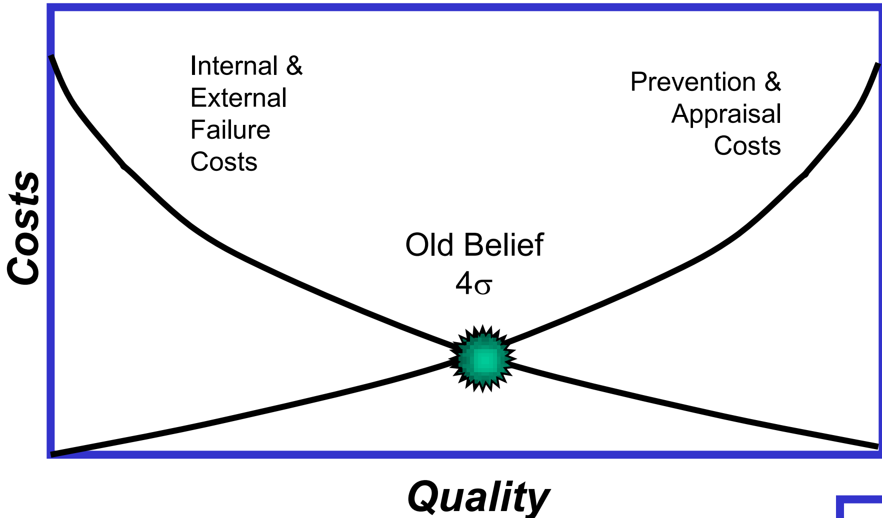
The answer is:

Six Sigma

What is Six Sigma

- A **Vision** and **Philosophical** commitment to our consumers to offer the highest quality, lowest cost products
- A **Metric** that demonstrates quality levels at 99.9997% performance for products and processs
- A **Benchmark** of our product and process capability for comparison to ‘best in class’
- A practical application of statistical **Tools** and **Methods** to help us measure, analyze, improve, and control our process

Six Sigma as a Philosophy



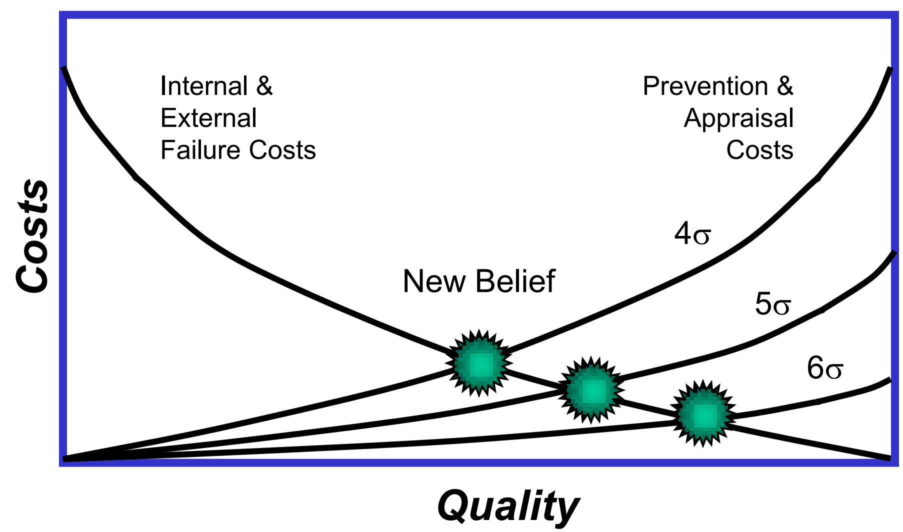
σ is a measure of how much variation exists in a process

Old Belief

High Quality = High Cost

New Belief

High Quality = Low Cost



Better Processes Reduce Cost

3 Sigma Vs. 6 Sigma

The 3 sigma Company	The 6 sigma Company
• ***Spends 15~25% of sales dollars on cost of failure***	• ***Spends 5% of sales dollars on cost of failure***
• ***Relies on inspection to find defects***	• ***Relies on capable process that don't produce defects***
• ***Does not have a disciplined approach to gather and analyze data***	• ***Use Measure, Analyze, Improve, Control and Measure, Analyze, Design***
• ***Benchmarks themselves against their competition***	• ***Benchmarks themselves against the best in the world***
• ***Believes 99% is good enough***	• ***Believes 99% is unacceptable***
• ***Define CTQs internally***	• ***Defines CTQs externally***

Focus: The End User

- ***Customer: Internal or External***
- ***Consumer: The End User***

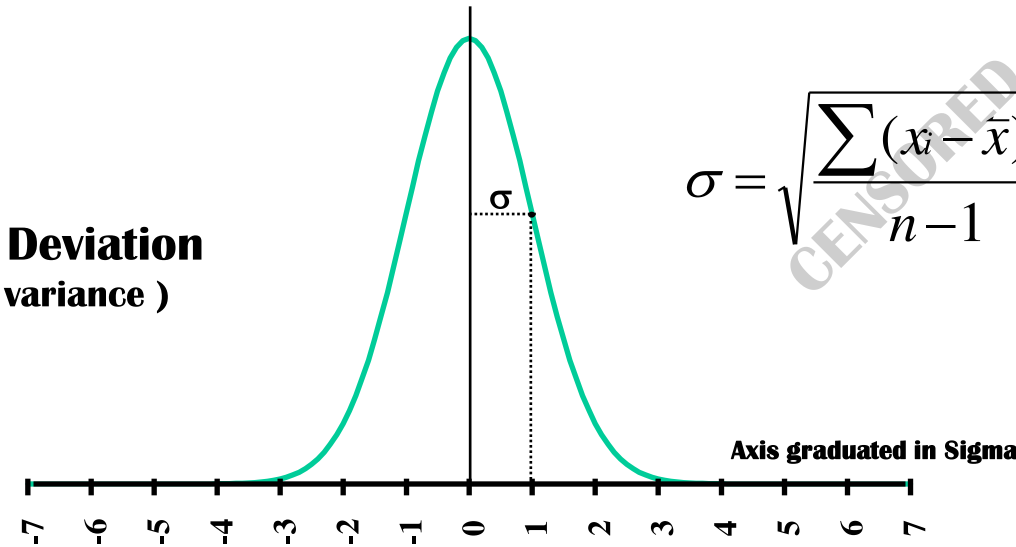
the "Voice of the Consumer" (Consumer Cue)

must be translated into

the "Voice of the Engineer" (Technical Requirement)

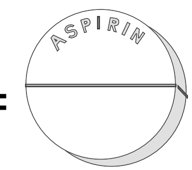
Six Sigma as a Metric

Sigma = **σ** = **Deviation**
(Square root of variance)

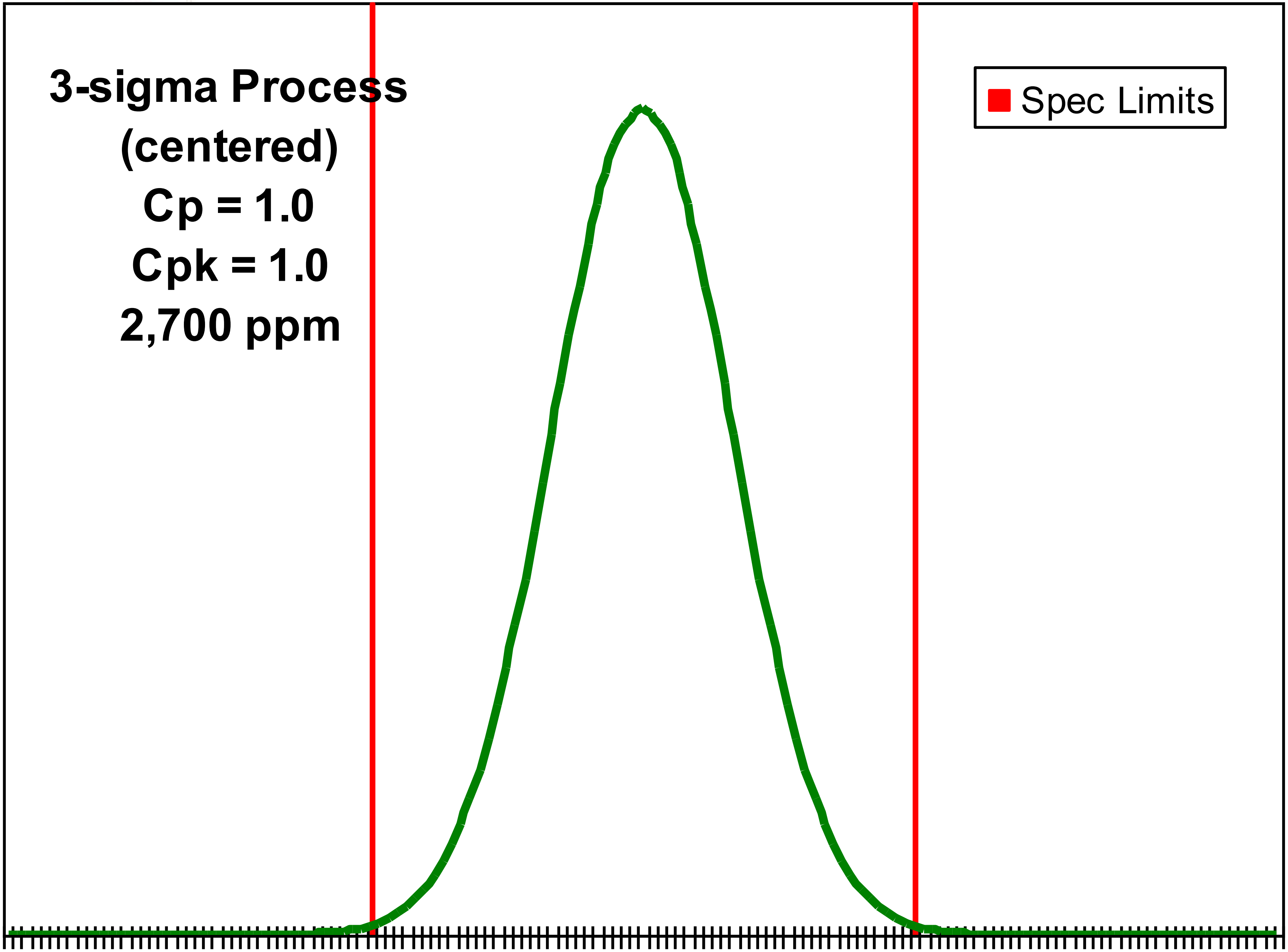


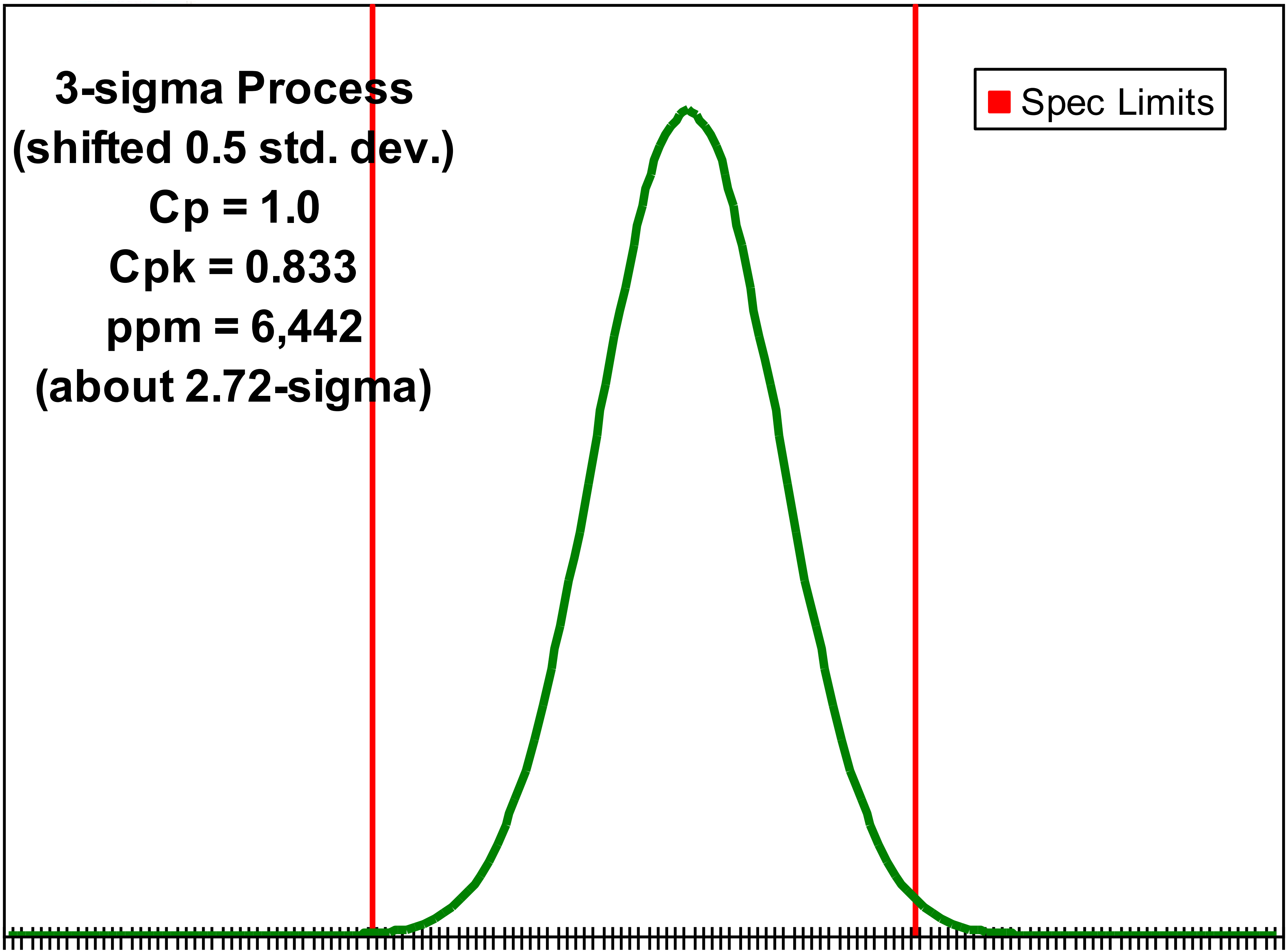
$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} =$$

