BASICS OF SIX SIGMA

INTRODUCTION

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Participants

- **Names**
- **Roles**
- **Expectations from this training**

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What is Six Sigma

What is Six Sigma?

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- **Sigma is a measurement that indicates how a process is performing**

- **Six Sigma stands for Six Standard Deviations (Sigma is the Greek letter used to represent standard deviation in statistics) from mean. Six Sigma methodology provides the techniques and tools to improve the capability and reduce the defects in any process.**

- **Six sigma is a fact-based, data-driven philosophy of improvement that values defect prevention over defect detection.**

What is Six Sigma?

- **<u>Philosophy:</u>** The philosophical perspective views all works as a processes that can be defined, measured, analyzed, improved & controlled (DMAIC). Processes require inputs & produce outputs. If you control the inputs, you will control the outputs. This is generally expressed as the y= f (x) concept.

- **<u>Set of Tools:</u>** Six Sigma as a set of tools includes all the qualitative and quantitative techniques used by the six sigma expert to drive process improvement. A few such tools include statistical process control (SPC), Control charts, failure mode & effects analysis, process mapping etc.

What is Six Sigma?

- **Methodology:** This view of Six Sigma recognizes the underlying and rigorous approach known as DMAIC. DMAIC defines the steps a Six Sigma practitioner is expected to follow, starting with identifying the problem and ending with the implementation of long-lasting solutions. While DMAIC is not only Six Sigma Methodology in use, it is certainly the most widely adopted and recognized.

- **Metrics:** In simple terms, Six Sigma quality performance means 3.4 defects per million opportunities.

A little bit of History ….

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- Six Sigma was developed by Bill Smith, QM at Motorola
- It's implementation began at Motorola in 1987
- It allowed Motorola to win the first Baldrige Award in 1988
- Motorola recorded more than $16 Billion savings as a result of Six Sigma
- Several of the major companies in the world have adopted Six Sigma since then ….

  Texas Instruments, Asea Brown Boveri, AlliedSignal, General Electric, Bombardier, Nokia Mobile Phones, Lockheed Martin, Sony, Polaroid, Dupont, American Express, Ford Motor,…..

The Six Sigma Breakthrough Strategy has become a Competitive Tool

Sigma as a Measure of Quality

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σ	DPMO	RTY
2	308,537	69.1%
3	66,807	93.3%
4	6,210	99.4%
5	233	99.97%
6	3.4	99.99966%
Process Capability	**Defect Per Million Opportunities**	**Rolled Throughput Yield (Long Term)**

- **Sigma is a statistical unit for measuring quality**
- **It is correlated to the defect rate and the complexity of the process / product**

Six Sigma is a Standard of Excellence.
It means no more than 3.4 Defects per Million Opportunities.

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Why Six Sigma

The Classical View of Performance

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Practical Meaning of “99% Good”

- 20,000 lost articles of mail per hour
- Unsafe drinking water almost 15 minutes each day
- 5,000 incorrect surgical operations per week
- 2 short or long landings at major airports each day
- 200,000 wrong drug prescriptions each year
- No electricity for almost 7 hours each month

3 σ Capability	Long Term Yield 93.32%	Historical Standard
4 σ Capability	Long Term Yield 99.38%	Current Standard
6 σ Capability	Long Term Yield 99.99966%	New Standard

