Six Sigma

Outline

- What is Six Sigma?
- Phases of Six Sigma
  - Define
  - Measure
  - Evaluate / Analyze
  - Improve
  - Control
- Design for Six Sigma
- Green Belts & Black Belts

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

What Six Sigma is Not

- Just about statistics
- A quality program
- Only for technical people
- Used when the solution is known
- Used for “firefighting”

Why Companies Need Six Sigma

1. Reduces dependency on "Tribal Knowledge"
   - Decisions based on facts and data rather than opinion

2. Attacks the high-hanging fruit (the hard stuff)
   - Eliminates chronic problems (common cause variation)
   - Improves customer satisfaction

3. Provides a disciplined approach to problem solving
   - Changes the company culture

4. Creates a competitive advantage (or disadvantage)

5. Improves profits!

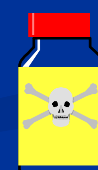
How good is good enough?

99.9% is already VERY GOOD

But what could happen at a quality level of 99.9% (i.e., 1000 ppm),

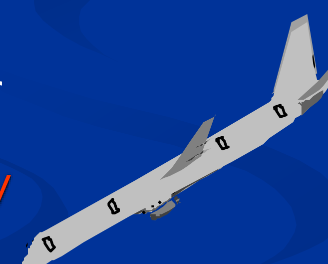
in our everyday lives (about 4.6σ)?

- 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



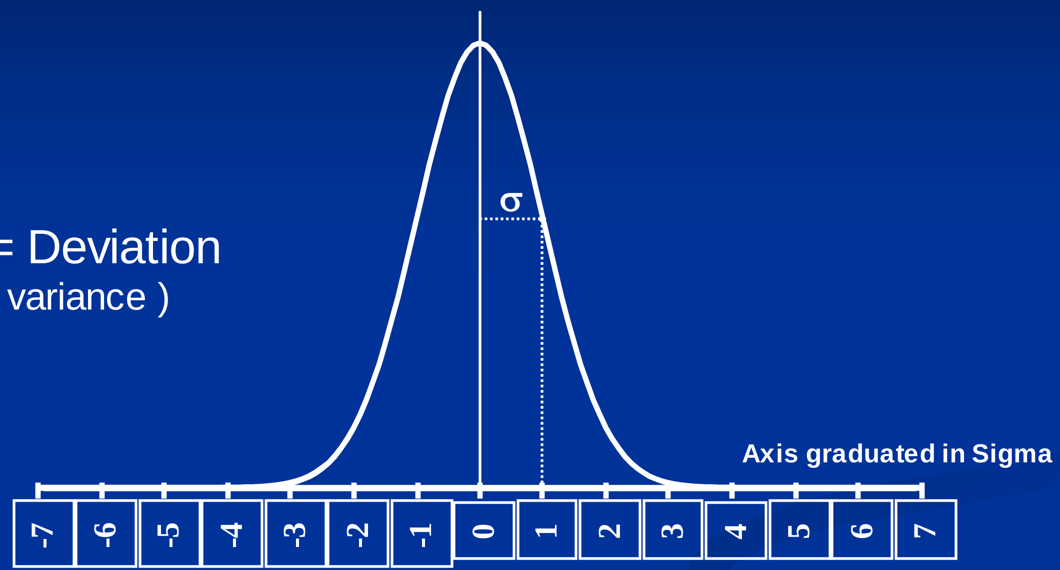
- 400 letters per hour which never arrive at their destination

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

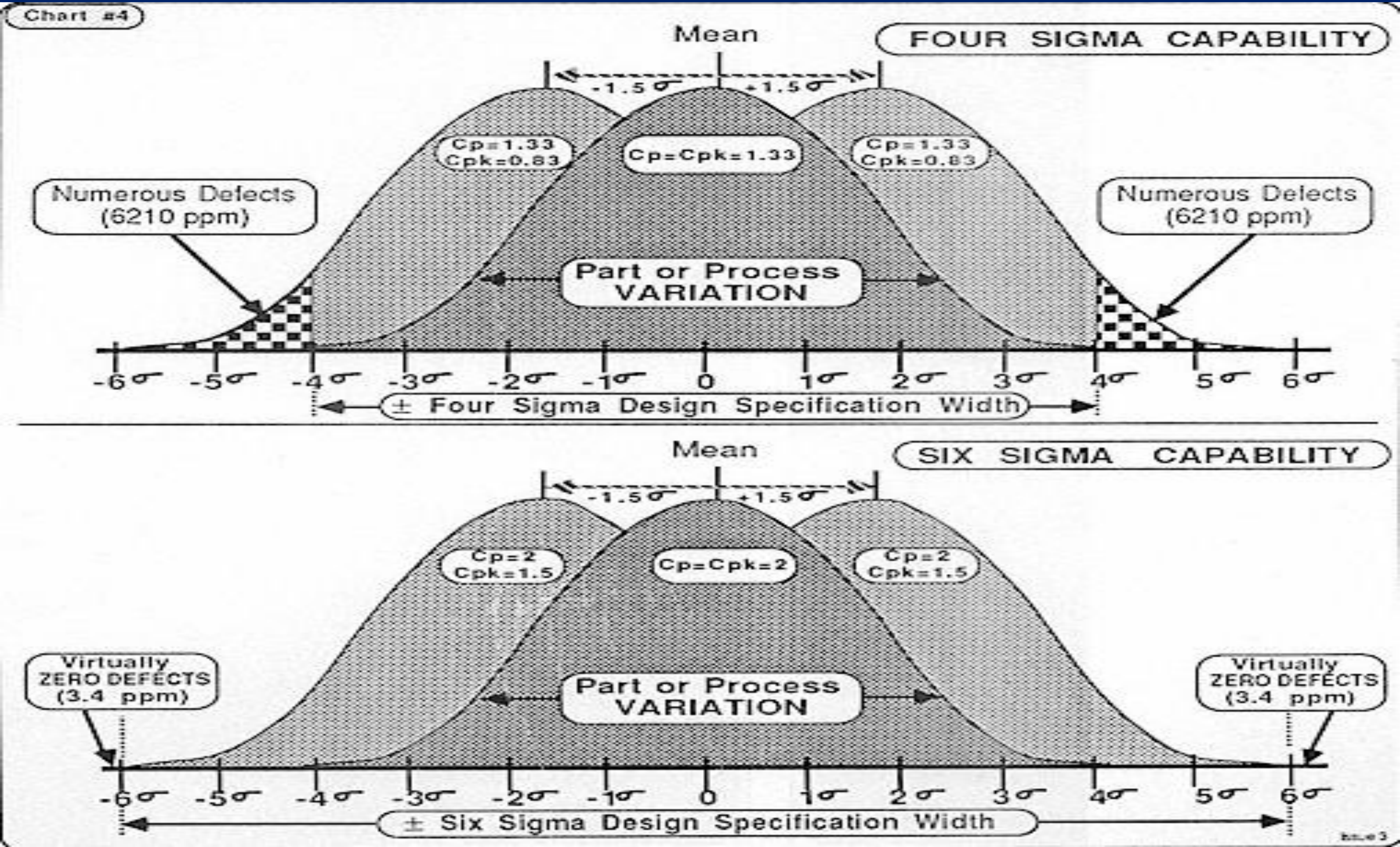
Six Sigma as a Metric

Sigma = σ = Deviation
(Square root of variance)



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

Effect of 1.5 Sigma Process Shift

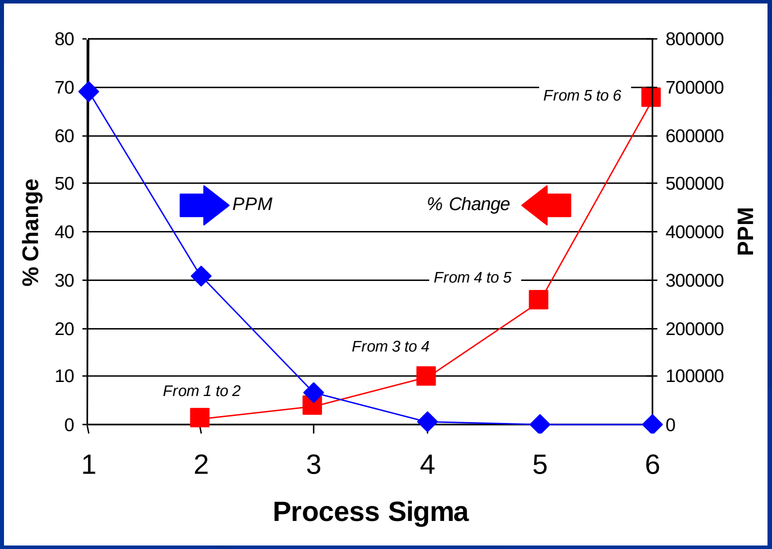


3 Sigma Vs. 6 Sigma

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

Sigma and PPM

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



Focusing on σ requires thorough process understanding and breakthrough thinking

Six Sigma ROI

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

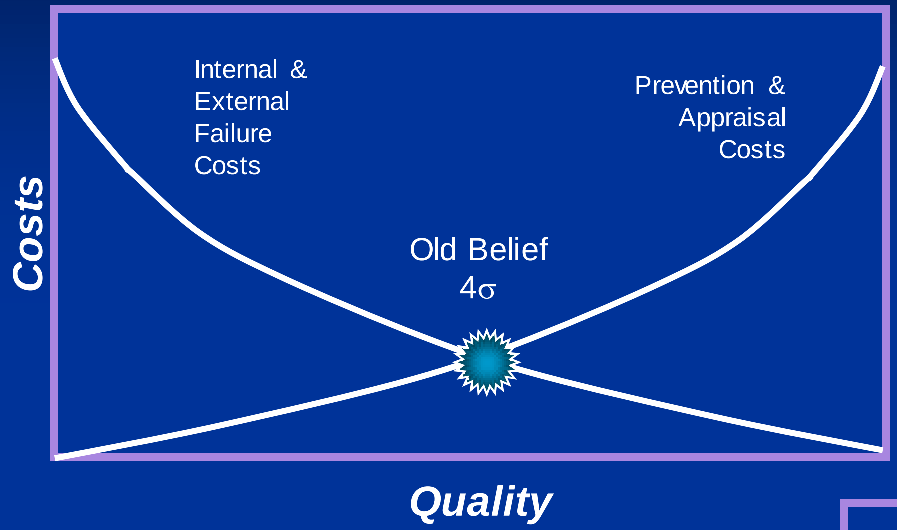
- $1.4 Billion cost reduction.
- 14% growth per quarter.
- 520% price/share growth.
- Reduced new product introduction time by 16%.
- 24% bill/cycle reduction.