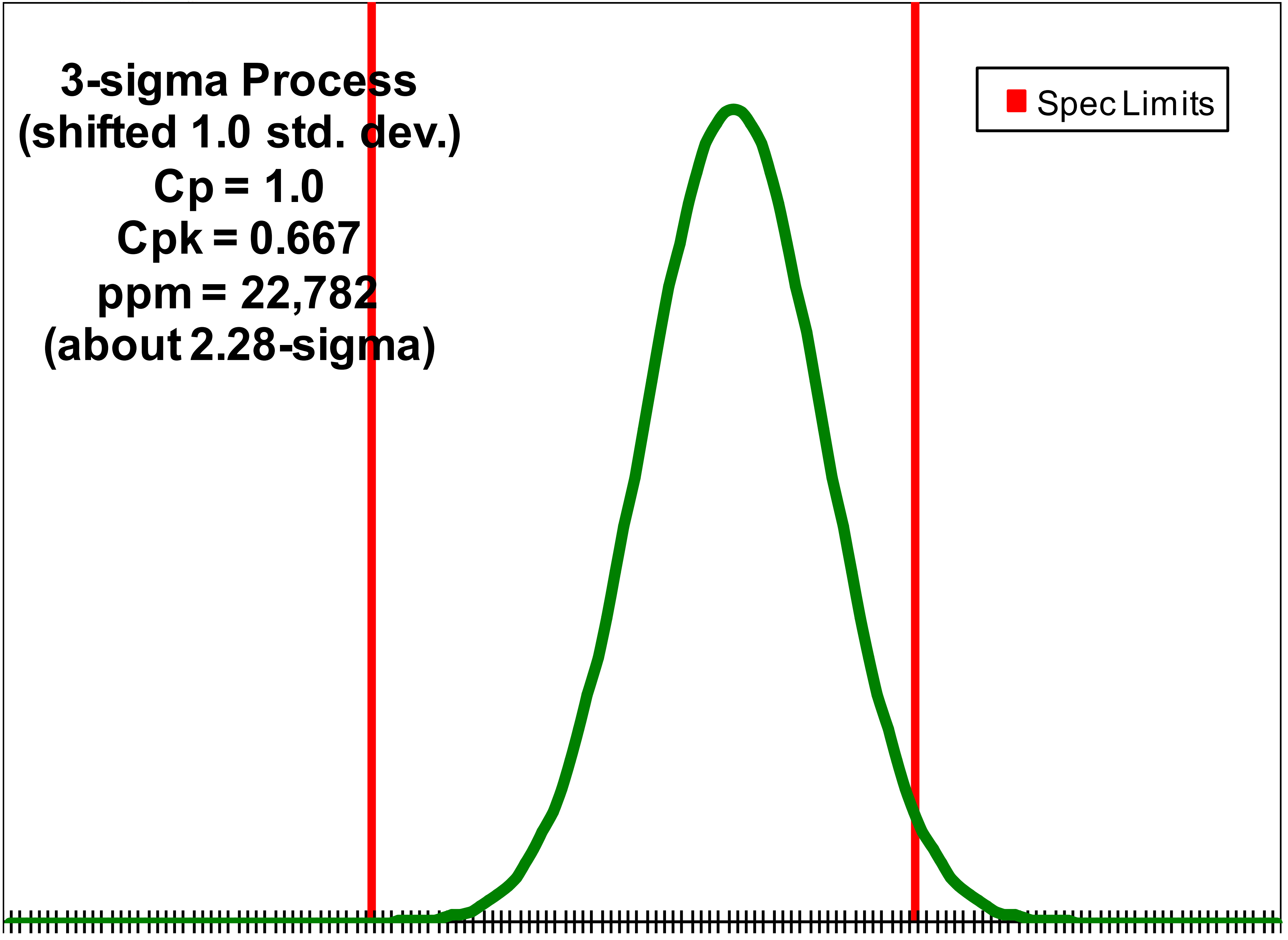
CENSORED

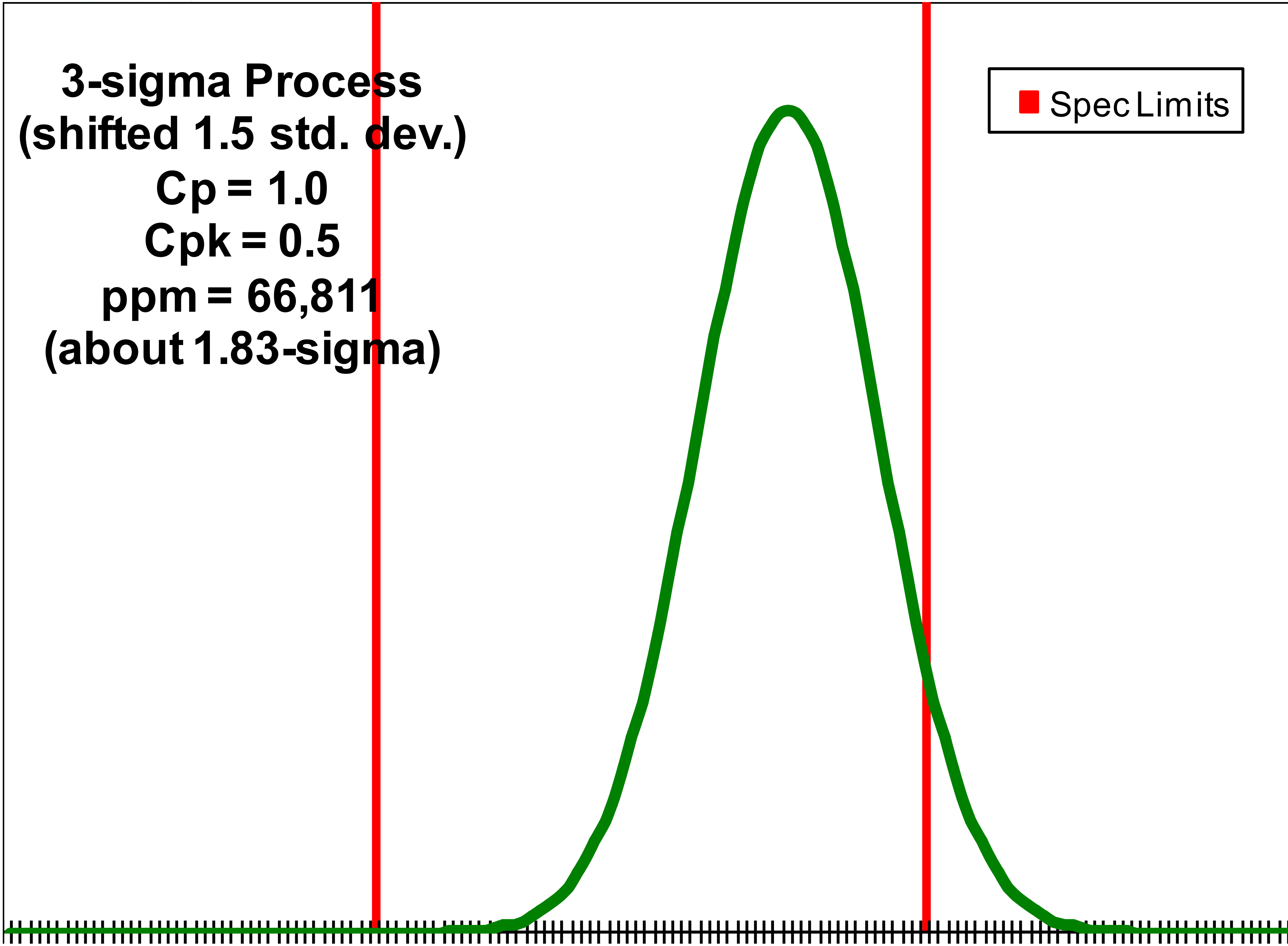


between + / - 1σ	68.27 %	result: 317300 ppm outside (deviation)
between + / - 2σ	95.45 %	45500 ppm
between + / - 3σ	99.73 %	2700 ppm
between + / - 4σ	99.9937 %	63 ppm
between + / - 5σ	99.999943 %	0.57 ppm
between + / - 6σ	99.9999998 %	0.002 ppm


3-sigma Process
(centered)
Cp = 1.0
Cpk = 1.0
2,700 ppm
Spec Limits


3-sigma Process
(shifted 0.5 std. dev.)
Cp = 1.0
Cpk = 0.833
ppm = 6,442
(about 2.72-sigma)
Spec Limits

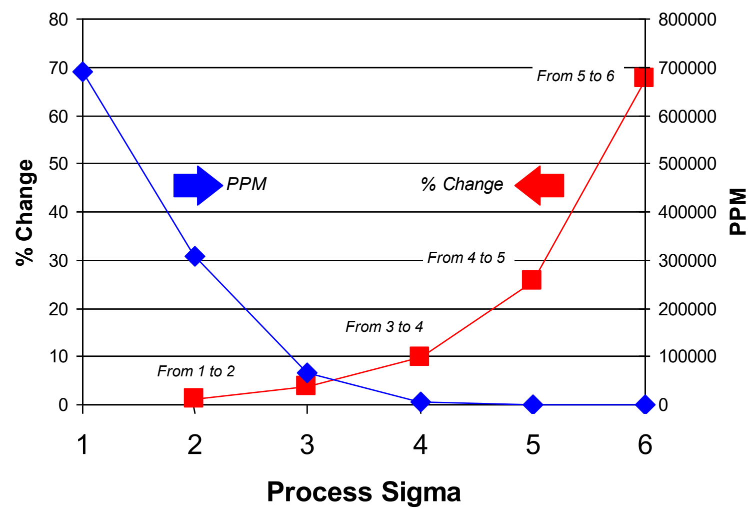

3-sigma Process
(shifted 1.0 std. dev.)
Cp = 1.0
Cpk = 0.667
ppm = 22,782
(about 2.28-sigma)
Spec Limits


3-sigma Process
(shifted 1.5 std. dev.)
Cp = 1.0
Cpk = 0.5
ppm = 66,811
(about 1.83-sigma)
Spec Limits

Non-Liner Decrease

σ	PPM
2	308,537
3	66,811
4	6,210
5	233
6	3.4
Process Capability	*Defects per Million Opportunities*

** Includes 1.5σ shift*



Focusing on σ requires thorough process understanding and breakthrough thinking

Six Sigma as a Tool

Process Mapping

Structure Tree

Pareto Analysis

Gauge R & R

Rational Subgrouping

Baselining

Tolerance Analysis

Components Search

Hypothesis Testing

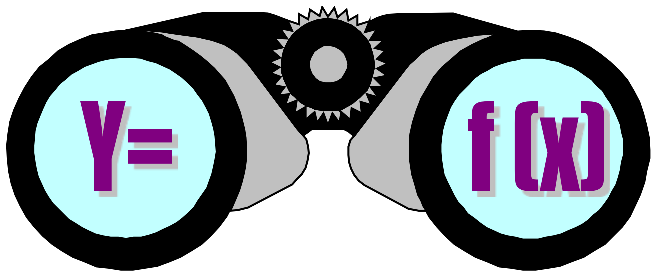
Regression

DOE

SPC

Many familiar quality tools applied in a structured methodology

Six Sigma as a Method



To get results, should we focus our behavior on the Y or X

•Y	•X1…Xn
•Dependent	•Independent
•Output	•Input-Process
•Effect	•Cause
•Symptom	•Problem
•Monitor	•Control

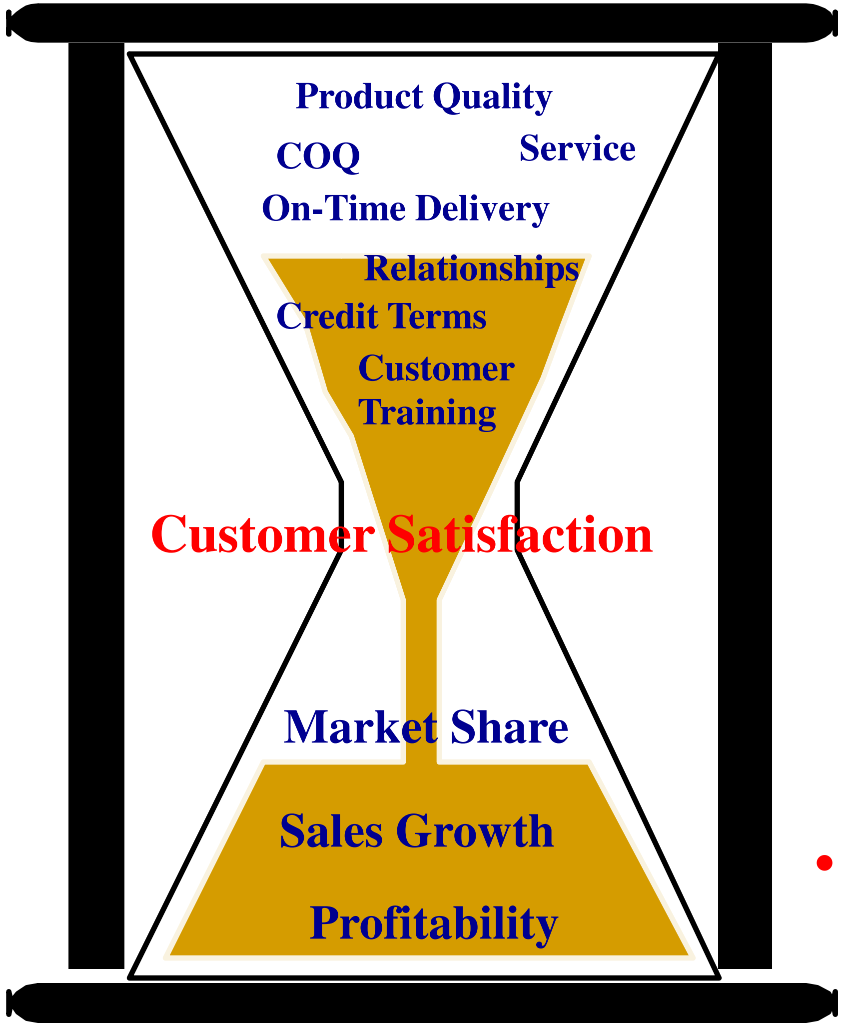
A Traditional View

- **Output Variables**

Manage the outputs.

A Non-Traditional View

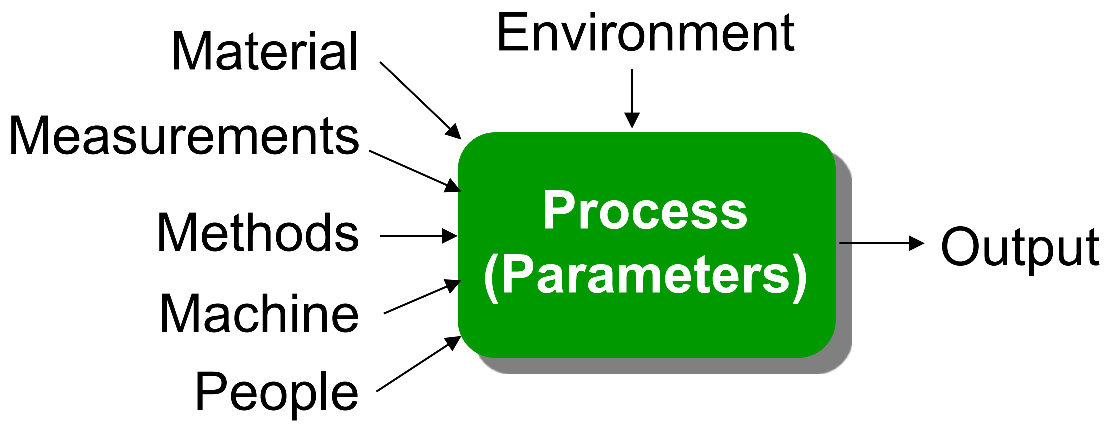
• Input Variables



• Output Variables

Manage the inputs; respond to the outputs.

Distinguish "Vital Few" from "Trivial Many"

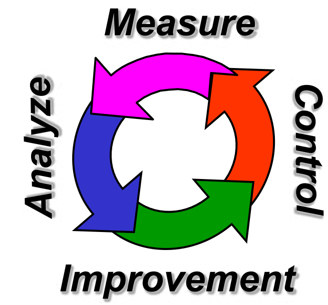


Define the Problem / Defect Statement

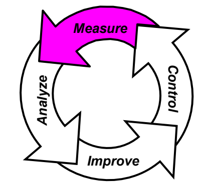
$$Y = f\,(\,x_1^{*},\, x_2,\, x_3,\, x_4^{*},\, x_5 \,.\,.\,.\, X_n)$$

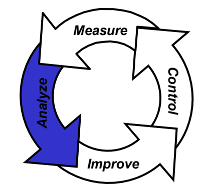
Y =	Dependent Variable	➔	Output, Defect
x =	Independent Variables	➔	Potential Cause
x* =	Independent Variable	➔	Critical Cause

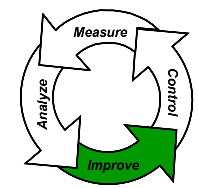
Strategy by Phase -

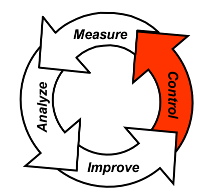


Phase	Step	Focus
Process Characterization		
Measure (What)	***What is the frequency of Defects?***	
	• Define the defect	Y
	• Define performance standards	Y
	• Validate measurement system	Y
	• Establish capability metric	Y
Analyze (Where, When, Why)	***Where, when and why do Defects occur?***	
	• Identify sources of variation	X
	• Determine the critical process parameters	Vital X
Process Optimization		
Improve (How)	***How can we improve the process?***	
	• Screen potential causes	X
	• Discover relationships	Vital X
	• Establish operating tolerances	Vital X
	Were the improvements effective?	
	• Re-establish capability metric	Y, Vital X
Control (Sustain, Leverage)	***How can we maintain the improvements?***	Y, Vital X
	• Implement process control mechanisms	
	• Leverage project learning's	
	• Document & Proceduralize	