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Benchmarking Chart

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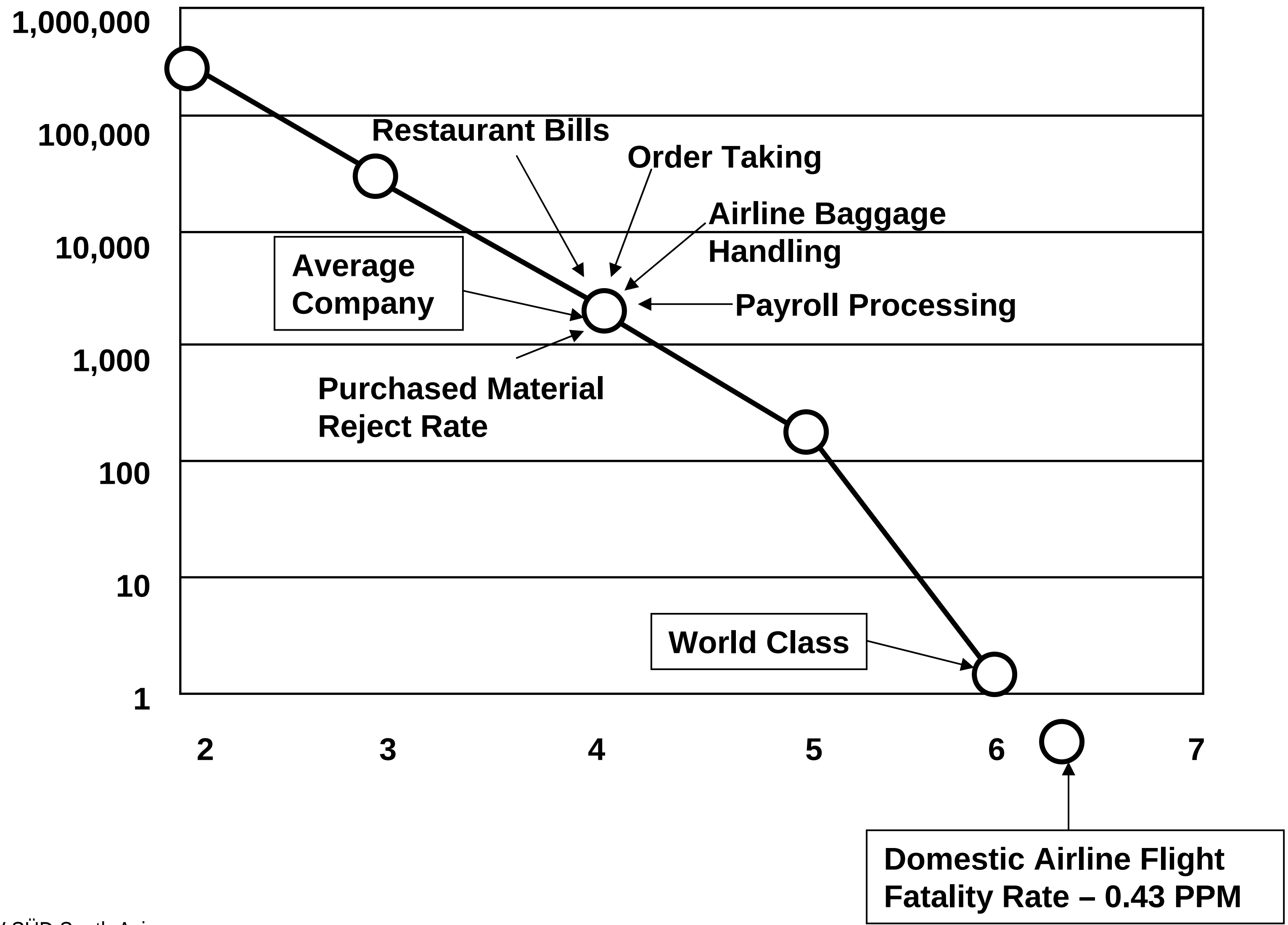

Six Sigma Results

- **Defects are eliminated**
- **Production and development costs are reduced**
- **Cycle Times and Inventory Levels are reduced**
- **Profit Margin and Customer Satisfaction are improved**

1 Sigma Shift Improvement Yields

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- **20% Margin Improvement**
- **12% - 18% Capacity Increase**
- **12% Workforce Reduction**
- **10% - 30% Capital Reduction**

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Six Sigma & Cost of Poor Quality (COPQ)

Cost of Poor Quality (COPQ) Correlation

- Process Control is pre-requisite for error free Quality
- COPQ is a result of poorly controlled process
- Process Control can be measured in PPM/Yield
- PPM/Yield measurements are correlated to COPQ

Six Sigma has shown that the Highest Quality Producer is also the Lowest Cost Producer

What is the Cost Poor Quality

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Internal Costs

- Scrap
- Rework/Repair
- Downtime
- Redesign
- Excess Inspection
- Excess Inventory

External Costs

- Warranty
- Retrofits
- Service Calls
- Recalls
- Lost Sales
- Long Cycle Times

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Components of Cost of Poor Quality

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People (Indirect Labor)
- Rework
- Inspection
- Material Handling
- Maintenance
- Setup
- Excess Overtime
- Labor Variance off standard

Inventory
- Raw Material Holding Cost
- WIP Holding Cost
- Finished Good Holding Cost
- Obsolescence
- Inventory Shrinkage

Maintenance
- Maintenance
- Repairs
- Rearrangement

Defects
- Scrap
- Rework
- Defects
- Warranty & Recalls
- Returned Good Handling

Premium Freight
- Air Freight
- Expedited Truck Freight

COPQ & Sigma / DPMO Relationship

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COPQ	Sigma	DPMO	
30-40% of Sales	2.0	308,537	Non Competitive
20-30% of Sales	3.0	66,807	
15-20% of Sales	4.0	6,210	Industry Average
10-15% of Sales	5.0	233	
<10% of Sales	6.0	3.4	World Class