Six Sigma ROI

General Electric ROI
1995-1998

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

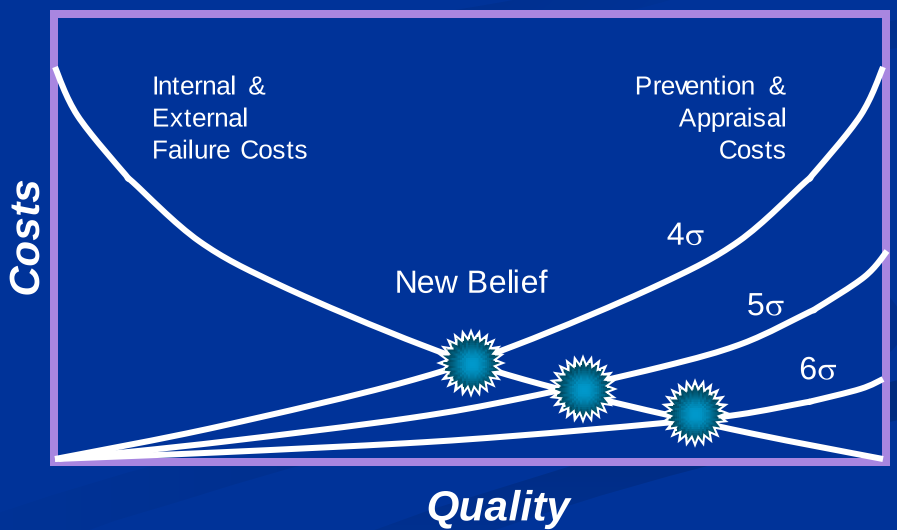
Six Sigma as a Philosophy



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

Old Belief

High Quality = High Cost



New Belief

High Quality = Low Cost

"The fact is, there is more reality with this [Six Sigma] than anything that has come down in a long time in business. The more you get involved with it, the more you're convinced."

Larry Bossidy
CEO, Honeywell

Six Sigma as a Strategic Tool

Issue	Classical	Six Sigma
Outlook	Short term	Long term
Analysis	Point estimate	Variability
Tolerance	Worst case design	RMS
Process	Tweaking	SPC
Problem	Fixing	Preventing
Behavior	Reactive	Proactive
Reasoning	Experience	Statistics
Aim	Organization	Customer
Direction	Seat of Pants	Benchmarking
Improvement	Automation	Optimization

Six Sigma Tools

Process Mapping

Structure Tree

Pareto Analysis

Gauge R & R

Rational Subgrouping

Baselining

Tolerance Analysis

Components Search

Hypothesis Testing

Regression

DOE

SPC

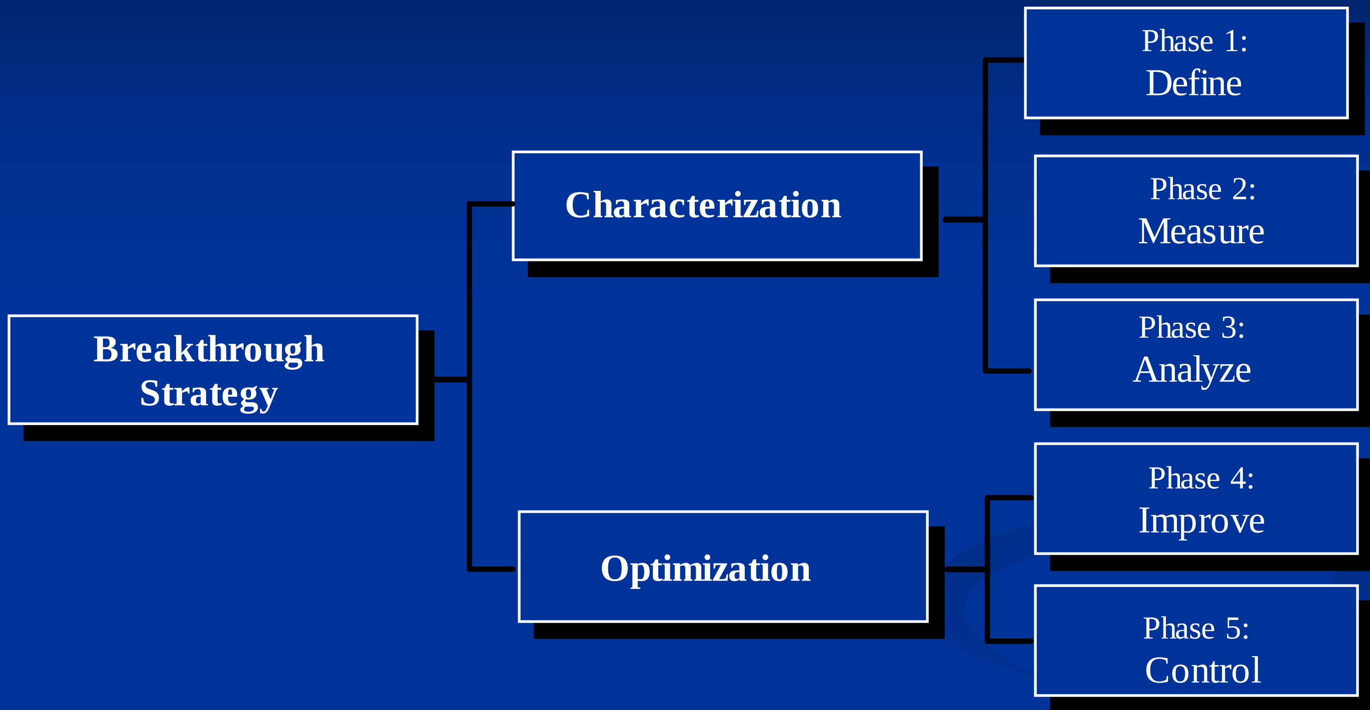
What Does Six Sigma Look Like?

- Project defined in Business Terms
- Cross Functional Team Involvement
- DMAIC Problem Strategy used
- Qualitative and Statistical tools used
- Sustained Business Results Achieved

Six Sigma Principles

- Customer Focus
- Leadership
- Innovative and Proactive
- Boundary-less
- World Class Quality
- Fact Driven
- Process Management

Problem Solving Methodology



Projects are worked through these 5 main phases of the Six Sigma methodology.

Project Charter

- Business Case
- Problem Statement
- Goal Statement
- Team Members
- Team Role & Responsibility
- Action plan VS. budget

Define Phase

- Define Process
- Define Customer requirement
- Prioritize Customer requirement

Define Phase

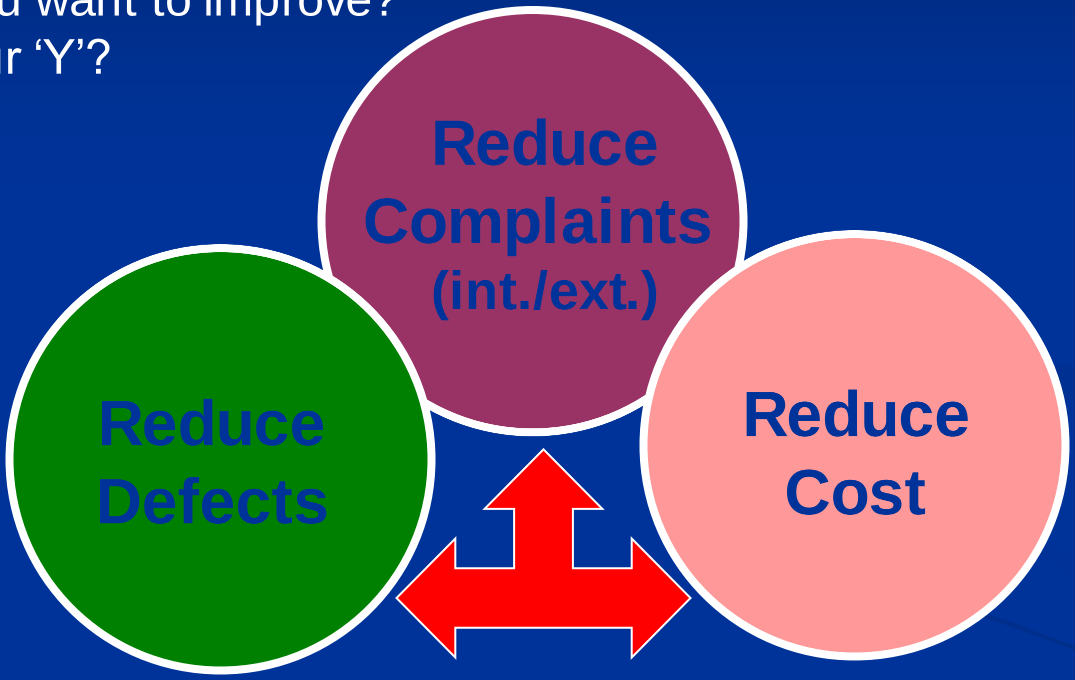
- SIPOC Model Kano Analysis
- Customer Survey CTQ Diagram
- Customer Requirement Analysis
- QFD Literature Review
- Standard / Regulation Review

Define Phase

- Project Review
  - Project Charter
  - Business Case
  - Problem Statement
  - Goal Statement
  - Scope of process
  - Prioritized customer requirement

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.