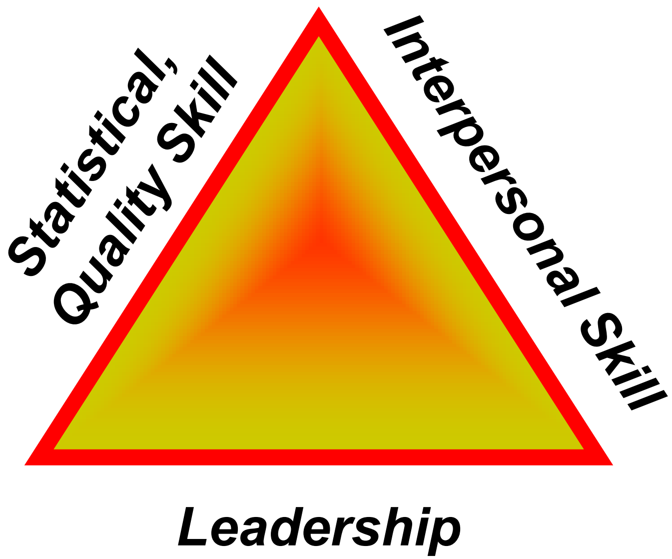


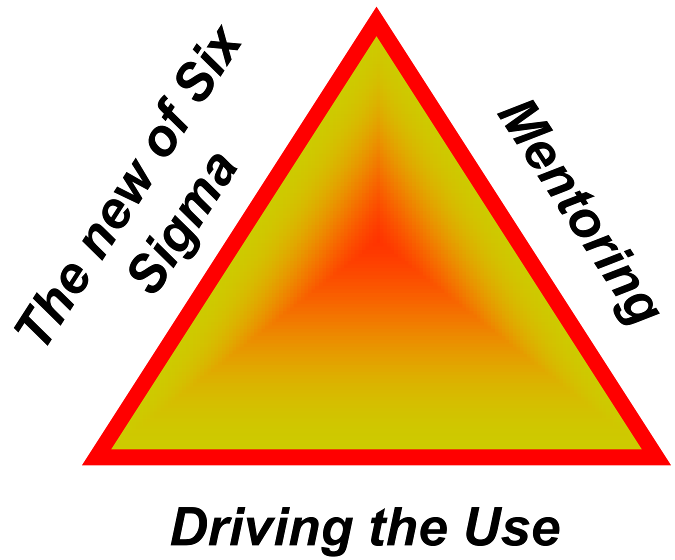




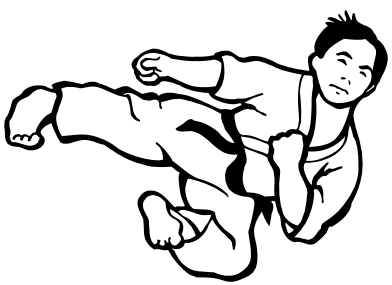
Six Sigma Organization

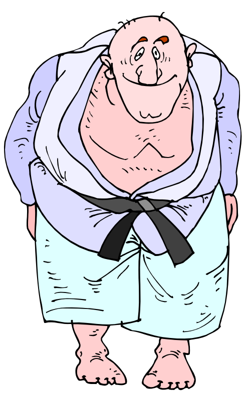
A Black Belt has…, and will…





Black Belt Training





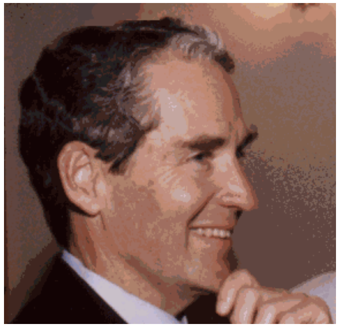
	Task	Time on Consulting/ Training	Mentoring	Related Projects
Green Belt	Utilize Statistical/ Quality technique	2%~5%	Find one new green belt	2 / year
Black Belt	Lead use of technique and communic-ate new ones	5%~10%	Two green belts	4 / year
Master Black Belt	Consulting/ Mentoring/ Training	80~100%	Five Black Belts	10 / year

Six Sigma

Core	Statistical Skills	Core	Six Sigma Quality Skills	Core	Interpersonal Ski
GBM	Statistical Software (JMP, Minitab) *MIN101*	GBM	AIEG QMS	GBM	Communication (oral, writ *AEC722, DDI121*
GBM	Numerical and Graphical Techniques *MIN101, IBM548*	GBM	QS 9000 *AEC279*	GBM	Team Facilitation *DDI170*
GBM	Statistical Process Control *AEC506, AEC661, AEC662, AEC663*	GBM	Customer Satisfaction *SSG100, TCS100*	GBM	Coaching and Mentoring *LDR380, PER119*
GBM	Process Capability *AEC661, AEC662, SCP201*	GBM	Six Steps to Six Sigma *SSG100, SSG102CD*	GBM	Managing Change *MGT564, MGT124, PDE5.*
GBM	Comparative Tests *MIN101, SPC201*	GBM	Concurrent Engineering	BM	Leadership *MGT561, MGT562, DDI1*
GBM	Analysis of Variance (ANOVA) *ENG998, AEC603*	GBM	TCS *TCS100*	BM	Team Building *MGT560, MGT562, EC72*
GBM	Measurement System Analysis *AEC663*	GBM	Systemic Approach to Problem Solving *QUA392*	M	Instructional/Teaching *MOT132*
GBM	Design of Experiments (e.g. Full, Fractional, Taguchi Designs) *ENG998, QUA389*	GBM	Team Oriented Problem Solving (8D, 7D, 5P)	M	Managing Projects *AEC471, MGT839*
GBM	Regression (e.g. linear, nonlinear)	BM	Quality System Review *QUA590*		
GBM	Statistical Process Characterization Strategies and Techniques *ENG227*	BM	Team Problem Solving Non-Manufacturing *CES103*		
BM	Statistical Inference *MIN101, SPC201*	BM	Design for Manufacturability *ENG123, ENG123CD*		
BM	Confidence Intervals *MIN101, SPC201*	BM	Financial/Economic Quality Issues		
BM	Probability Concepts and Distributions *SPC201*	M	Quality Function Deployment *QUA200A, QUA200B, QUA200C*		
BM	Response Surface Methods *QUA393*	M	Total Quality Management		
BM	Screening DOE *QUA391*	M	Benchmarking *BMK220*		
M	Advanced Problem Solving Strategies and Technologies *ENG998*	M	Product Development Assessment		
M	Acceptance Sampling *SPC201*				
M	Sample Size Estimation				
M	Robust Design of Processes and Products				
M	Survival Analysis / Reliability				

MOTOROLA

Corporate Commitment



Motorola is committed to developing these leaders…

We provide these people with extensive training in statistical and interpersonal tools, skilled guidance and management support…

Once their development has achieved a level worthy of recognition, we even have a term for those exceptional individuals :

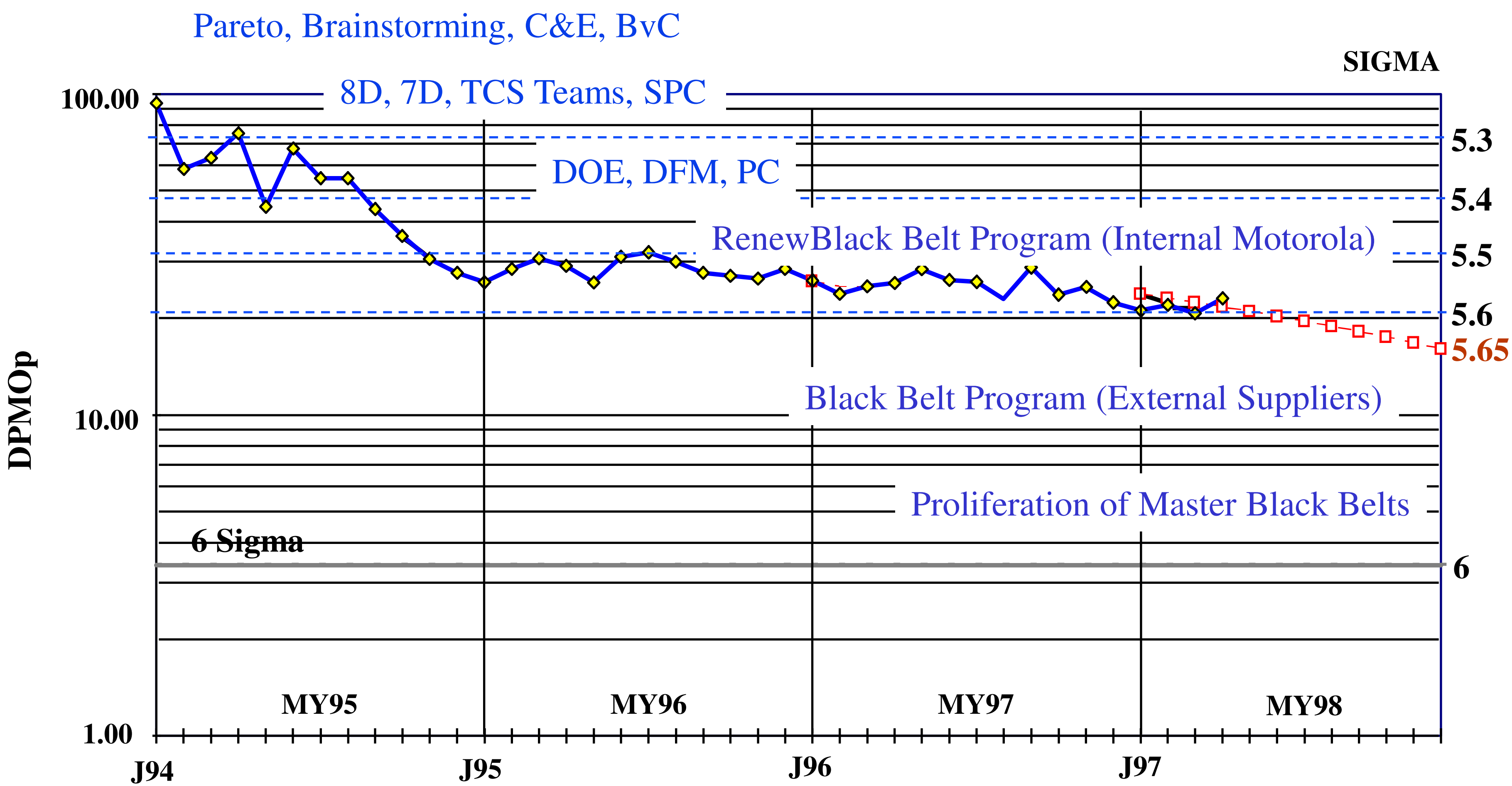
Six Sigma Black Belts

Chris Galvin

Corporate Commitment (Cont'd)

- Motto:
  - Quality is our job
  - Customer satisfaction is our duty
  - Customer loyalty is our future

Barrier Breakthrough Plan



Other Companies have Black Belts Program

- GE has very successfully instituted this program
  - 4,000 trained Black Belts by YE 1997
  - 10,000 trained Black Belts by YE 2000
  - "You haven't much future at GE unless they are selected to become Black Belts" - Jack Welch
- Kodak has instituted this program
  - CEO and COO driven process
  - Training includes both written and oral exams
  - Minimum requirements: a college education, basic statistics, presentation skills, computer skills
- Other companies include:
  - Allied Signal
  - IBM
  - Navistar
  - Texas Instruments
  - ABB
  - Citibank

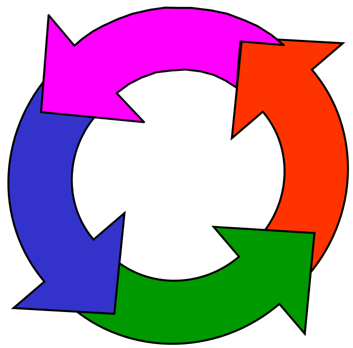
SIX SIGMA

Measure

Characterize Process

Evaluate

Understand Process



Control

Maintain New Process

Improve

Improve and Verify Process

Six Sigma

SIX SIGMA

Measure Phase

Define Problem

- Defect Statement
- Project Goals

Understand Process

- Define Process-Process Mapping
- Historical Performance
- Brainstorm Potential Defect Causes

Collect Data

- Data Types
  - Defectives
  - Defects
  - Continuous
- Measurement Systems Evaluation (MSE)

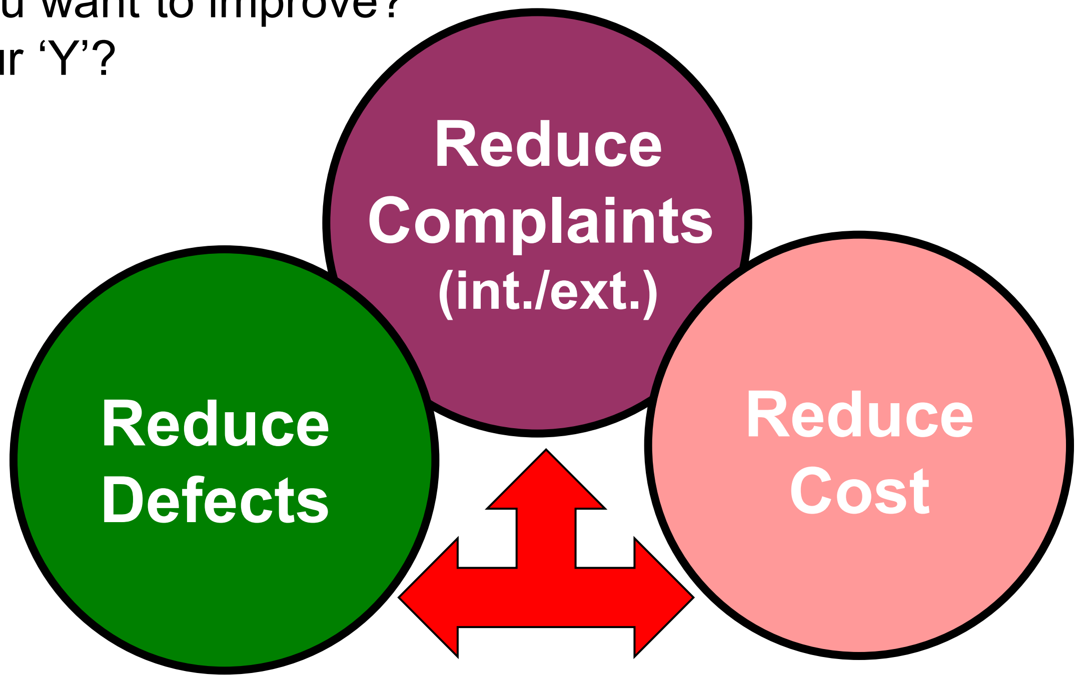
Process Performance

- Process Capability
  - Cp/Cpk
  - Run Charts
- Understand Problem (Control or Capability)

Understand the Process and Potential Impact

Problem Definition

- ✓ What do you want to improve?
- ✓ What is your ‘Y’?



What are the ***Goals?***

Problem Definitions need to be based on quantitative facts supported by analytical data.

Baselining:

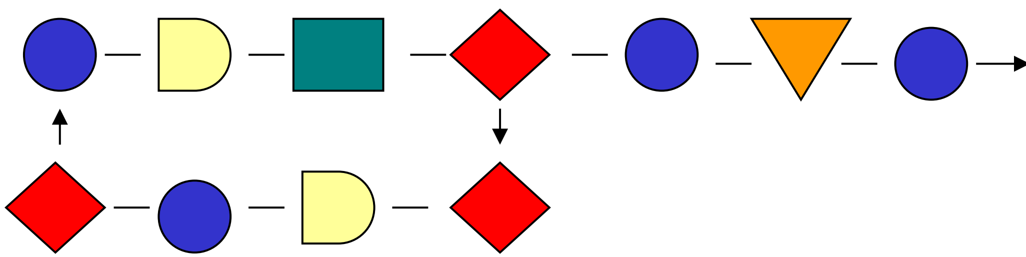
Quantifying the goodness (or badness!) of the current process, before ANY improvements are made, using sample data. The key to baselining is collecting representative sample data

Sampling Plan

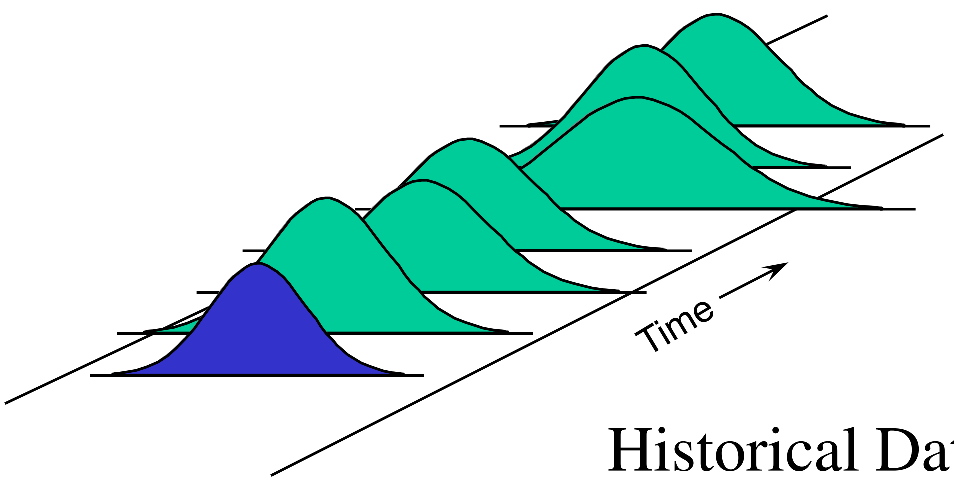
- Size of Subgroups
- Number of Subgroups
- Take as many "X" as possible into consideration

SIX SIGMA

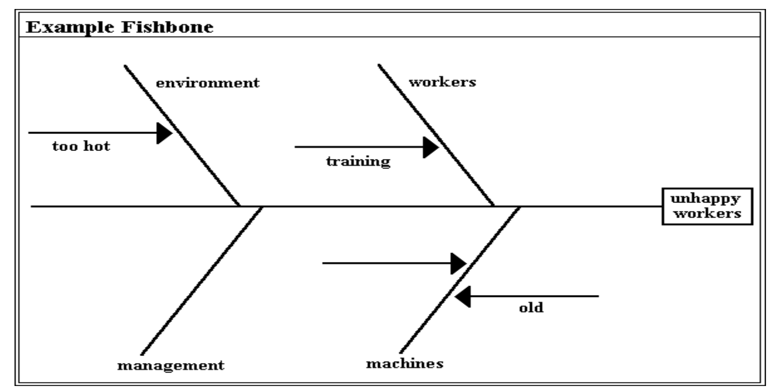
How do we know our process?