Map the Process

Identify the variables - ‘x’

Measure the Process

Understand the Problem -
’Y’ = function of variables -’x’
Y=f(x)

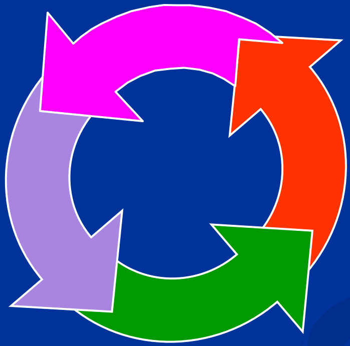
To understand where you want to be, you need to know how to get there.v

Measure

Characterize Process

Evaluate

Understand Process



Control

Maintain New Process

Improve

Improve and Verify Process

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)

Measure Phase

- Identify measurement and variation
- Determine data type
- Develop data collection plan
- Perform measurement system analysis
- Perform data collection
- Perform capability analysis

Measure Phase

- Effectiveness of existing process
- Efficiency of existing process
- Calculate Sigma Level
- Calculate Cost of poor quality

Measure Phase

- SIPOC-RM
- CTQ-R
- Check Sheet
- MSA
- Basic Statistics

Graph
Role Throughput Yield
Process Capability
DPMO
COPQ Calculation

Measure Phase

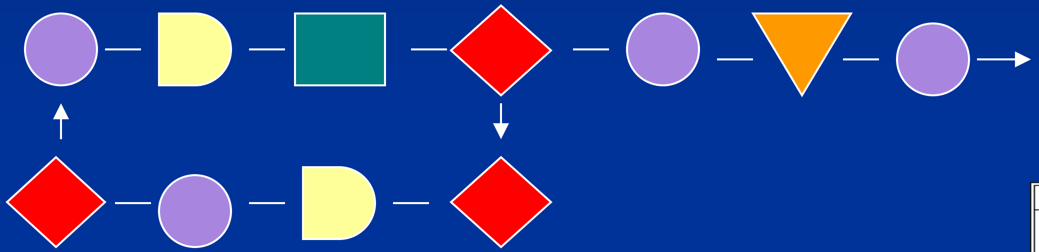
- Project Review
  - Customer satisfaction
  - Effectiveness of process
  - Efficiency of process
  - Base line sigma (Yield, DPMO, CPk)
  - Cost of poor quality

Measure Phase

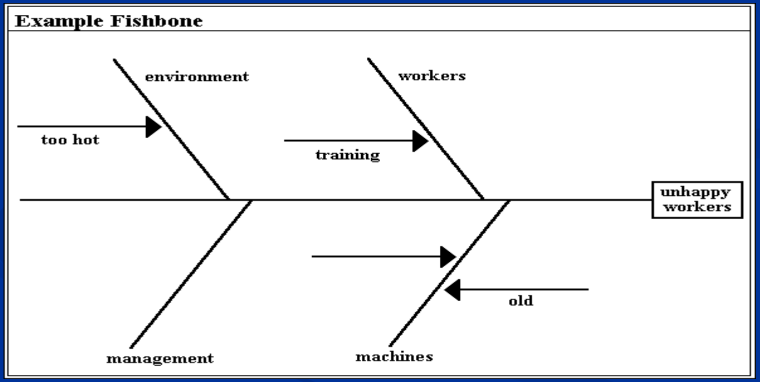
Baselining:
Quantifying the goodness (or badness!) of the current process, before ANY improvements are made, using sample data. The key to baselining is collecting representative sample data

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

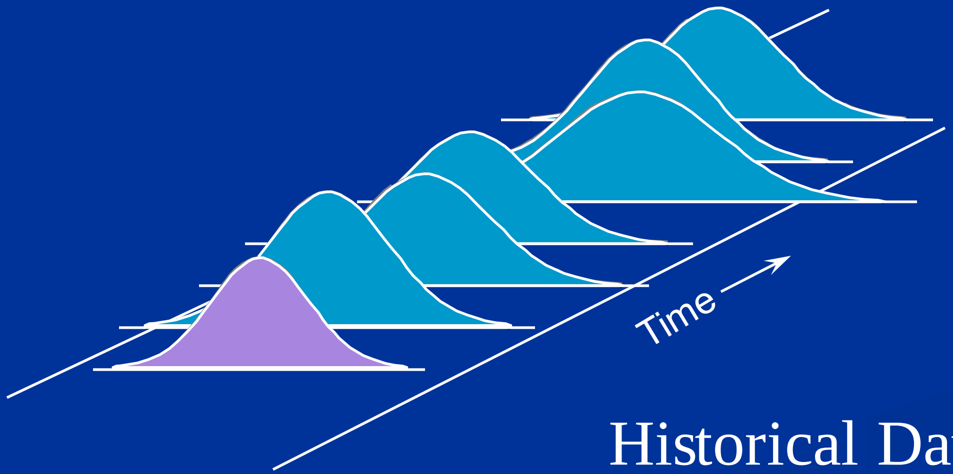
How do we know our process?



Process Map

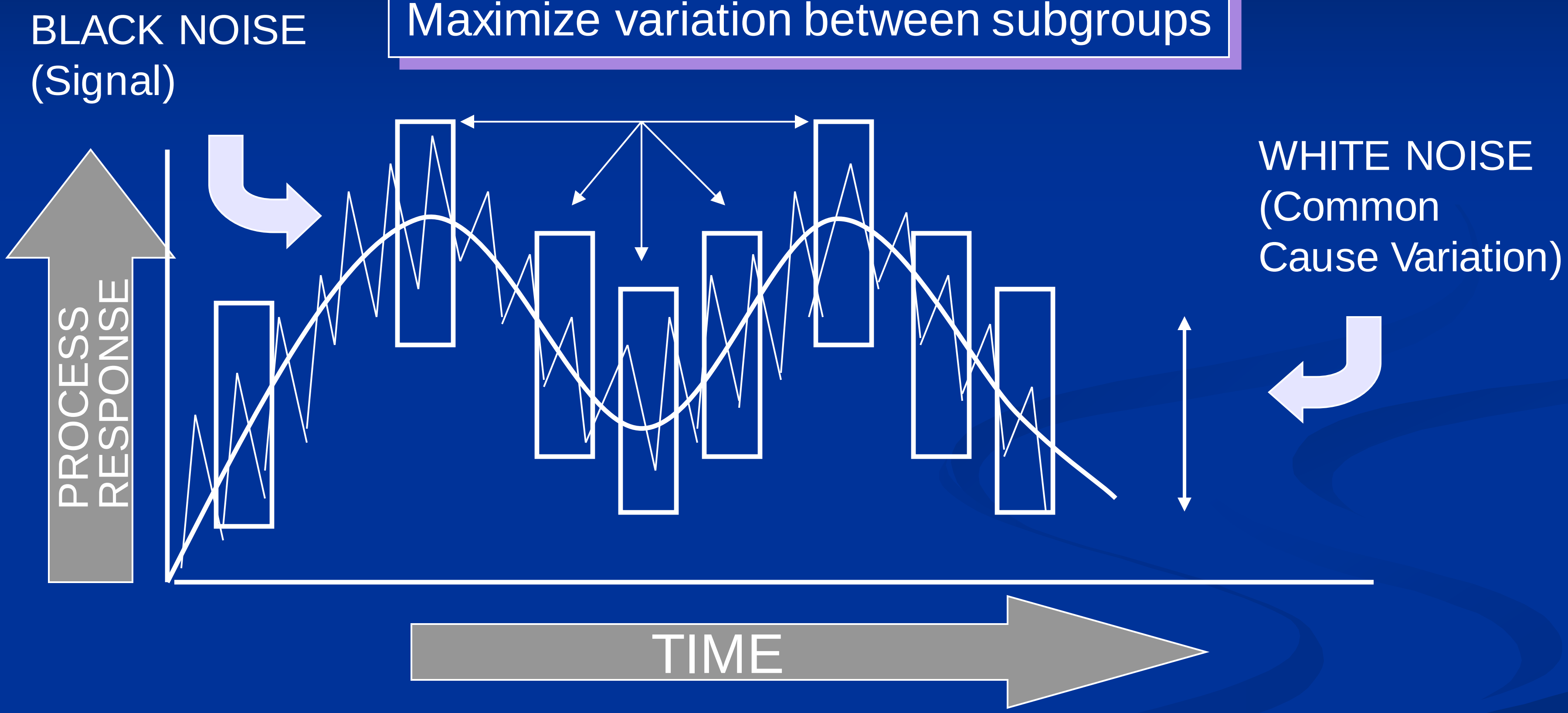


Fishbone



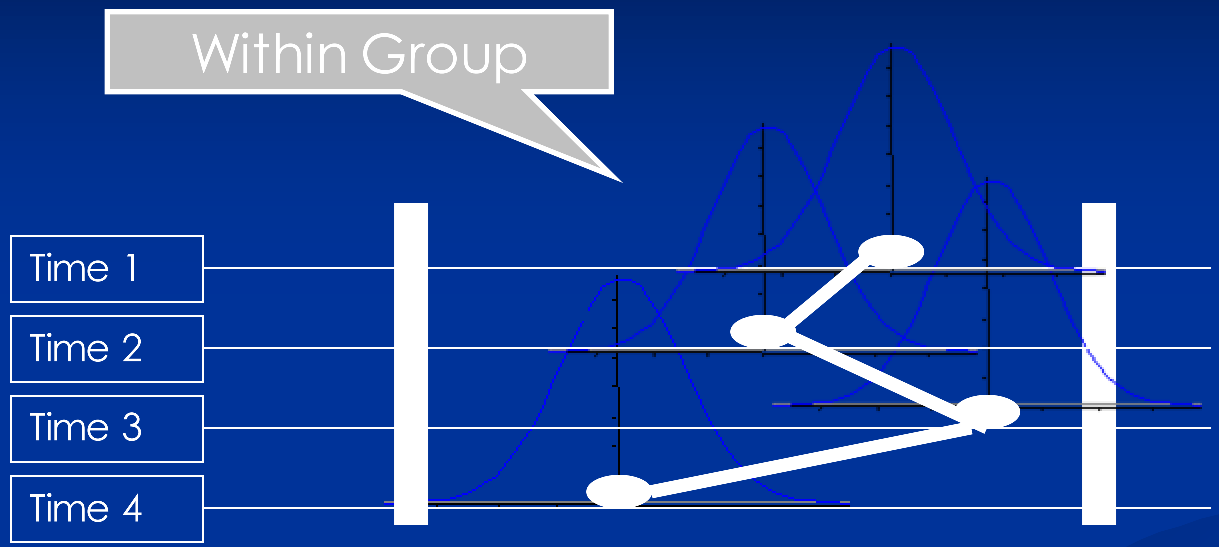
Historical Data

<u>RATIONAL SUBGROUPS</u>
Minimize variation within subgroups
Maximize variation between subgroups



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.

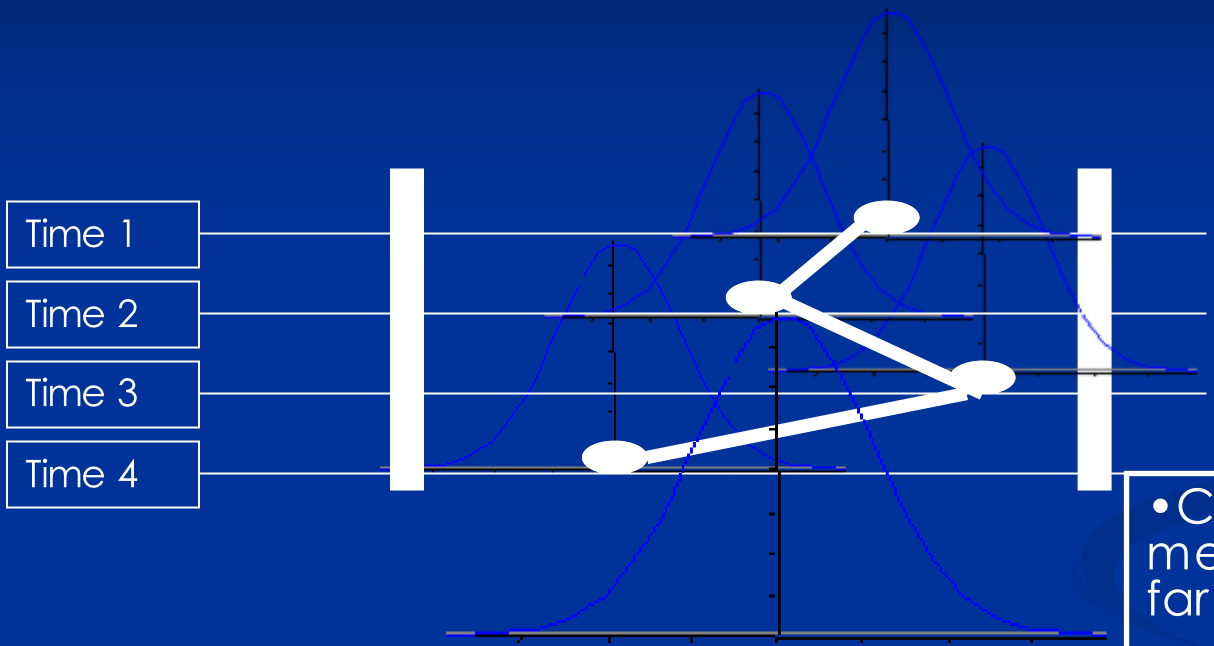
Visualizing the Causes



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

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

Visualizing the Causes



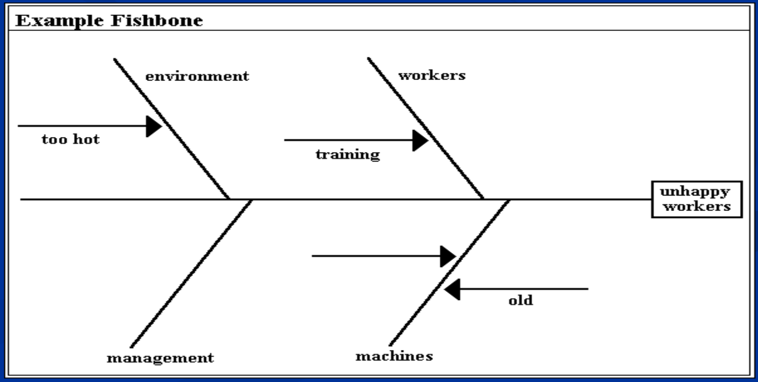
$\sigma_{st} + \sigma_{shift} = \sigma_{total}$

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

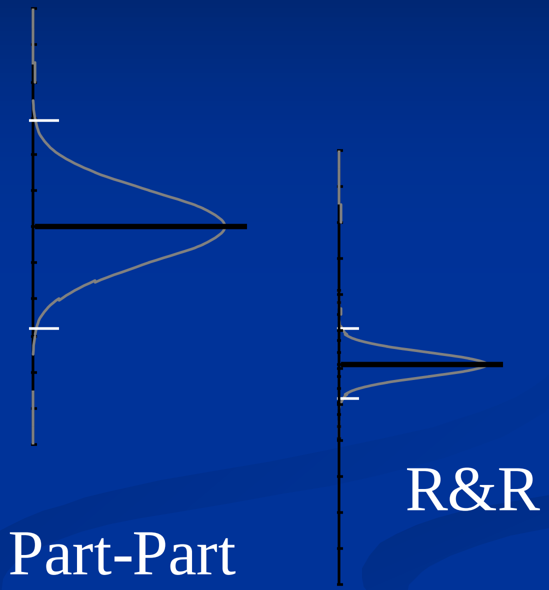
- Variation present in every process
- Not controllable
- The best the process can be within the present technology

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



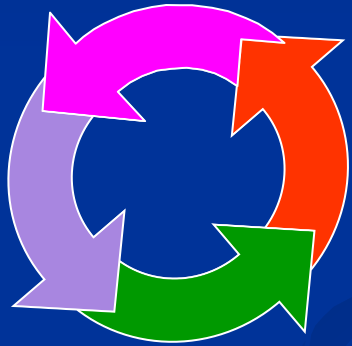
- ***Repeatability (Equipment variation)***
  Variation observed with one measurement device when used several times by one operator while measuring the identical characteristic on the same part.
- ***Reproducibility (Appraised variation)***
  Variation Obtained from different operators using the same 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.