Process Map



Historical Data



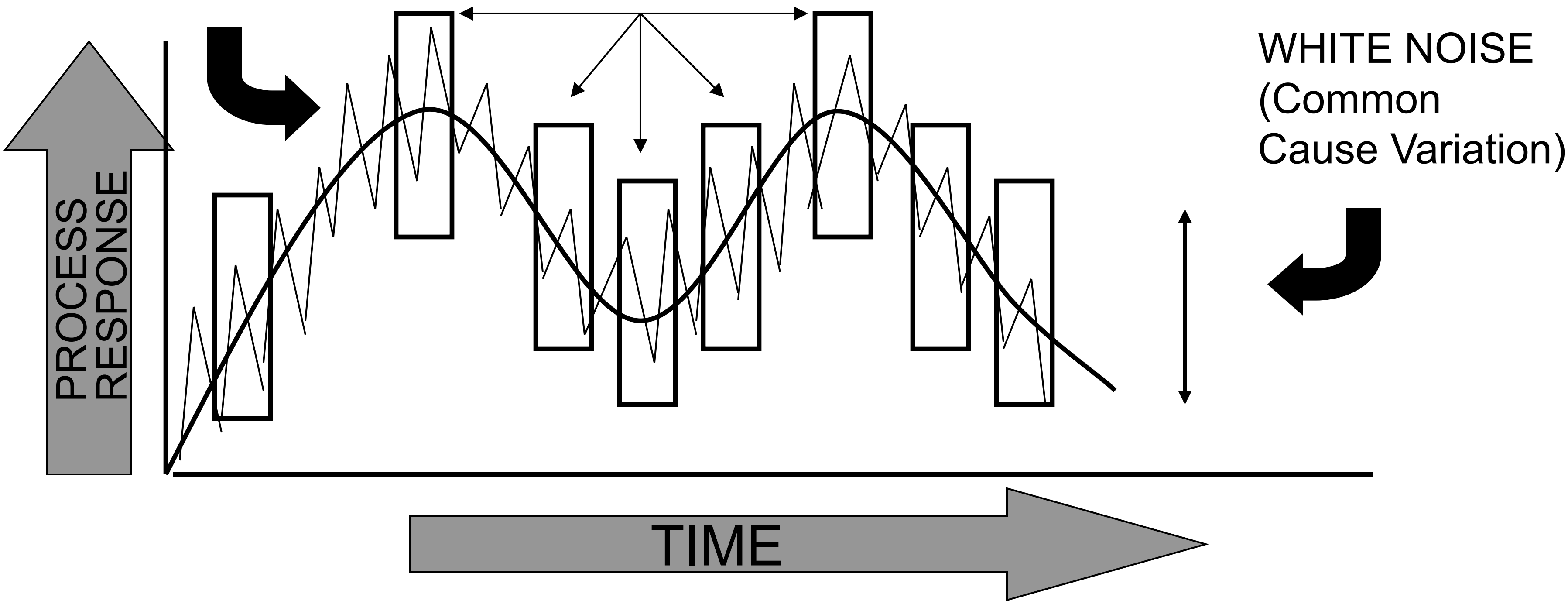
Fishbone

SIX SIGMA

RATIONAL SUBGROUPS

Minimize variation within subroups

Maximize variation between subrgoups



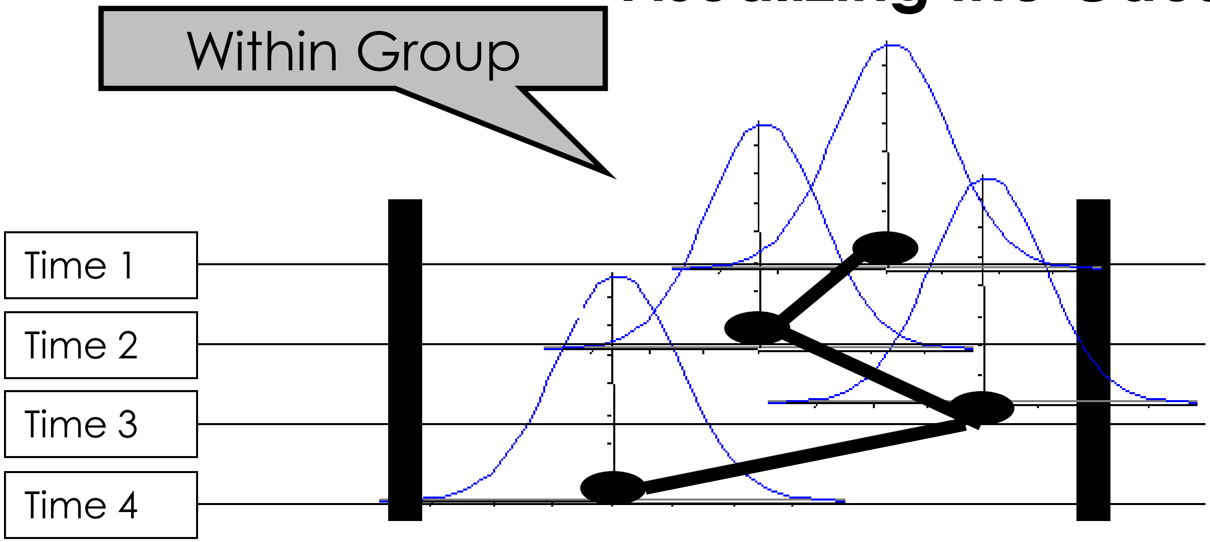
RATIONAL SUBROUPING Allows samples to be taken that include only white noise, <u>within</u> the samples. Black noise occurs <u>between</u> the samples.

SIX SIGMA

Sample	Day	Size	Shift	Operator	Air Pressure
1	1	0.045	1	1	80
2	1	0.046	1	1	80
3	1	0.04	1	1	80
4	1	0.047	1	1	80
5	1	-	1	-	-
6	4	-	2	-	-
7	4	-	2	-	-
8	4	-	2	-	-
9	4	-	2	-	
10	4	-	2	-	
11	3	-	1		
12	3	-			
13	3	-			
14					

SIX SIGMA

Visualizing the Causes

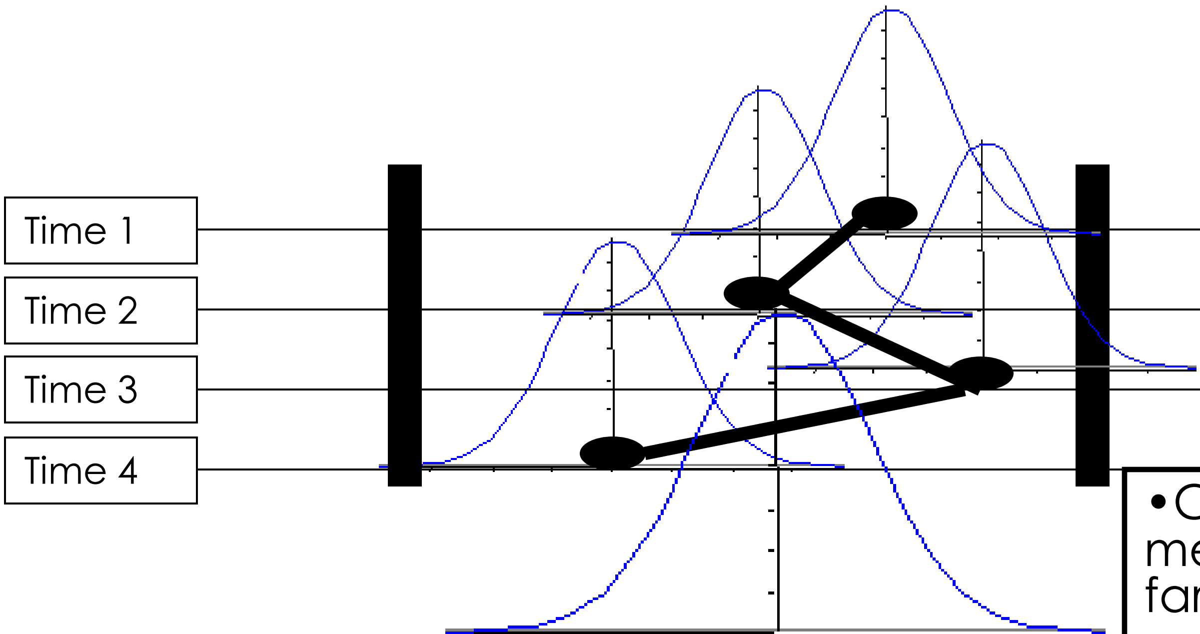


$\sigma_{st} + \sigma_{shift} = \sigma_{total}$

- Called σ short term (σ_{st})
- Our potential – the best we can be
- The s reported by all 6 sigma companies
- The trivial many

SIX SIGMA

Visualizing the Causes



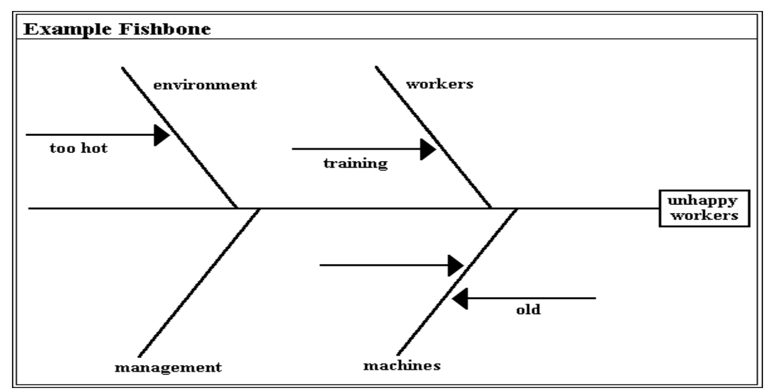
$\sigma_{st} + \sigma_{shift} = \sigma_{total}$

Between Groups

- Called σ_{shift} (truly a measurement in sigmas of how far the mean has shifted)
- Indicates our process control
- The vital few

Assignable Cause

- Outside influences
- Black noise
- Potentially controllable
- How the process is actually performing over time



Fishbone

Common Cause Variation

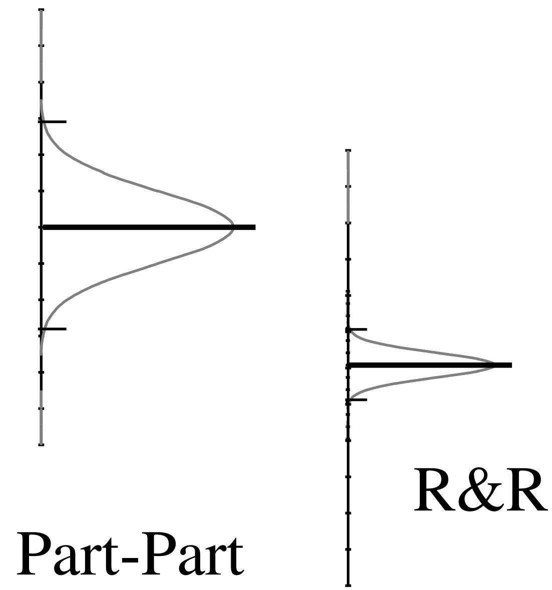
- Variation present in every process
- Not controllable
- The best the process can be within the present technology

Data within subgroups (Z.st) will contain only Common Cause Variation

SIX SIGMA

Gauge R&R

$$\sigma^2_{Total} = \sigma^2_{Part\text{-}Part} + \sigma^2_{R\&R}$$



Recommendation:

Resolution $\leq$ 10% of tolerance to measure
Gauge R&R $\leq$ 20% of tolerance to measure

- ***Repeatability (Equipment variation)***
  Variation observed with one measurement device when used several times by one operator while measuring the identical characteristic on the same part.
- ***Reproducibility (Appraised variation)***
  Variation Obtained from different operators using the same device when measuring the identical characteristic on the same part.
- ***Stability or Drift***
  Total variation in the measurement obtained with a measurement obtained on the same master or reference value when measuring the same characteristic, over an extending time period.

SIX SIGMA

- Map the Process
- Identify the variables - ‘x’
- Measure the Process
- Understand the Problem - ’Y’ = function of variables -’x’ Y=f(x)

To understand where you want to be, you need to know how to get there.v

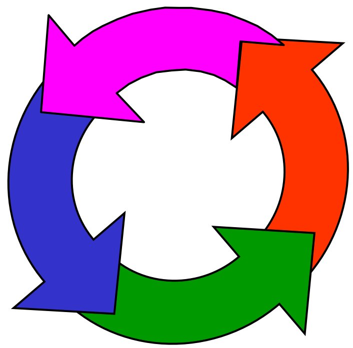
SIX SIGMA

Measure

Characterize Process

Evaluate

Understand Process



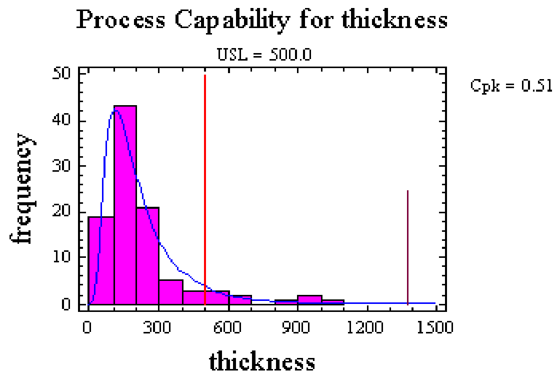
Control

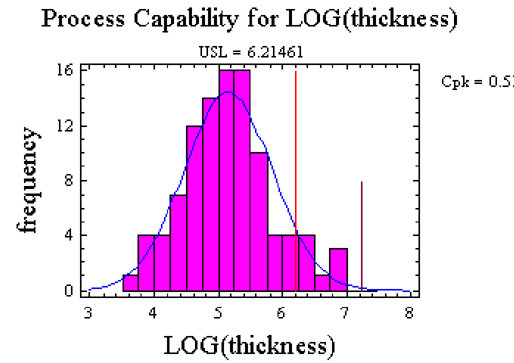
Maintain New Process

Improve

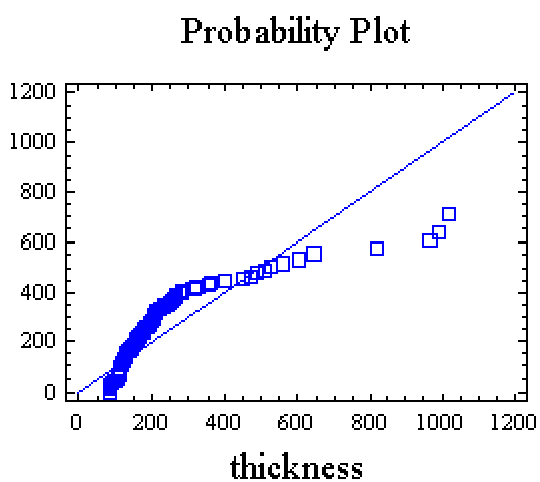
Improve and Verify Process

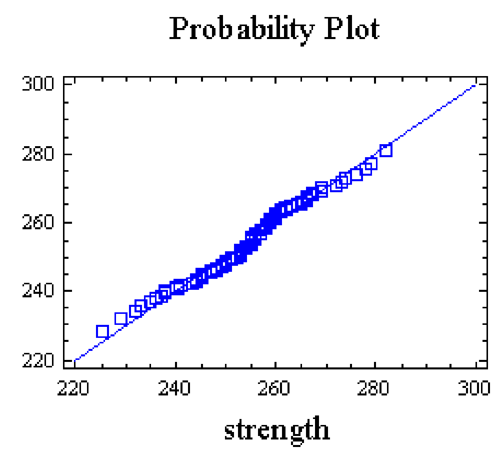
SIX SIGMA





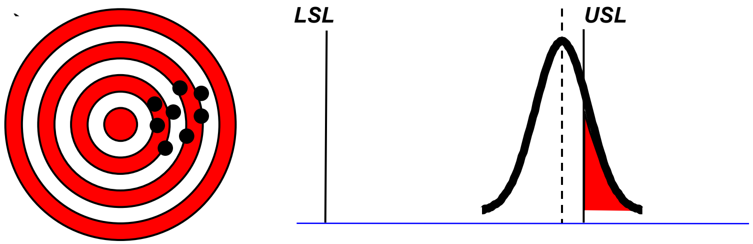
In many cases, the data sample can be transformed so that it is approximately normal. For example, square roots, logarithms, and reciprocals often take a positively skewed distribution and convert it to something close to a bell-shaped curve



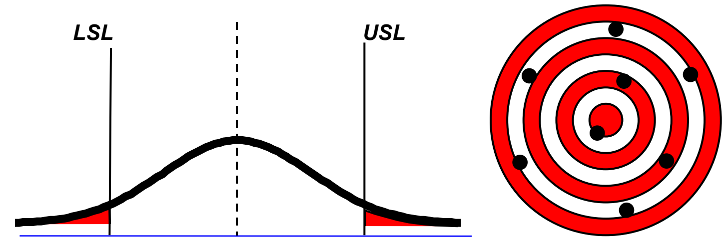


SIX SIGMA

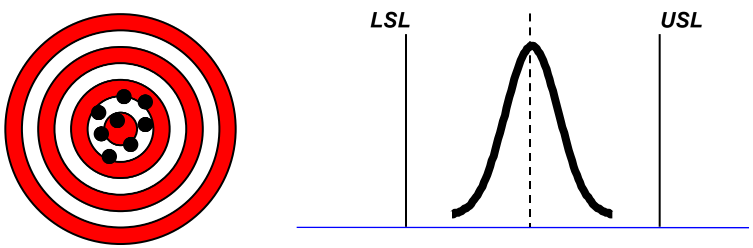
What do we Need?