Measure

Characterize Process

Evaluate

Understand Process



Control

Maintain New Process

Improve

Improve and Verify Process

Evaluate / Analysis Phase

- Data Analysis
- Process Analysis
- Formulate Hypothesis
- Test Hypothesis

Evaluate / Analysis Phase

- Run chart
- Pareto chart
- Relation Diagram
- Process Analysis
- Hypothesis Testing

  Chi-square T-Test ANOVA Correlation Regression

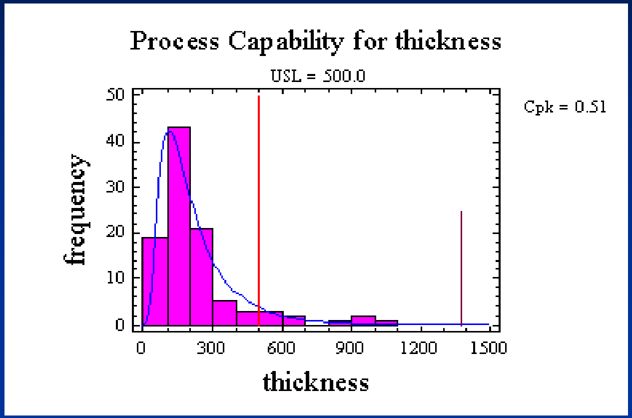
Histogram

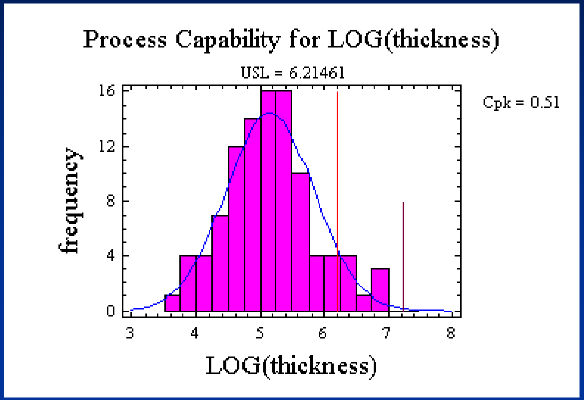
Scatter Diagram

CE Diagram

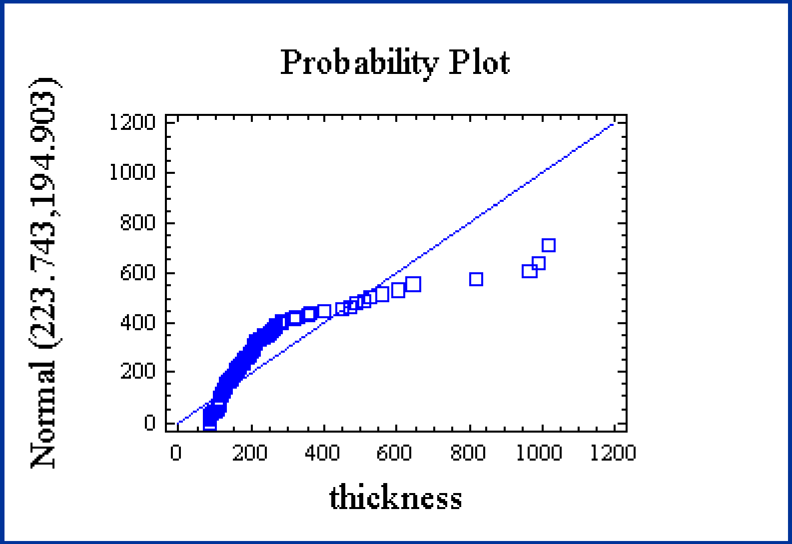
Evaluate / Analysis Phase

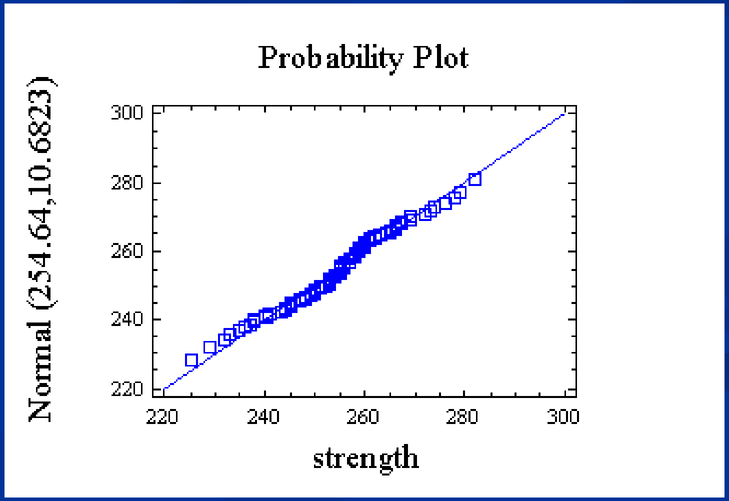
- Project Review
  - Validated root cause statement



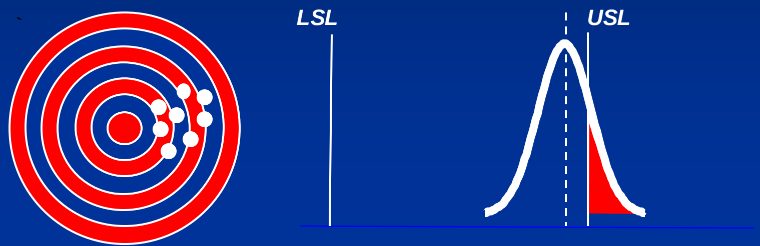


In many cases, the data sample can be transformed so that it is approximately normal. For example, square roots, logarithms, and reciprocals often take a positively skewed distribution and convert it to something close to a bell-shaped curve

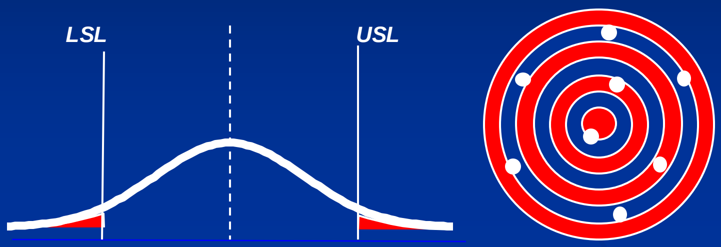




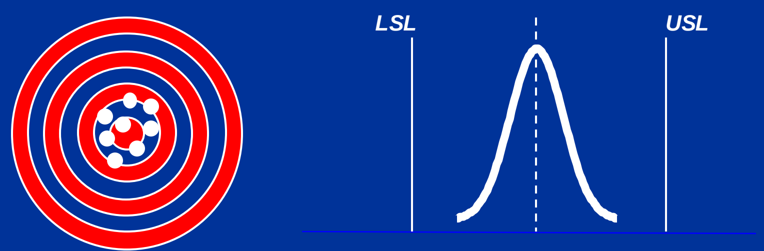
What do we Need?



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)

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

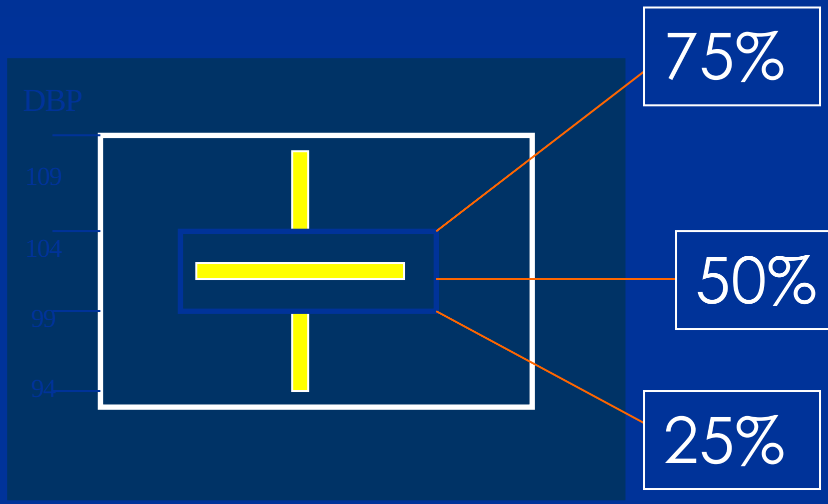
- % Reduction in Variation
- Cost/ Benefit

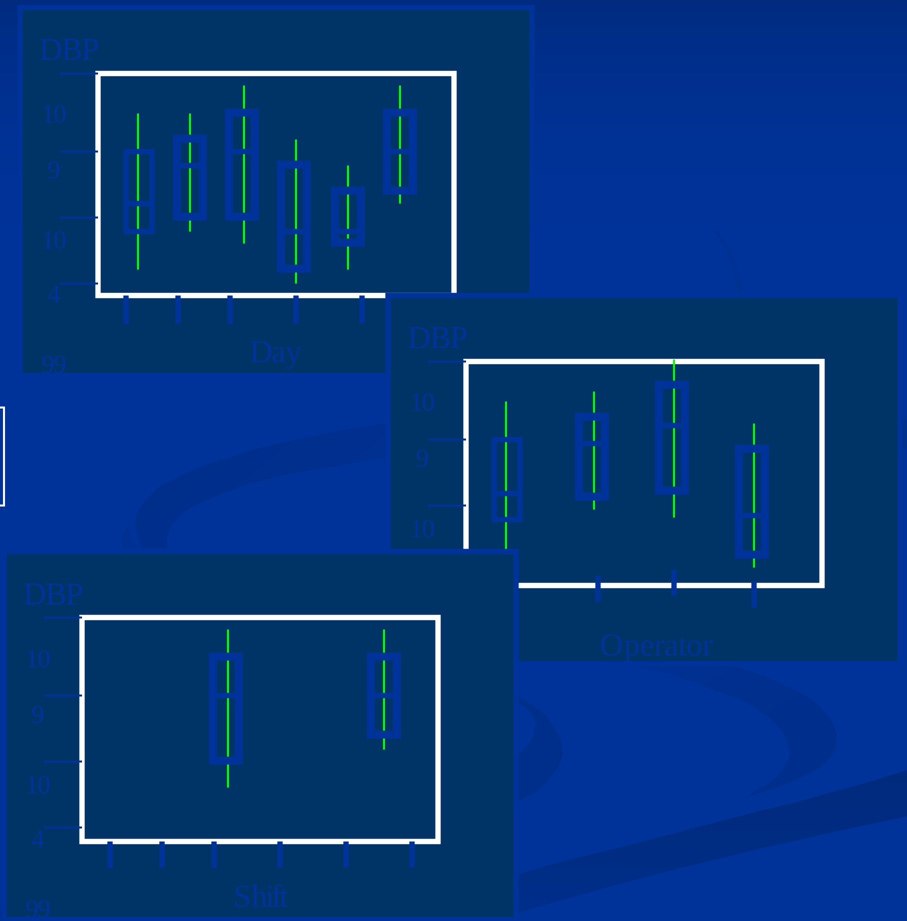
Our Goal:
Identify the Key Factors (x’s)