Off-Target, Low Variation
High Potential Defects
Good Cp but Bad Cpk



On Target
High Variation
High Potential Defects
No so good Cp and Cpk



On-Target, Low Variation
Low Potential Defects
Good Cp and Cpk

- Variation reduction and process centering create processes with less potential for defects.
- The concept of defect reduction applies to **ALL** processes (not just manufacturing)

SIX SIGMA

Eliminate “Trivial Many”

- Qualitative Evaluation
- Technical Expertise
- Graphical Methods
- Screening Design of Experiments

Identify “Vital Few”

- Pareto Analysis
- Hypothesis Testing
- Regression
- Design of Experiments

Quantify Opportunity

- % Reduction in Variation
- Cost/ Benefit

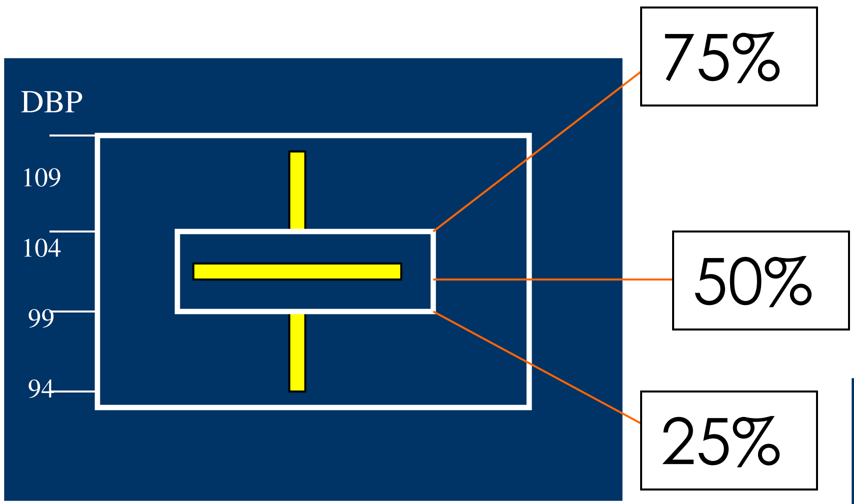
Our Goal:
Identify the Key Factors (x’s)

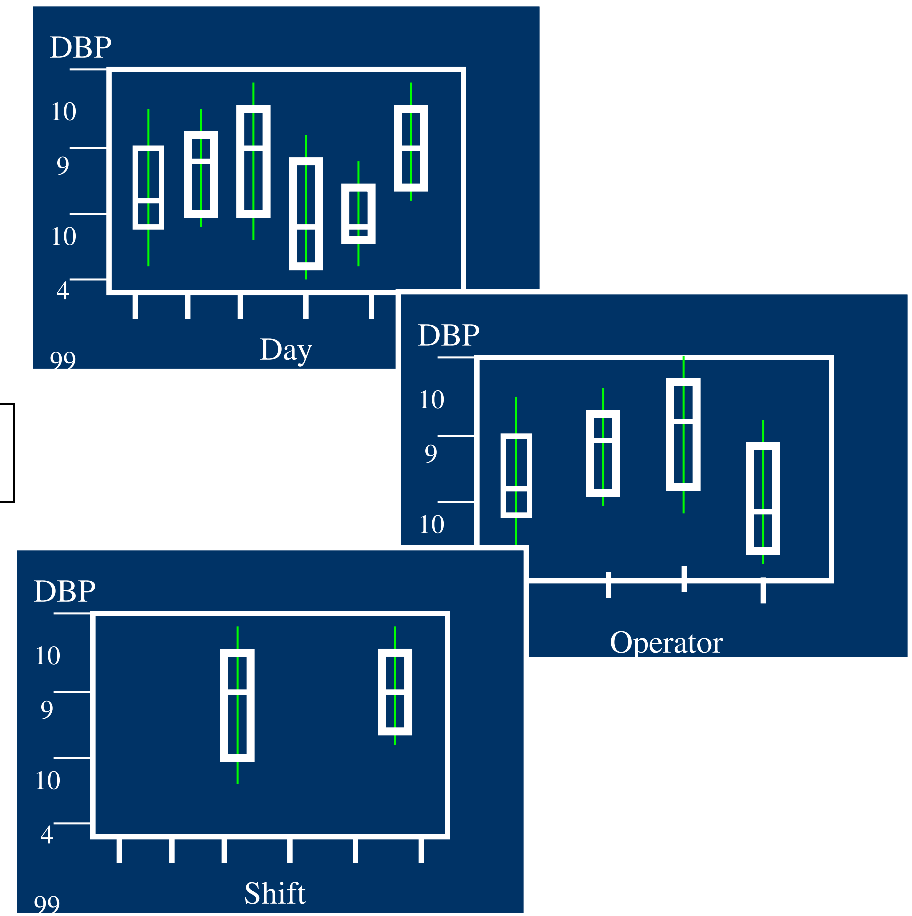
SIX SIGMA

Graph>Box plot

Graph>Box plot

Without X values





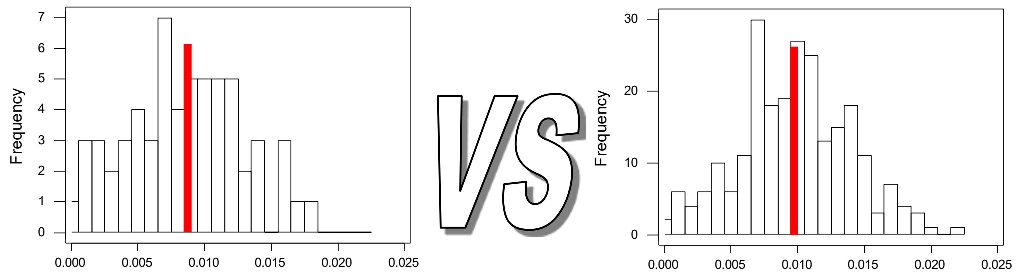
Box plots help to see the data distribution

SIX SIGMA

Statistical Analysis

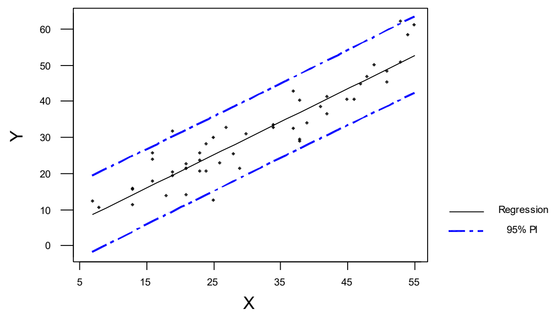
Apply statistics to validate actions & improvements

Hypothesis Testing



Compare Sample Means & Variances

Regression Analysis

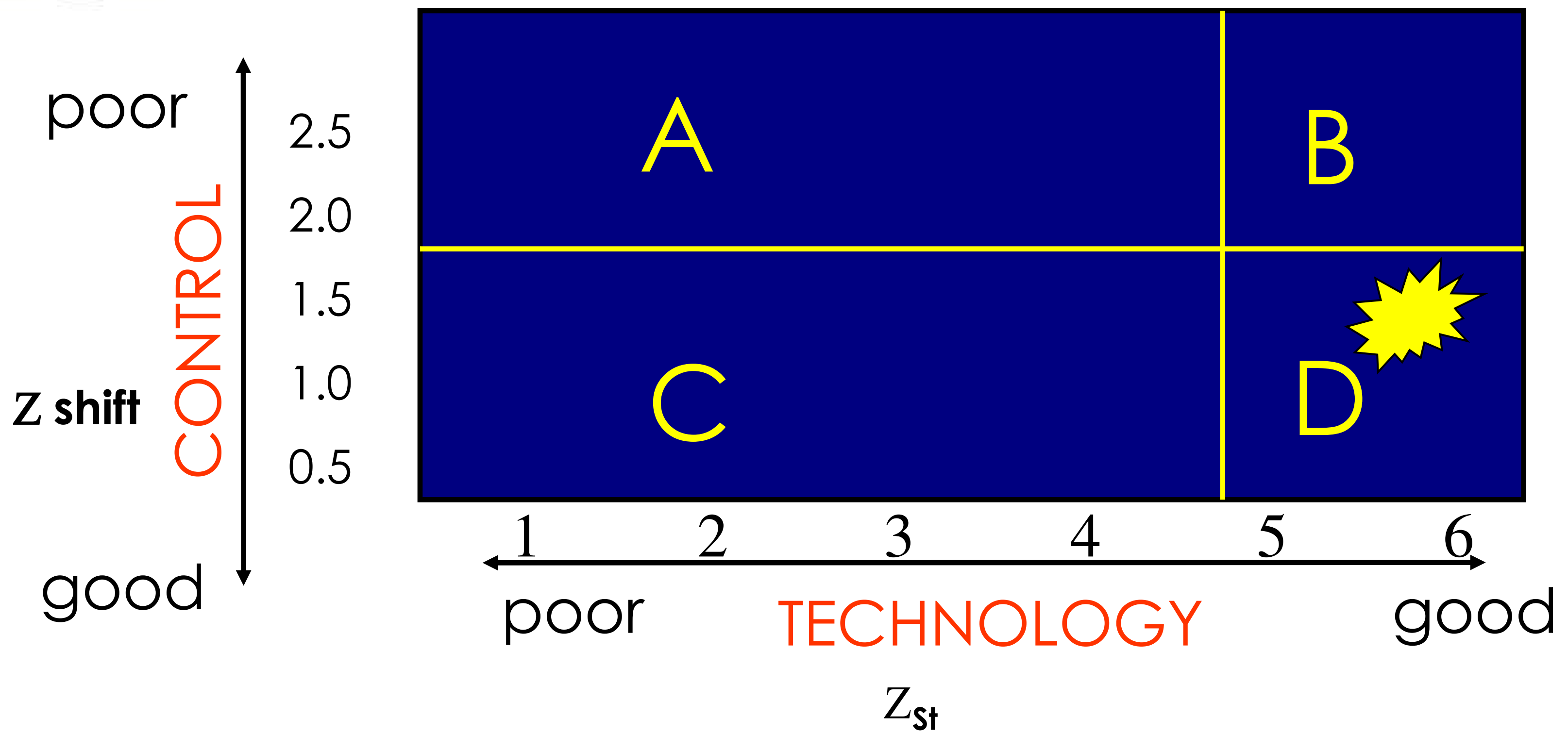


Identify Relationships

Establish Limits

- Is the factor really important?
- Do we understand the impact for the factor?
- Has our improvement made an impact
- What is the true impact?

SIX SIGMA



A- Poor Control, Poor Process

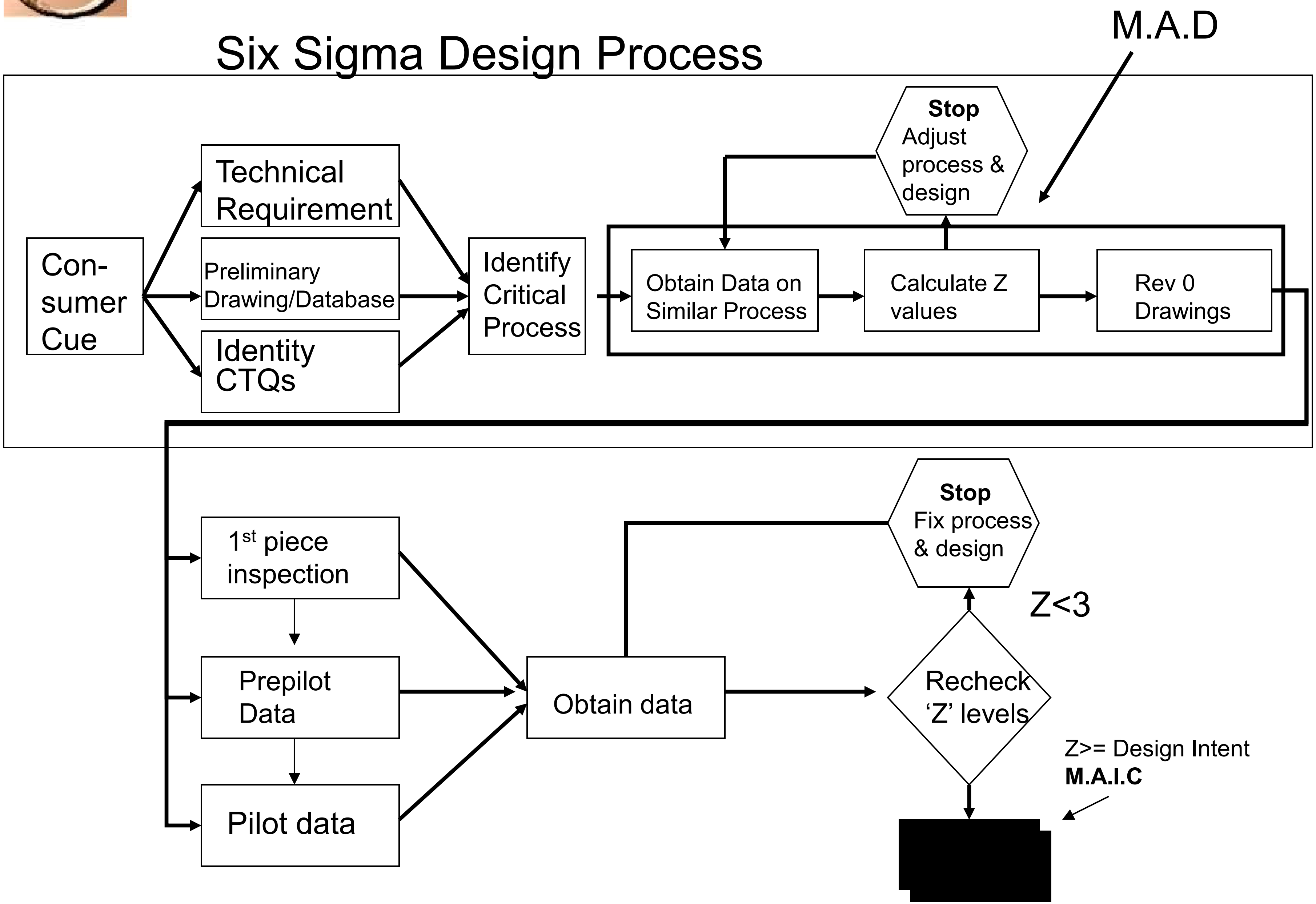
B- Must control the Process better, Technology is fine

C- Process control is good, bad Process or technology

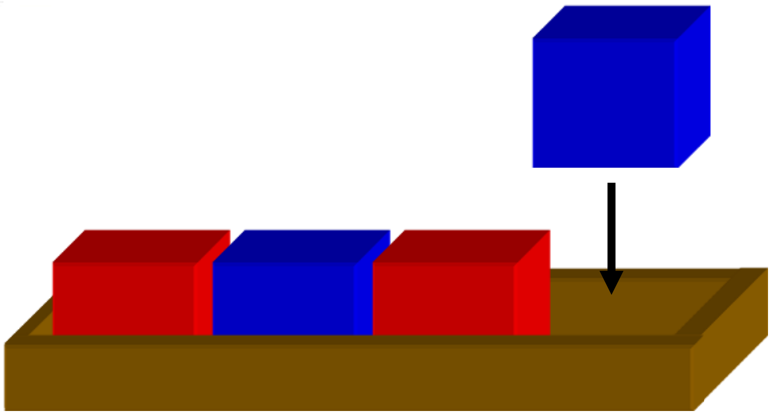
D- World Class

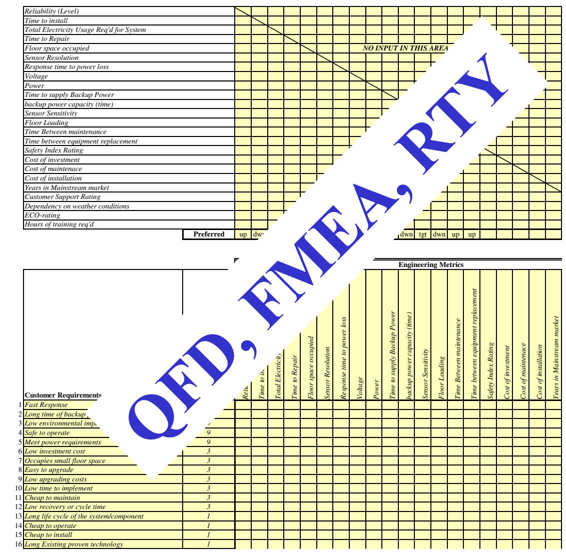
SIX SIGMA

Six Sigma Design Process



SIX SIGMA





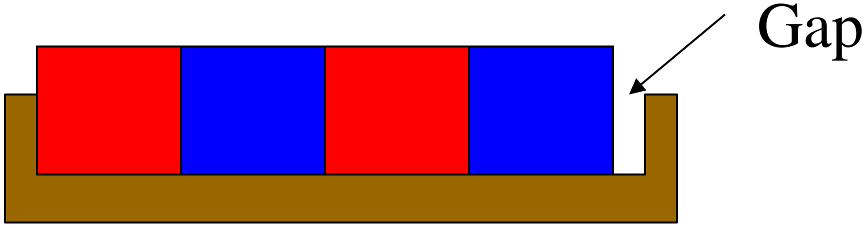
- **#1 Define the customer Cue and technical requirement we need to satisfy**

Consumer Cue: Blocks Cannot rattle and must not interfere with box

Technical Requirement: There must be a positive Gap

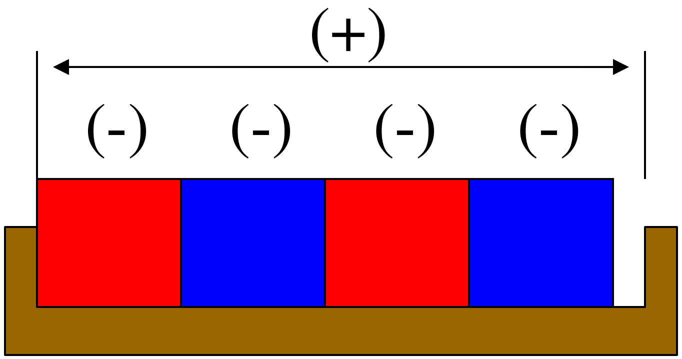
SIX SIGMA

- #2 Define the target dimensions (New designs) or process mean (existing design) for all mating Parts



Gap Must Be T=.011, LSL=.001 and USL = .021

SIX SIGMA



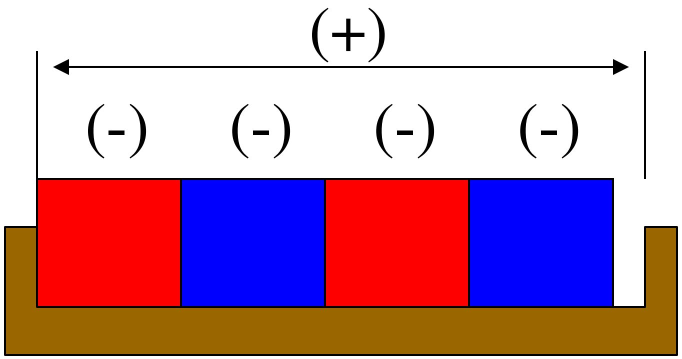
Gap Requirements

$\mu_T = .010$
USL = .020
LSL = .001

Step #3

- Gather process capability data.
- Use actual or similar part data to calculate SS of largest contributors.
- May use expert data for minimal contributors
- Do not calculate s from current tolerances

SIX SIGMA



From process:

	Average	σ_{st}
Cube	1.250	.001
Box	5.080	.001

$$\mu_{gap} = \mu_{box} - \mu_{cube1} - \mu_{cube2} - \mu_{cube3} - \mu_{cube4}$$

Zshift = 1.6

$$\sigma_{gap} = \sqrt{\sigma^2_{box} + \sigma^2_{cube1} + \sigma^2_{cube2} + \sigma^2_{cube3} + \sigma^2_{cube4}}$$

Short Term

$$\mu_{gap} = 5.080 - 1.250 - 1.250 - 1.250 - 1.250 = .016$$

$$\sigma_{gap} = \sqrt{(.001)^2 + (.001)^2 + (.001)^2 + (.001)^2 + (.001)^2} = .00224$$

Long Term

$$\sigma_{gap} = \sqrt{(.0015)^2 + (.0015)^2 + (.0015)^2 + (.0015)^2 + (.0015)^2} = .00335$$

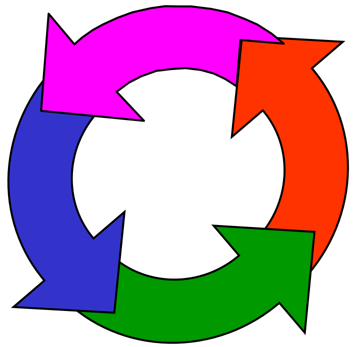
SIX SIGMA

Measure

Characterize Process

Evaluate

Understand Process



Control

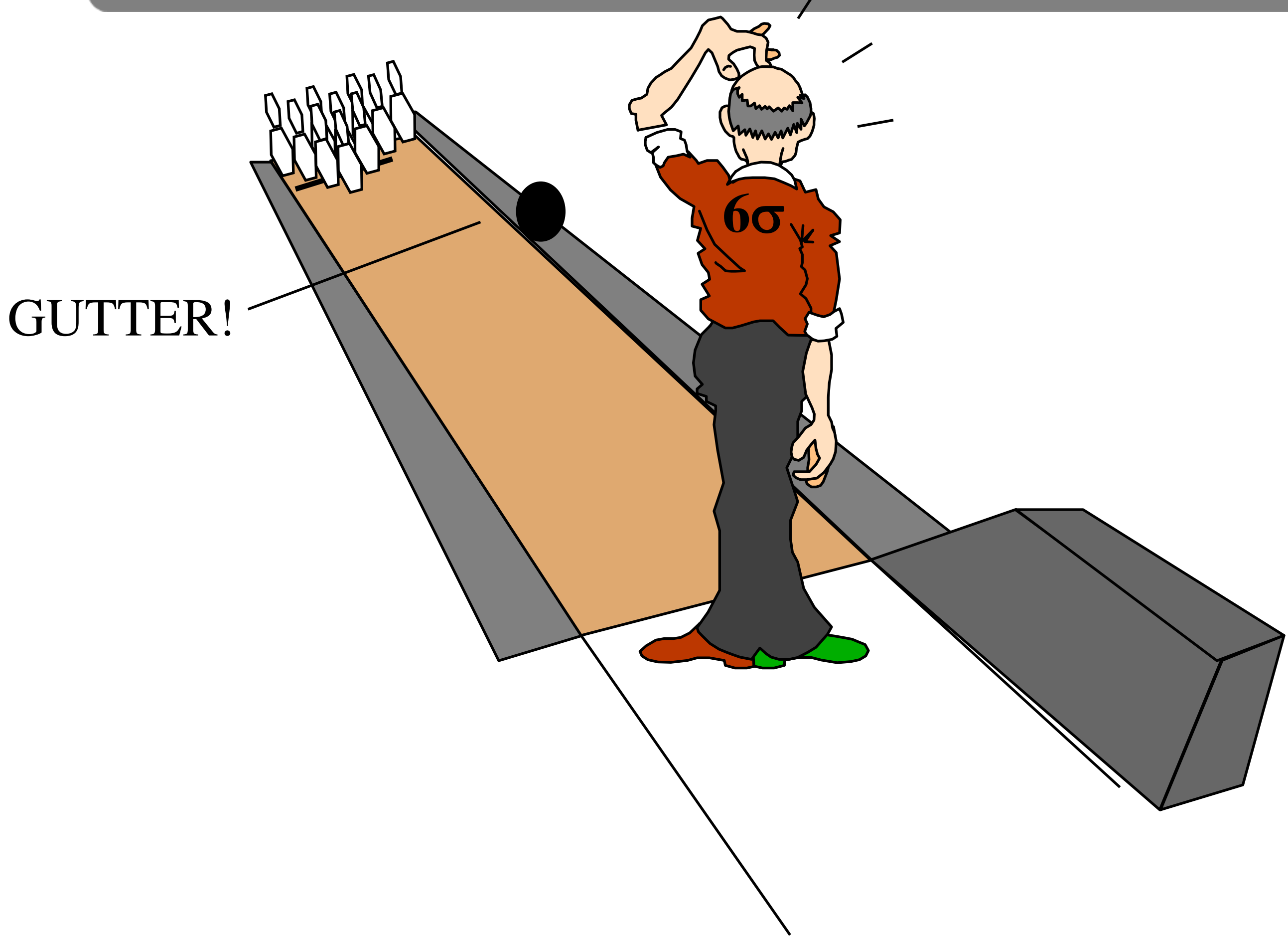
Maintain New Process

Improve

Improve and Verify Process

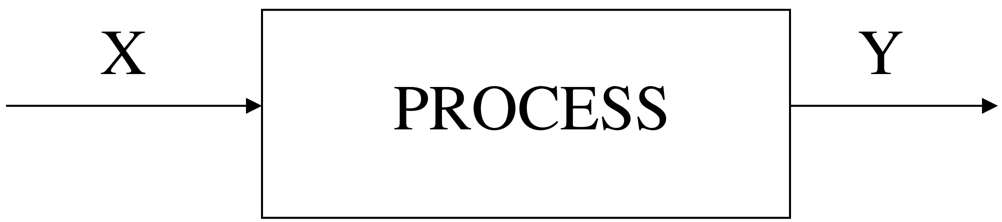
SIX SIGMA

What Do I need to do to <u>improve</u> my Game?



Design of Experiments (DOE)

- To estimate the effects of independent Variables on Responses.



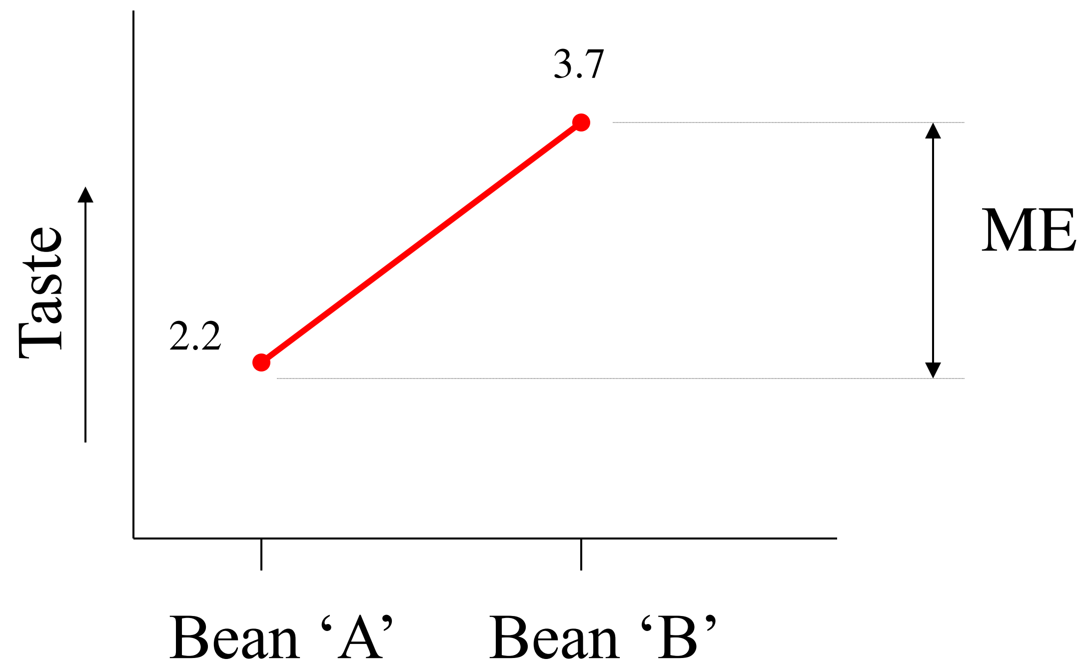
- Terminology
  - Factor – An independent variable
  - Level – A value for the factor.
  - Response - Outcome

THE COFFEE EXAMPLE

Factor	Level	
	Low	High
Coffee Brand	Maxwell House	Chock Full o Nuts
Water	Spring	Tap
Coffee Amount	1	2

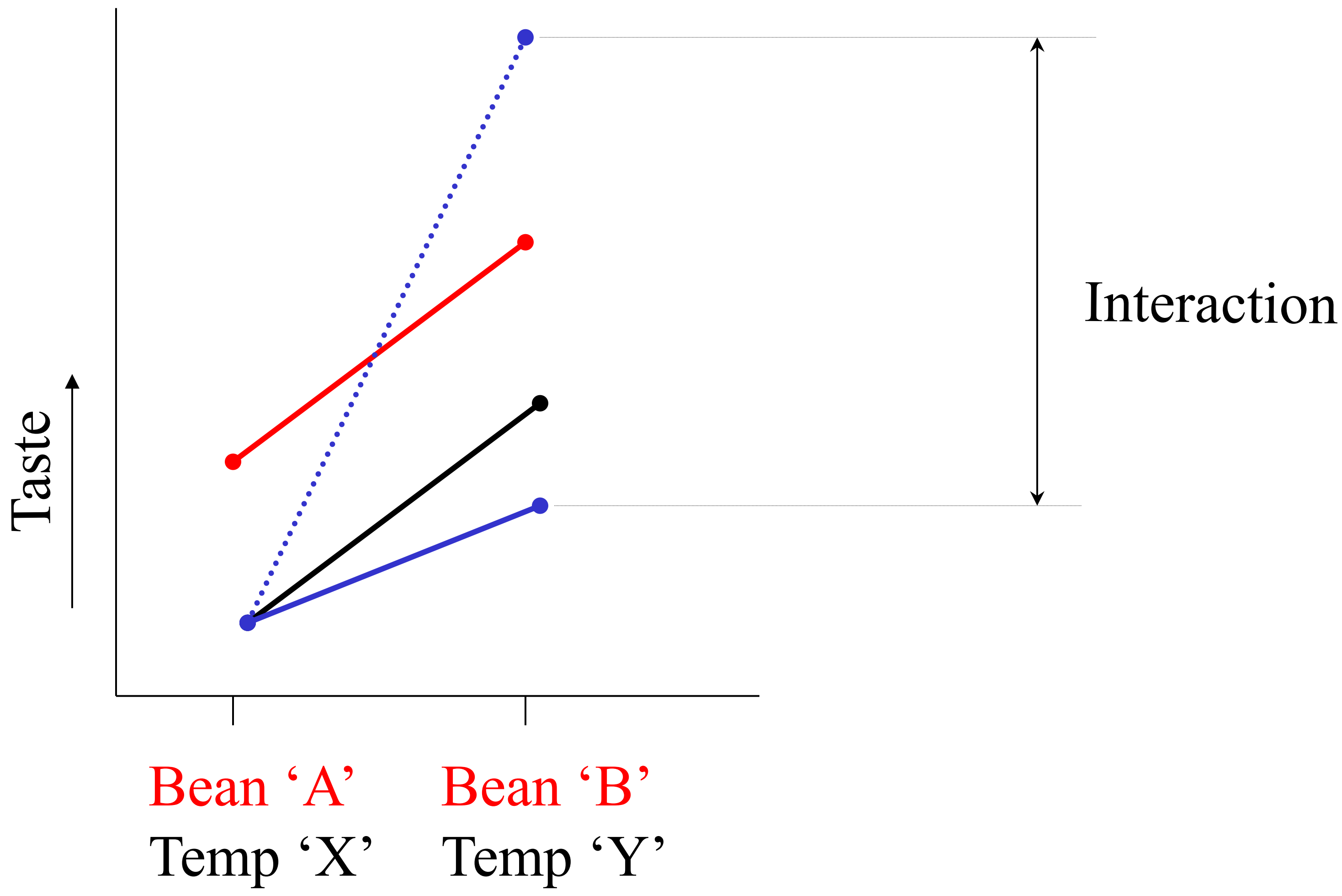
SIX SIGMA

Main Effects: Effect of each individual factor on response



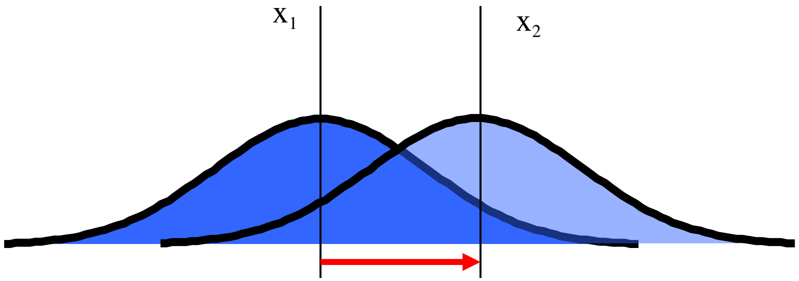
SIX SIGMA

Concept of Interaction

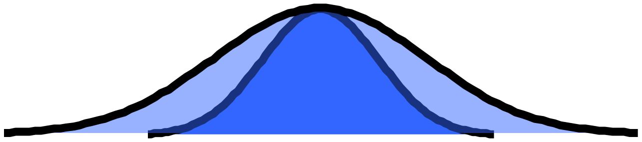


Why use DoE ?