Graph>Box plot

Graph>Box plot

Without X values



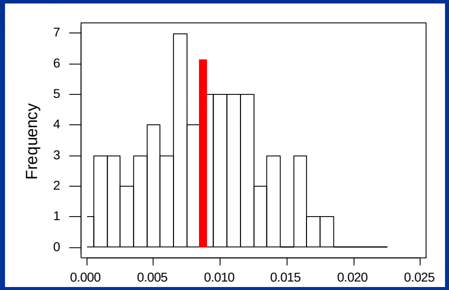


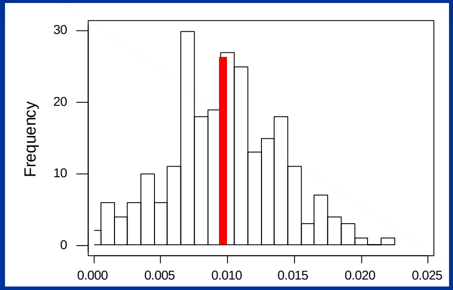
Box plots help to see the data distribution

Statistical Analysis

Apply statistics to validate actions & improvements

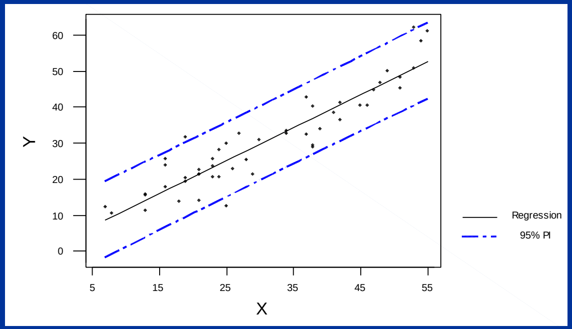
Hypothesis Testing





Compare Sample Means & Variances

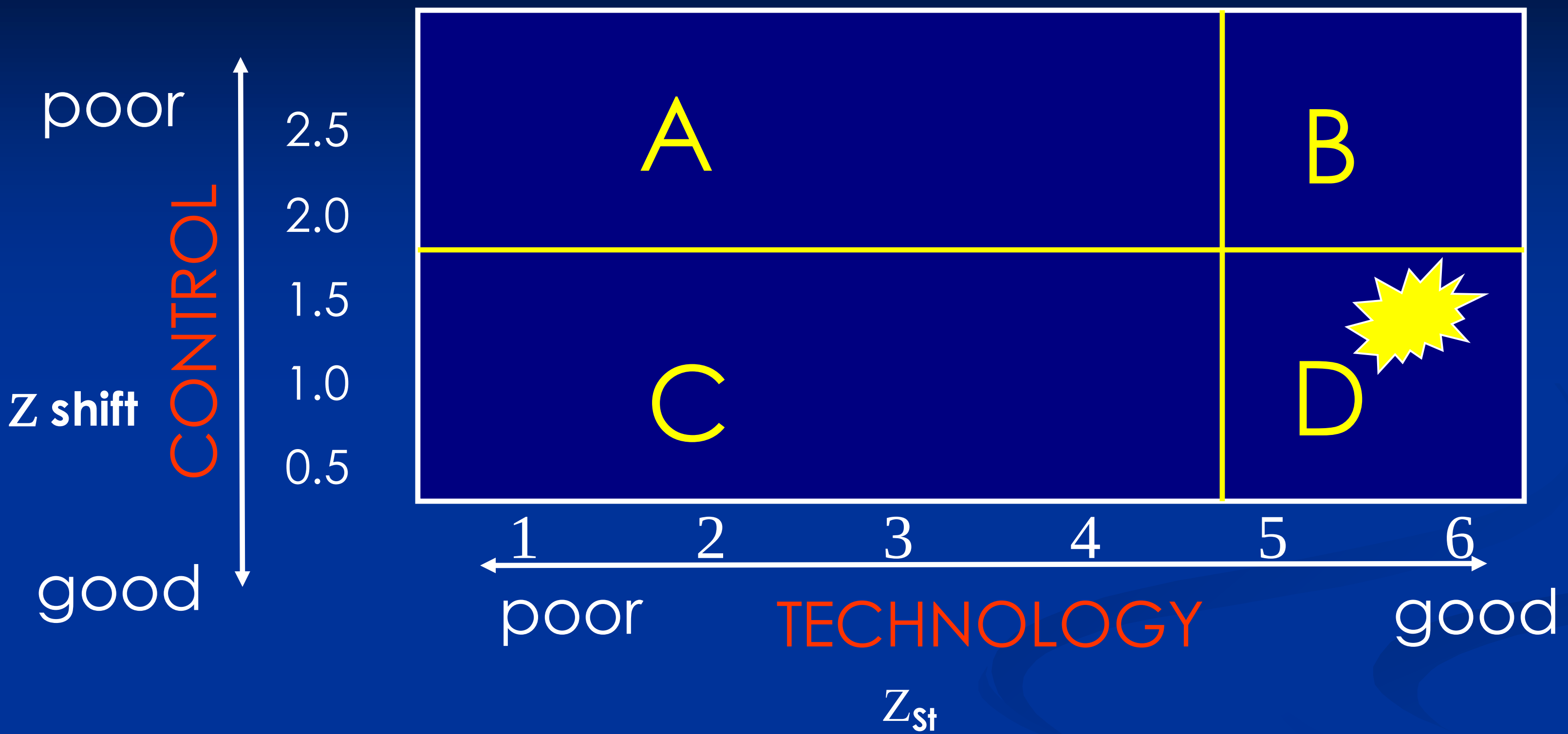
Regression Analysis



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?



A- Poor Control, Poor Process

B- Must control the Process better, Technology is fine

C- Process control is good, bad Process or technology

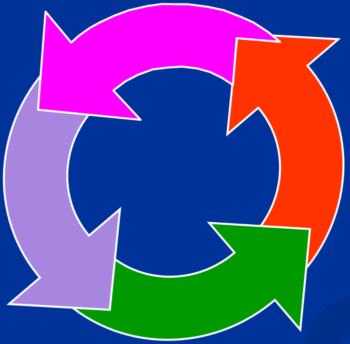
D- World Class

Measure

Characterize Process

Evaluate

Understand Process



Control

Maintain New Process

Improve

Improve and Verify Process

Improvement Phase

- Generate Improvement alternatives
- Validate Improvement
- Create “should be” process map
- Update FMEA
- Perform Cost/Benefit analysis

Improvement Phase

- Brain Storming
- Creativity
- Criteria Weighting
- Change Management tools
- DOE
- Cost/Benefit Analysis

Improvement Phase

- Project Review
  - Validated pilot study
  - Result of cost benefit analysis
  - Plan of control phase

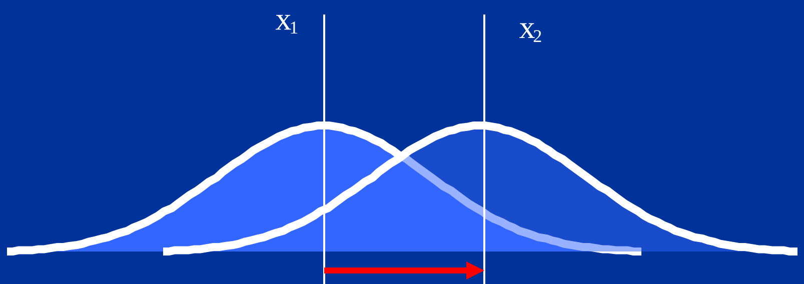
Design of Experiments (DOE)

- To estimate the effects of independent Variables on Responses.

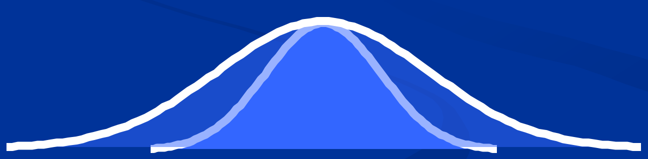
- Terminology
  - Factor – An independent variable
  - Level – A value for the factor.
  - Response - Outcome

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

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

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.

"....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."