- Shift the average of a process.



- Reduce the variation.



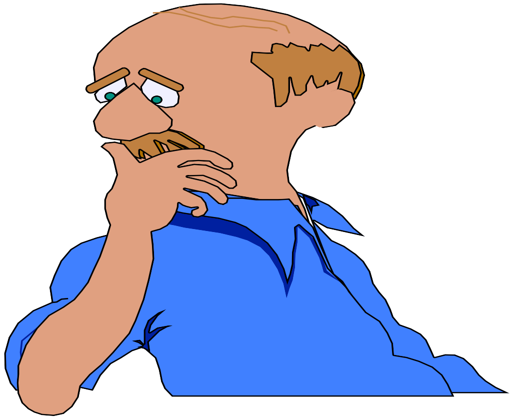
- Shift average and reduce variation

DoE techniques

- Full Factorial.
  - $2^4 = 16$ trials
  - 2 is number of levels
  - 4 is number of factors
- All combinations are tested.
- Fractional factorial can reduce number of trials from 16 to 8.

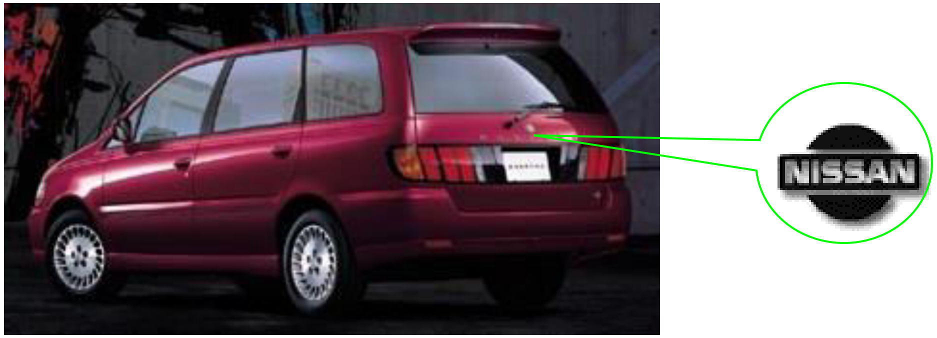
DoE techniques….contd.

- Fractional Factorial
- Taguchi techniques
- Response Surface Methodologies
- Half fraction



SIX SIGMA

Mini Case - NISSAN MOTOR COMPANY



Factor	Level	
	High	Low
Adhesion Area (cm^2)	15	20
Type of Glue	Acryl	Urethan
Thickness of Foam Styrene	Thick	Thin
Thickness of Logo	Thick	Thin
Amount of pressure	Short	Long
Pressure application time	Small	Big
Primer applied	Yes	No

SIX SIGMA

Design Array

A - Adhesion Area (cm^2)

B - Type of Glue

C - Thickness of Foam Styrene

D - Thickness of Logo

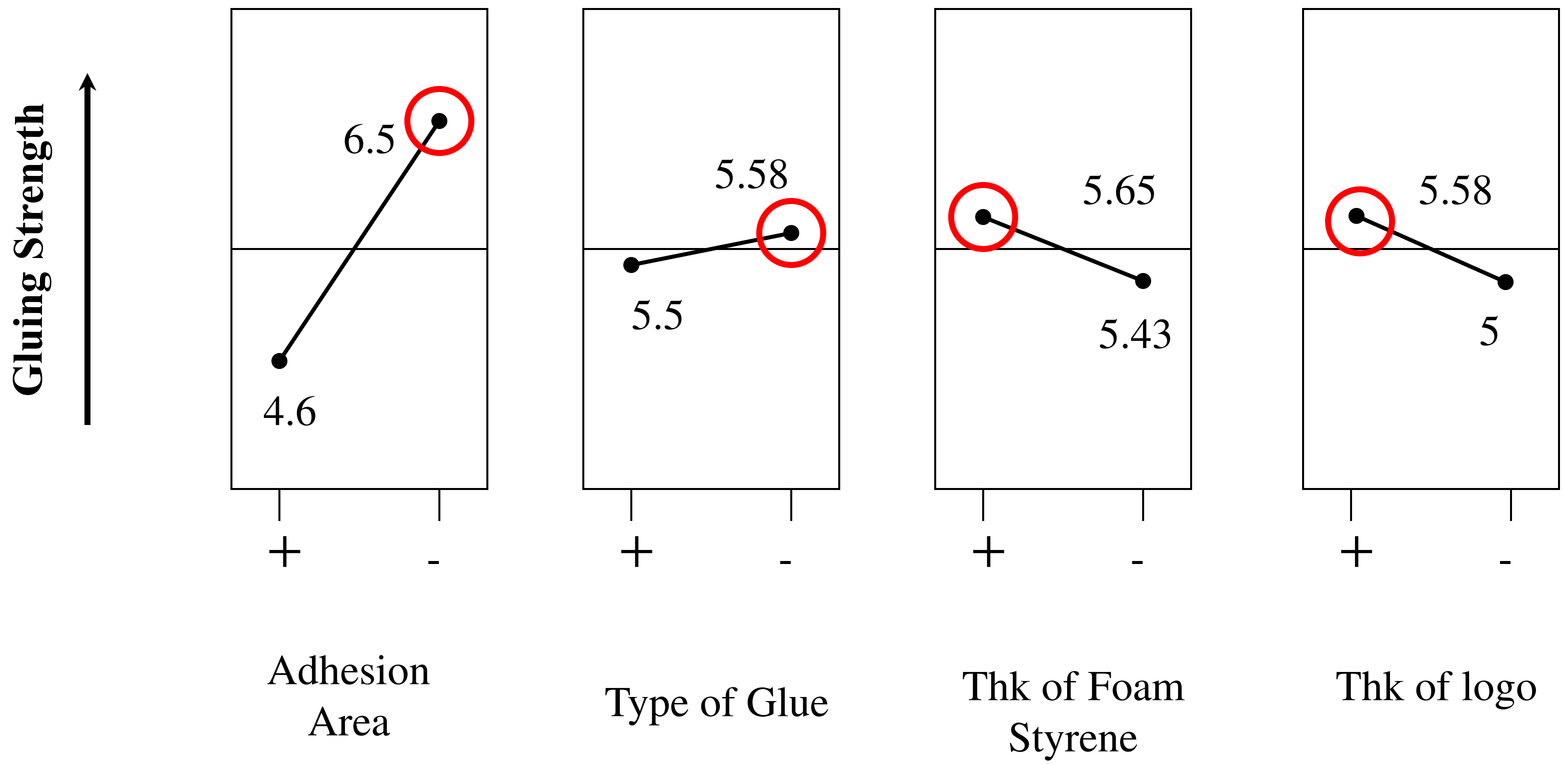
No	A	B	C	D	Gluing Str
1	+	+	+	-	9.8
2	+	+	-	-	8.9
3	+	-	+	+	9.2
4	+	-	-	+	8.9
5	-	+	+	-	12.3
6	-	+	-	-	13
7	-	-	+	+	13.9
8	-	-	-	+	12.6

Effect Tabulation

	A	B	C	D
+	4.60	5.50	5.65	5.58
-	6.48	5.58	5.43	5.50

SIX SIGMA

Factor Effect Plot



SIX SIGMA

STEPS IN PLANNING AN EXPERIMENT

1. Define Objective.
2. Select the Response (Y)
3. Select the factors (Xs)
4. Choose the factor levels
5. Select the Experimental Design
6. Run Experiment and Collect the Data
7. Analyze the data
8. Conclusions
9. Perform a confirmation run.

SIX SIGMA

"….No amount of experimentation can prove me right; a single experiment can prove me wrong".

"….Science can only ascertain what is, but not what should be, and outside of its domain value judgments of all kinds remain necessary."

- Albert Einstein

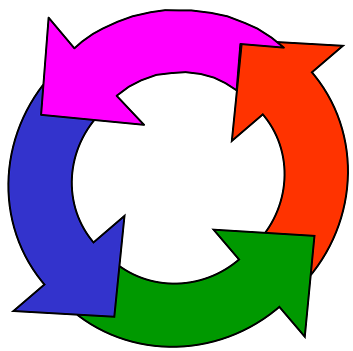
SIX SIGMA

Measure

Characterize Process

Evaluate

Understand Process



Control

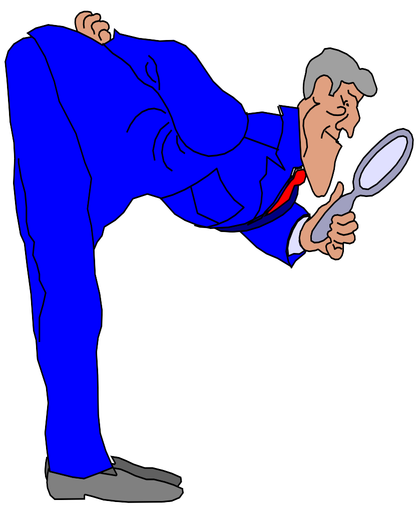
Maintain New Process

Improve

Improve and Verify Process

CONTROL PHASE - SIX SIGMA

Control Phase Activities:



-Confirmation of Improvement
-Confirmation you solved the practical problem
-Benefit validation
-Buy into the Control plan
-Quality plan implementation
-Procedural changes
-System changes
-Statistical process control implementation
-“Mistake-proofing” the process
-Closure documentation
-Audit process
-Scoping next project

CONTROL PHASE - SIX SIGMA

How to create a Control Plan:

1. Select Causal Variable(s). Proven vital few X(s)
2. Define Control Plan
   - 5Ws for optimal ranges of X(s)
3. Validate Control Plan
   - Observe Y
4. Implement/Document Control Plan
5. Audit Control Plan
6. Monitor Performance Metrics

CONTROL PHASE - SIX SIGMA

Control Plan Tools:

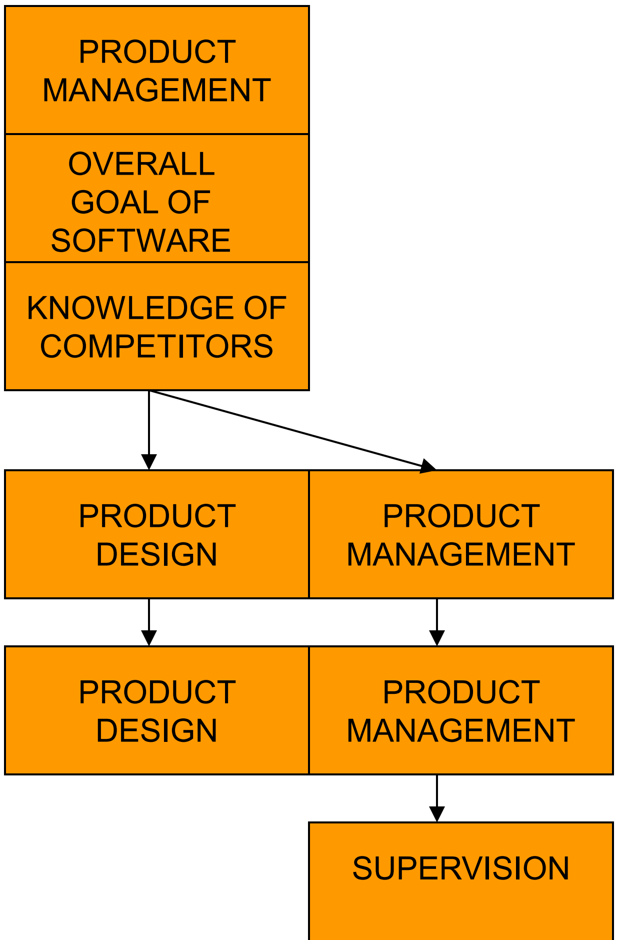
1. Basic Six Sigma control methods.
   - 7M Tools: Affinity diagram, tree diagram, process decision program charts, matrix diagrams, interrelationship diagrams, prioritization matrices, activity network diagram.

2. Statistical Process Control (SPC)
   - Used with various types of distributions
   - Control Charts
     - •Attribute based (np, p, c, u). Variable based (X-R, X)
     - •Additional Variable based tools
       - -PRE-Control
       - -Common Cause Chart (Exponentially Balanced Moving Average (EWMA))

SIX SIGMA

AFFINITY DIAGRAM

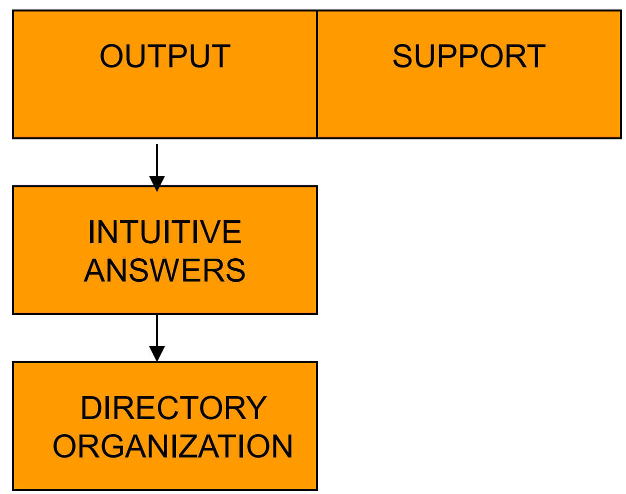
INNOVATION



CHARACTERISTICS:

- Organizing ideas into meaningful categories
- Data Reduction. Large numbers of qual. Inputs into major dimensions or categories.

METHODS TO MAKE EASIER FOR USERS



SIX SIGMA

MATRIX DIAGRAM

HOWS

RELATIONSHIP MATRIX

CUSTOMER IMPORTANCE MATRIX

WHATS

		Patient scheduled	Attendant assigned	Attendant arrives	Obtains equipment	Transports patient	Provide Therapy	Notifies of return	Attendant assigned	Attendant arrives	Patient returned
Arrive at scheduled time	5	5	5	5	1	5	0	0	0	0	0
Arrive with proper equipment	4	2	0	0	5	0	0	0	0	0	0
Dressed properly	4	0	0	0	0	0	0	0	0	0	0
Delivered via correct mode	2	3	0	0	1	0	0	0	0	0	0
Take back to room promptly	4	0	0	0	0	0	0	5	5	5	5
IMPORTANCE SCORE		39	25	25	27	25	0	20	20	20	20
RANK		1	3	3	2	3	7	6	6	6	6

5 = high importance, 3 = average importance, 1 = low importance

SIX SIGMA

COMBINATION ID/MATRIX DIAGRAM

⊘ (9) = Strong Influence

○ (3) = Some Influence

△ (1) = Weak/possible influence

↑ Means row leads to column item

← Means column leads to row item

	Add features	Make existing product faster	Make existing product easier to use	Leave as-is and lower price	Devote resources to new products	Increase technical support budget	Out arrows	In arrows	Total arrows	Strength
Add features	■	↑⊘	↑⊘	↑⊘	↑⊘	↑⊘	5	0	5	45
Make existing product faster	←⊘	■	↑⊘	↑⊘			2	1	3	27
Make existing product easier to use	←⊘	←⊘	■	↑○			1	2	3	21
Leave as-is and lower price	←⊘	←⊘	←○	■			0	3	3	21
Devote resources to new products	←⊘				■	↑⊘	1	1	2	18
Increase technical support budget	←⊘				←⊘	■	0	2	2	18

CHARACTERISTICS:

- Uncover patterns in cause and effect relationships.
- Most detailed level in tree diagram. Impact on one another evaluated.

CONTROL PHASE - SIX SIGMA

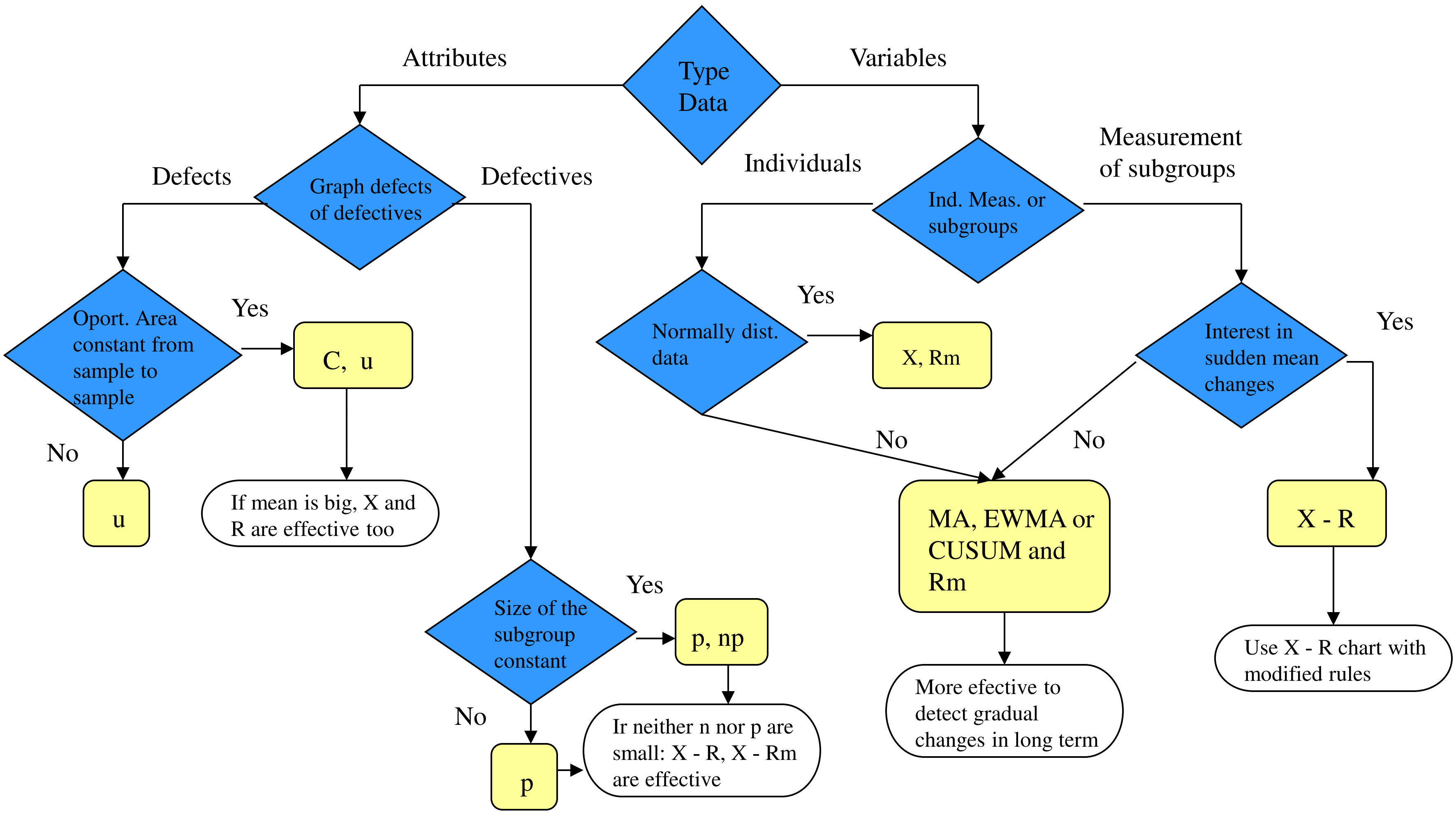
Control Plan Tools:

1. Basic Six Sigma control methods.
   - 7M Tools: Affinity diagram, tree diagram, process decision program charts, matrix diagrams, interrelationship diagrams, prioritization matrices, activity network diagram.

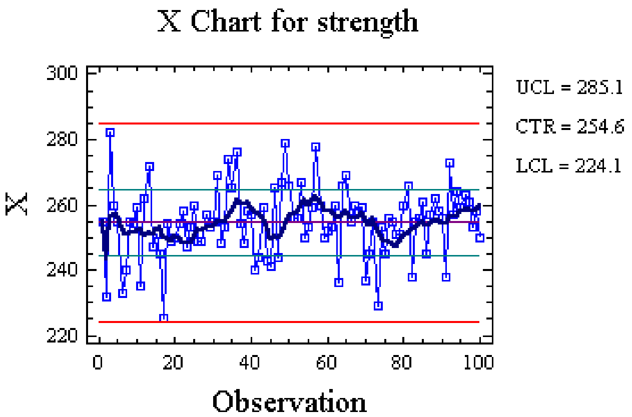
2. Statistical Process Control (SPC)
   - Used with various types of distributions
   - Control Charts
     - •Attribute based (np, p, c, u). Variable based (X-R, X)
     - •Additional Variable based tools
       - -PRE-Control
       - -Common Cause Chart (Exponentially Balanced Moving Average (EWMA))

SIX SIGMA

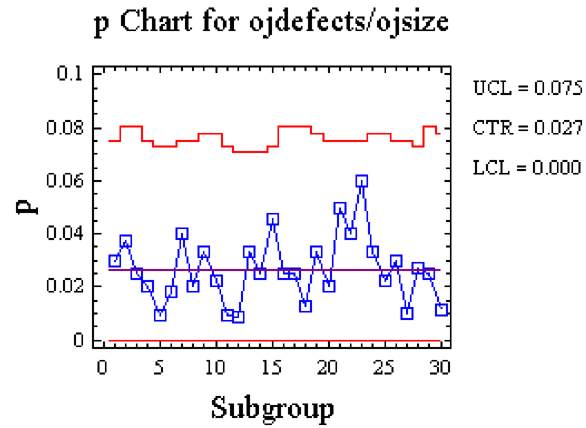
How do we select the correct Control Chart:



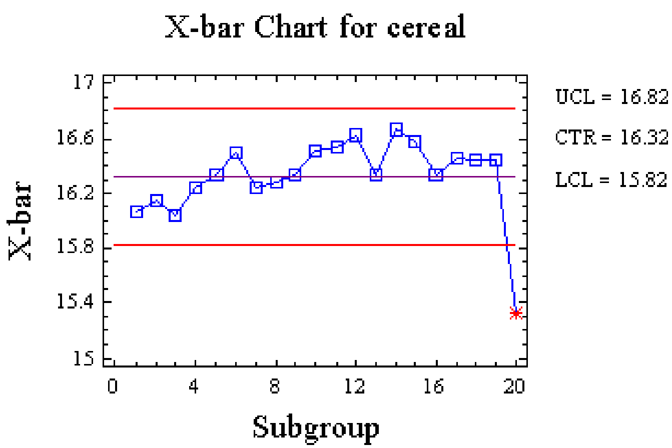
SIX SIGMA



X Chart for strength
300
280
260
240
220
X
0
20
40
60
80
100
Observation
UCL = 285.1
CTR = 254.6
LCL = 224.1



p Chart for ojdefects/ojsize
0.1
0.08
0.06
0.04
0.02
0
p
0
5
10
15
20
25
30
Subgroup
UCL = 0.075
CTR = 0.027
LCL = 0.000



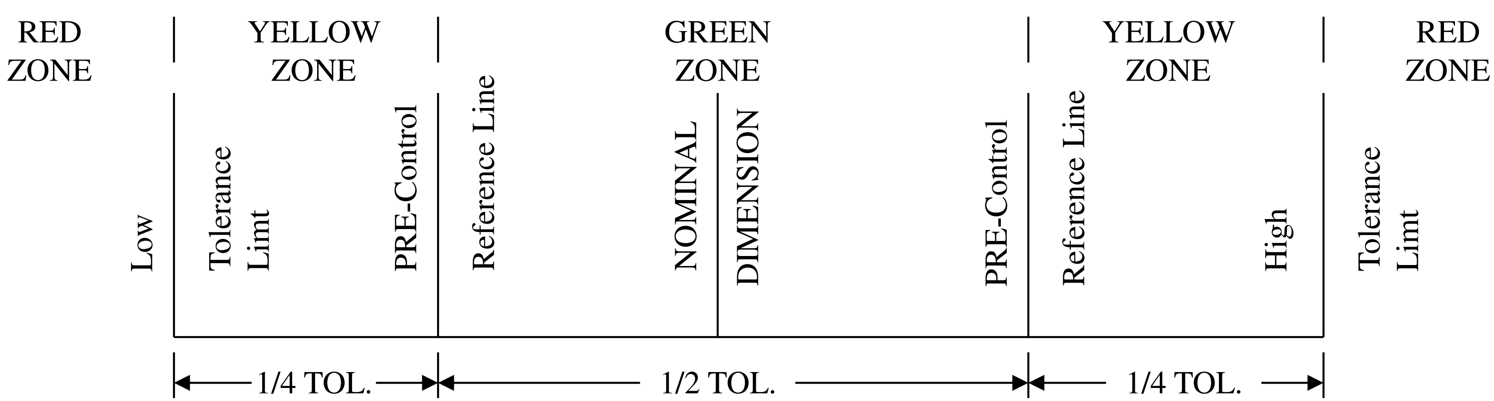
X-bar Chart for cereal
17
16.6
16.2
15.8
15.4
15
X-bar
0
4
8
12
16
20
Subgroup
UCL = 16.82
CTR = 16.32
LCL = 15.82

SIX SIGMA

Additional Variable based tools:

1. PRE-Control

- Algorithm for control based on tolerances
- Assumes production process with measurable/adjustable quality characteristic that varies.
- Not equivalent to SPC. Process known to be capable of meeting tolerance and assures that it does so.
- SPC used always before PRE-Control is applied.
- Process qualified by taking consecutive samples of individual measurements, until 5 in a row fall in central zone, before 2 fall in cautionary. Action taken if 2 samples are in Cau. zone.
- Color coded



SIX SIGMA

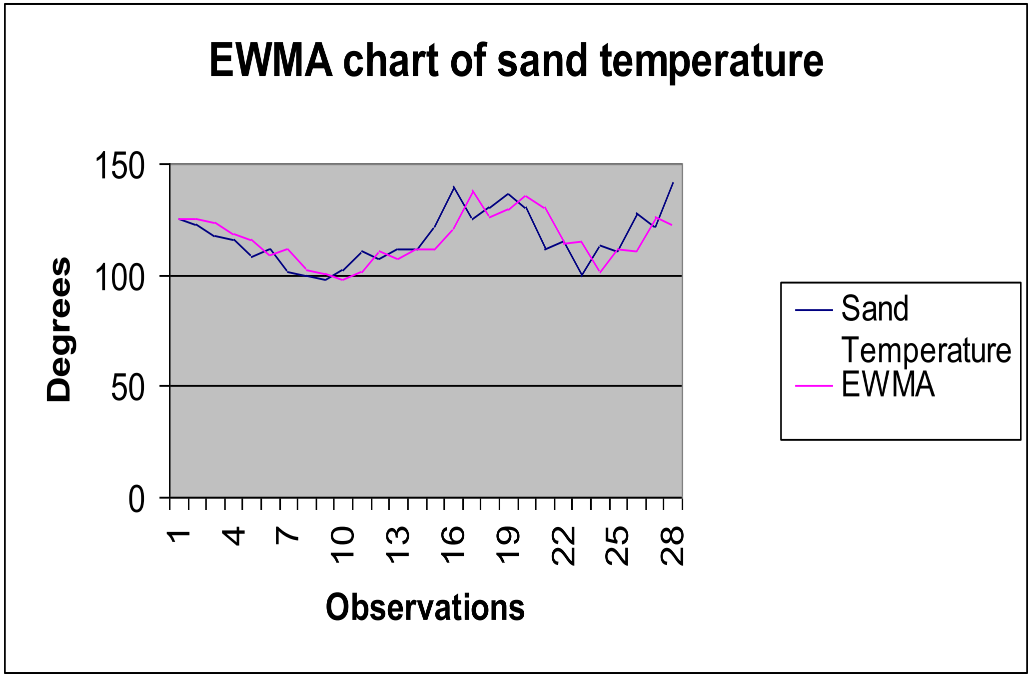
2. Common Causes Chart (EWMA).

- Mean of automated manufacturing processes drifts because of inherent process factor. SPC consideres process static.
- Drift produced by common causes.
- Implement a “Common Cause Chart”.
- No control limits. Action limits are placed on chart.
  - Computed based on costs
  - Violating action limit does not result in search for special cause. Action taken to bring process closer to target value.

- Process mean tracked by EWMA
- Benefits:
  - Used when process has inherent drift
  - Provide forecast of where next process measurement will be.
  - Used to develop procedures for dynamic process control
- Equation: EWMA = $\hat{y}_t + \sigma (y_t - \hat{y}_t)$ σ between 0 and 1

SIX SIGMA

Sand Temperature	EWMA	Error
125	125.00	0.00
123	125.00	-2.00
118	123.20	-5.20
116	118.52	-2.52
108	116.25	-8.25
112	108.83	3.17
101	111.68	-10.68
100	102.07	-2.07
92	100.21	-8.21
102	98.22	3.78
111	101.62	9.38
107	110.60	-3.60
112	107.30	4.70
112	111.53	0.47
122	111.95	10.05
140	121.00	19.00
125	138.00	-13.00
130	126.31	3.69
136	129.63	6.37
130	135.36	-5.36
112	130.54	-18.54
115	113.85	1.15
100	114.89	-14.89
113	101.49	11.51
111	111.85	-0.85



SIX SIGMA

Project Closure

- Improvement fully implemented and process re-baselined.
- Quality Plan and control procedures institutionalized.
- Owners of the process: Fully trained and running the process.
- Any required documentation done.
- History binder completed. Closure cover sheet signed.
- Score card developed on characteristics improved and reporting method defined.

SIX SIGMA

Motorola ROI
1987-1994

- Reduced in-process defect levels by a factor of 200.
- Reduced manufacturing costs by $1.4 billion.
- Increased employee production on a dollar basis by 126%.
- Increased stockholders share value fourfold.

AlliedSignal ROI
1992-1996

- $1.4 Billion cost reduction.
- 14% growth per quarter.
- 520% price/share growth.
- Reduced new product introduction time by 16%.
- 24% bill/cycle reduction.

SIX SIGMA

General Electric ROI
1995-1998

- Company wide savings of over $1 Billion.
- Estimated annual savings to be $6.6 Billion by the year 2000.

Bibliography

- Control Engineering On line, "Design for Six Sigma Capability" http://www.controleng.com/, 1999
- Forrest W. Breyfogle III, "Implementing Six Sigma", John Wiely & Sons, Inc,1999
- Infinity Performance Systems, "Six Sigma Overview", http://www.6sigmaworld.com/six_sigma.htm, 2000
- Motorola Inc., "What is 3 vs. 6 sigma", http://www.Motorola.com/MIMS/MSPG/Special/CLM/sld011.htm, 1997
- Sigma Holdings, Inc., "Six Sigma Breakthrough Strategy", http://www.6-sigma.com/Bts1.htm, 2000
- Six Sigma SPC / Jim Winings, "Six Sigma & SPC", http://www.sixsigmaspc.com/six_sigma.html, 2001
- StatPoint, LLC. "Six Sigma Tour", http://www.sgcorp.com/six-sigma_tour.htm, 2001