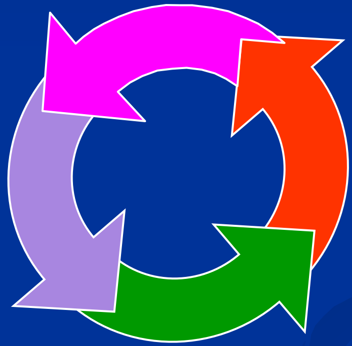
\- Albert Einstein

Measure

Characterize Process

Evaluate

Understand Process



Control

Maintain New Process

Improve

Improve and Verify Process

Control Phase

- Develop control strategy
- Develop control plan
- Update procedure and training plan
- Monitor result
- Corrective action as needed

Control Phase

- Control chart

Control Phase

- Project Review
  - Procedure
  - Work instruction
  - Full implementation
  - Control chart of result

Control Phase

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

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

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))

Control Phase

Control Plan Tools:

1. Basic Six Sigma control methods.
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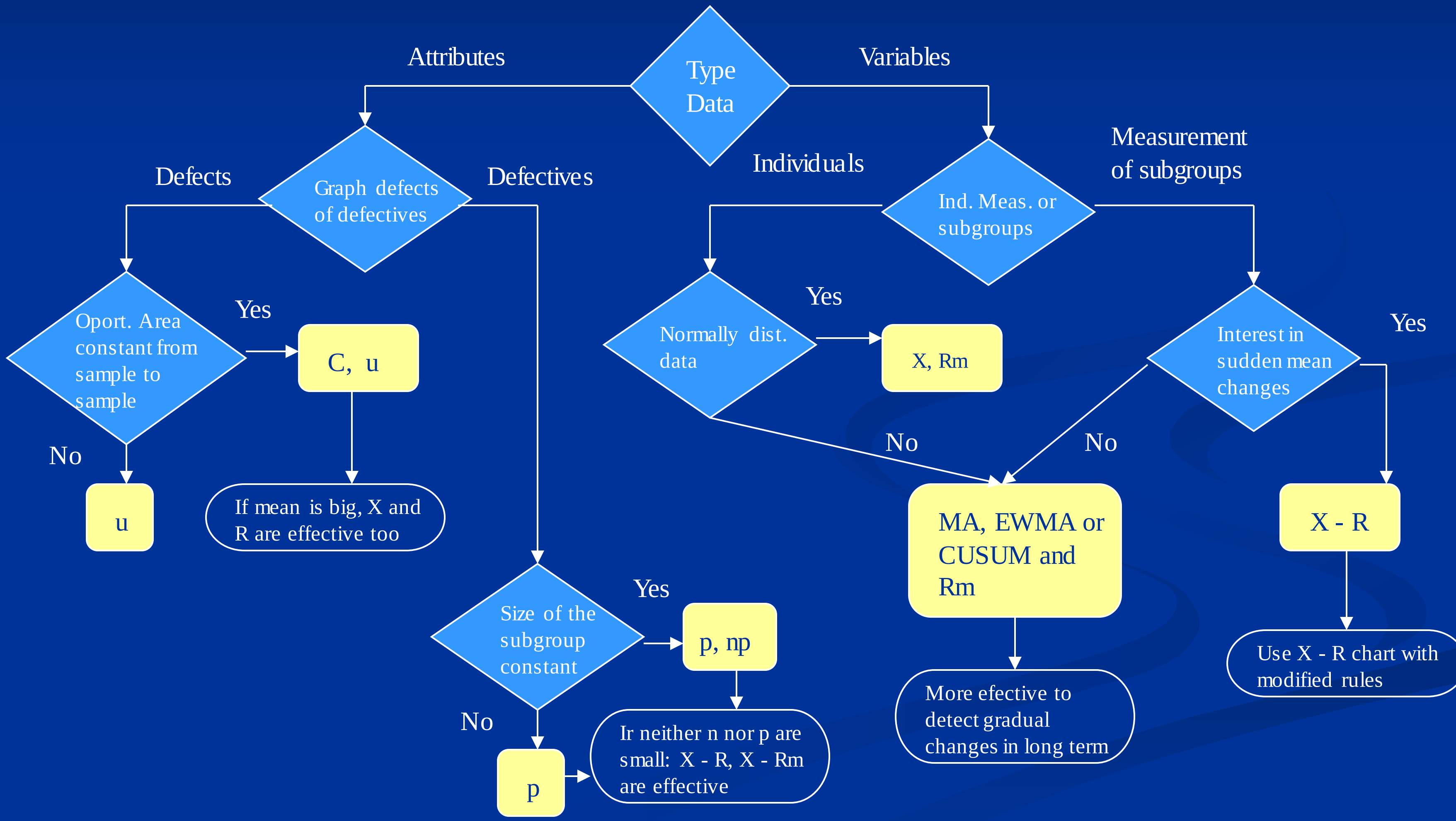
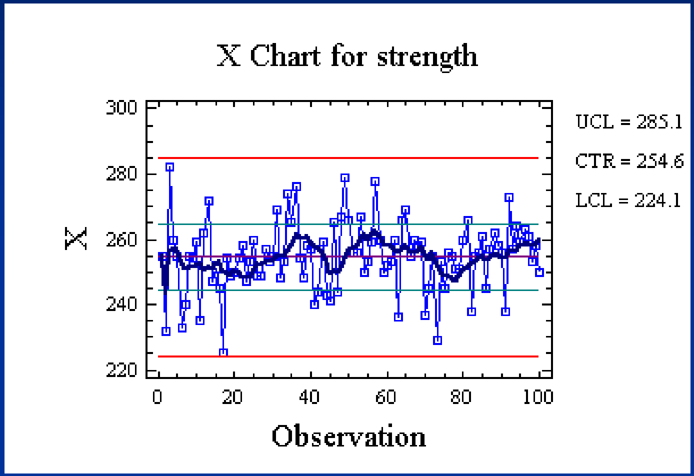
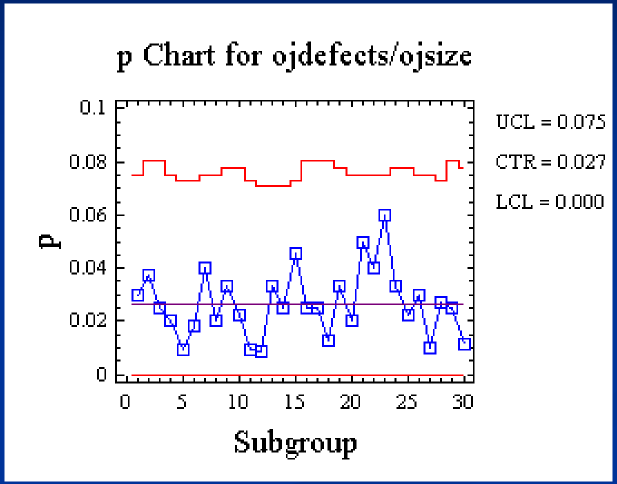
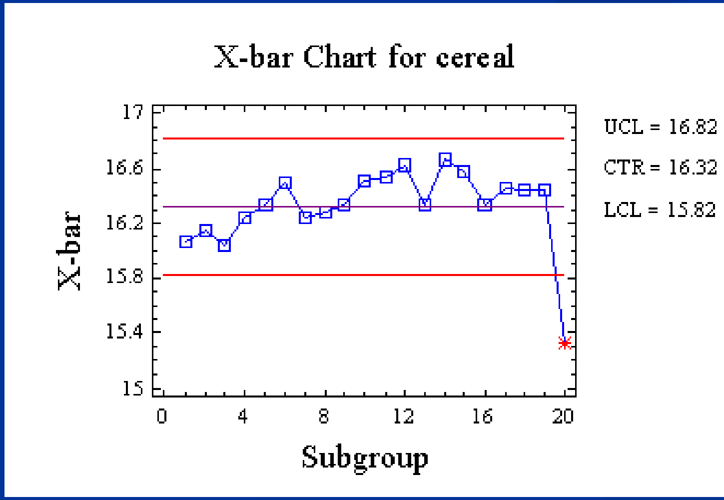
Control Phase

How do we select the correct Control Chart:



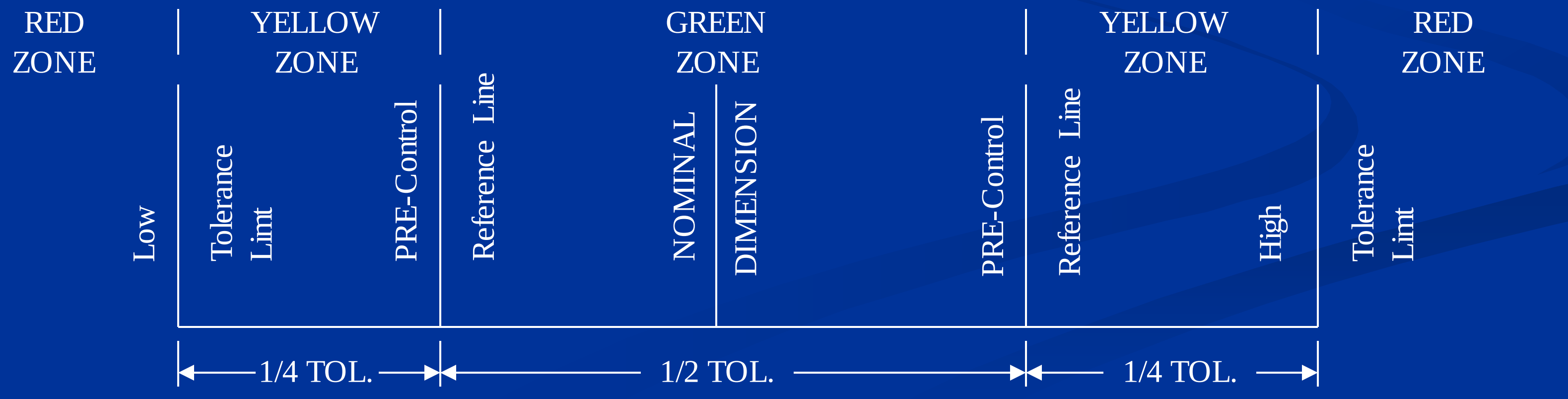

X Chart for strength
X
Observation
UCL = 285.1
CTR = 254.6
LCL = 224.1


p Chart for ojdefects/ojsize
p
Subgroup
UCL = 0.075
CTR = 0.027
LCL = 0.000


X-bar Chart for cereal
X-bar
Subgroup
UCL = 16.82
CTR = 16.32
LCL = 15.82

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



Additional Variable-Based Tools

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 = $y\hat{}t + \sigma (yt - y\hat{}t)$ σ between 0 and 1

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.

What is Design for Six Sigma (DFSS)?

- Customer-driven design of processes with 6σ capability.
- Predicting design quality up front.
- Top down requirements flowdown (CTQ flowdown) matched by capability flowup.
- Cross-functional integrated design involvement.
- Drives quality measurement and predictability improvement in early design phases.
- Utilizes process capabilities to make final design decisions.
- Monitors process variances to verify 6σ customer requirements are met.

DFSS Methodology & Tools

DESIGN FOR SIX SIGMA

Define	Measure	Analyze	Design	Verify
Initiate, scope, and plan the project	Under-stand customer needs and specify CTQs	Develop design concepts and high-level design	Develop detailed design and control/test plan	Test design and implement full-scale processes

DELIVERABLES

Define	Measure	Analyze	Design	Verify
Team Charter	CTQs	High-level Design	Detailed Design	Pilot

TOOLS

- Mgmt Leadership
- Project Management
- Customer Research
- QFD
- Benchmarking
- FMEA/Errorproofing
- Process Simulation
- Design Scorecards

Design for Six Sigma

- Pre-DEFINE Phase
  - Introduction to Six Sigma
  - DFSS / New Product Introduction (NPI) Process
    - Strategic vision
    - Logical chain of product concepts
    - Product evolution roadmap

Design for Six Sigma

- DEFINE Phase
  - Establish Design Project
  - Financial Analysis
  - Project Management and Risk Assessment

Design for Six Sigma

- MEASURE Phase
  - Establish CTQ’s and CTI’s
  - Design problem documentation
  - Design expectations
  - Probability, Statistics, and Prediction
  - MSA (Variables, Attribute and Data quality)
  - Process Capability (Variables and Attribute)
  - Risk Assessment
  - Failure prediction
  - Design Scorecard

Design for Six Sigma

- ANALYZE/HIGH-LEVEL DESIGN Phase
  - Develop Design Alternatives
  - Description of design options (alternatives)
  - Analysis of design alternatives for technological barriers and contradictions
  - Develop High Level Design (VA/VE)
  - Multi-Variable Analysis
  - Confidence Intervals & Sampling
  - Hypothesis Testing
  - Evaluate High Level Design
  - Failure analysis and prediction

Design for Six Sigma

- DETAIL DESIGN Phase
  - Risk Assessment Failure analysis
  - Taguchi Methods
  - Tolerancing
  - DOE with RSM

Design for Six Sigma

- DETAIL DESIGN Phase (cont'd)
  - Reliability and Availability
  - Non-Parametric Statistics
  - Simulation with Monte Carlo Methods
  - Design for Manufacturability/Assembly
  - DVT/Testability
  - Design Scorecard

Design for Six Sigma

- DETAIL DESIGN Phase
  - Concurrent Engineering
  - Software Engineering Tools
    (CMM, CASE)

ENHANCED DESIGN FOR:
- Commercial/Competitive Success
- Manufacturability
- Serviceability
- Reliability
- Availability
- Information Management
- Control

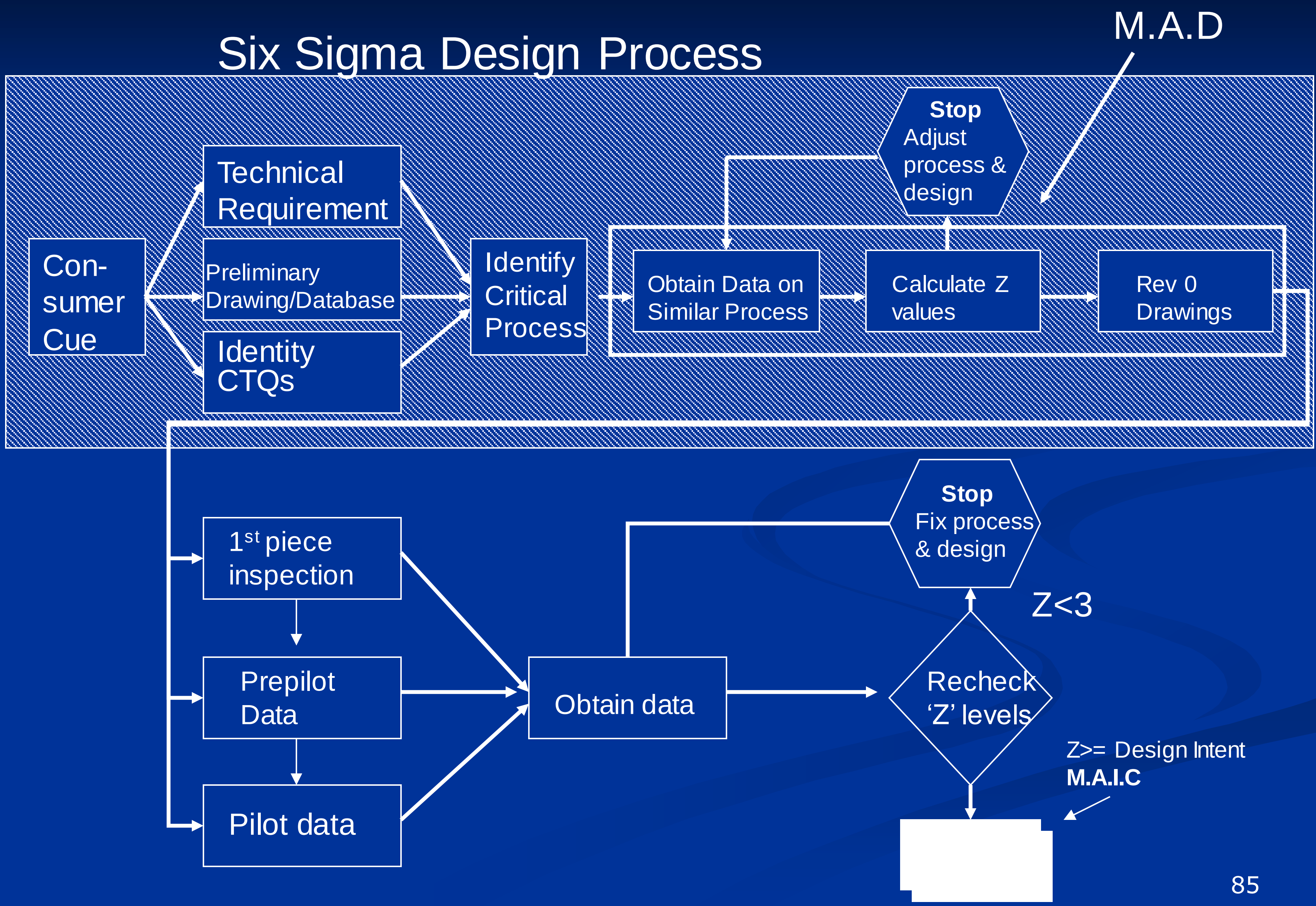
Design for Six Sigma

- VERIFY Phase
  - Design for Control
  - Design for Mistake Proofing
  - Statistical Process Control (SPC)
  - MVT
  - Transition to Process Owners
  - Logical sequence of new scenarios
  - Strategic knowledge base and patent portfolio
  - Targeted competitive intelligence
  - New product evolutionary stages
  - Project Closure

Design for Six Sigma

- VERIFY Phase -- continued
  - Pilot Testing
  - Full-Size Scale Up and Commercialization
  - Design Information and Data Management
  - Lean Manufacturing

Six Sigma Design Process



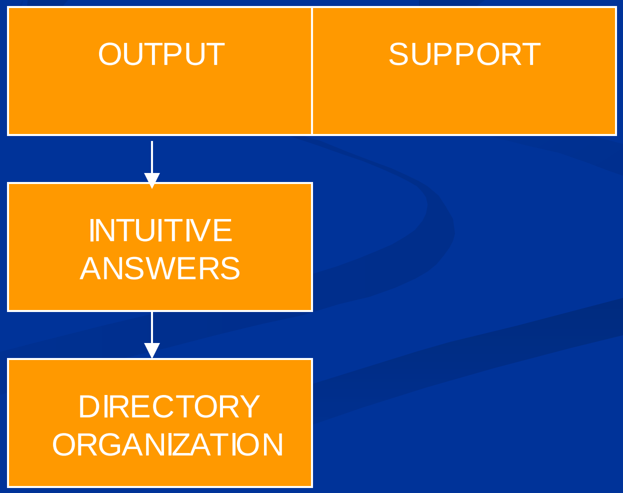
AFFINITY DIAGRAM

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



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

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.

Green Belts & Black Belts

- 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

Green Belts & Black Belts

	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 communicate new ones	5%~10%	Two green belts	4 / year
Master Black Belt	Consulting/Mentoring/Training	80~100%	Five Black Belts	10 / year

"It is reasonable to guess that the next CEO of this company, decades down the road, is probably a Six Sigma BB or MBB somewhere in GE right now…"

Jack Welch
Ex-CEO, GE