COPQ & Sigma/Yield Relationship

South Asia

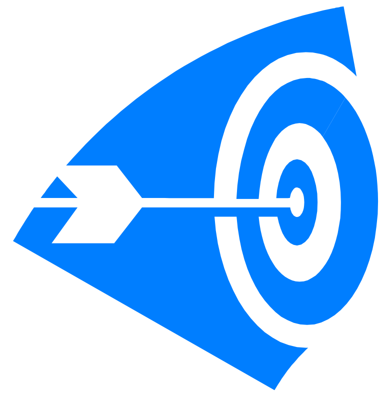
COPQ	Sigma	Yield	
30-40% of Sales	2.0	5%	Non Competitive
20-30% of Sales	3.0	93%	
15-20% of Sales	4.0	99.4%	Industry Average
10-15% of Sales	5.0	99.976%	
<10% of Sales	6.0	99.999655%	World Class

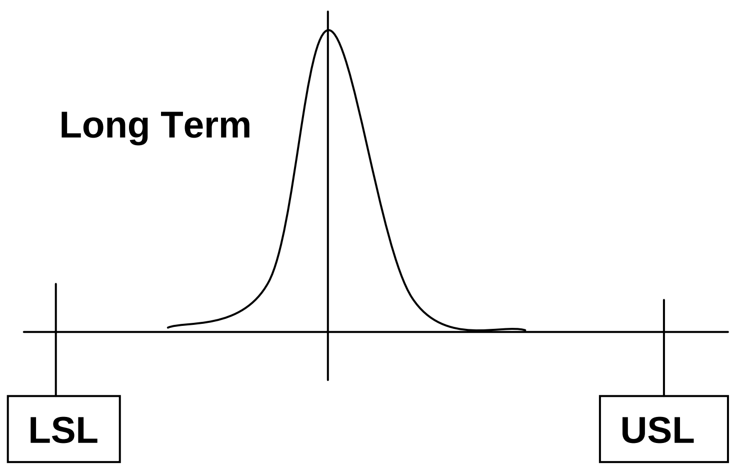
Six Sigma Improvement Strategy

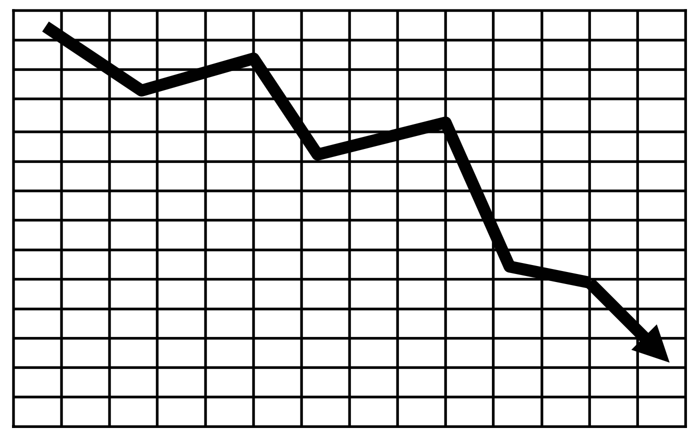
Know what is Important to the Customer and to the Business

Reduce Defect Levels by:

1. **Reducing the Variation**
2. **Centering around the Target**







The Goals of Six Sigma

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- Improved Customer Satisfaction
- Defect Reduction/Elimination
- Yield Improvement
- Reduced COPQ
- Improved Process Capability
- Stretch Goals – Target 6 Sigma standards
- Process Understanding
- Constant Measurement of Key Metrics
- Breakthrough Improvement

Six-Sigma Objectives Are Directly and Quantifiably Connected to the Objective of the Business.

A Final Note on Philosophy

Six Sigma is a relentless, constant Journey of Improvement

Phases of Six Sigma

Five Phases of Six Sigma

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- Define
- Measure
- Analysis
- Improve
- Control

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Define Phase Tools

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- Voice of Customer (VOC)
- CT Matrix
- Business Matrix
- Pareto Analysis
- Project Charter
- Team Selection (ARMI)
- Top Level Process Map (SIPOC)

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Voice of Customer (VOC)

Establishing Customer Focus

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- **Customer** – Anyone internal or external to the organization who comes in contract with the product or output of work
- **Quality** – Performance to the standard expected by the Customer

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The Customer Problem

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<u>Customers</u> will not repurchase a company's product if they are not satisfied with the current company product.

The stronger the degree of satisfaction with a company's current product or service, the greater the likelihood that a customer will repurchase from the same company.

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Variation Is The Enemy in Achieving Customer Satisfaction

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Variation ⇒

- **Uncertainty**
- **Unknown**
- **Disbelief**
- **Risk**
- **Defect Rate**

What Do You Measure Now?

What Numbers get the most attention in your area?

⇩

What Quality Measurements do you have?
Do they have a Customer Focus?
Do they have a Quality Focus?
Do they have an Input Focus?

⇩

How do you use these Measures?

Switching to a Sigma base measurement system

σ →

- Measure of Variation and Quality
- Measure of Process Capability

What Do You Measure Now?

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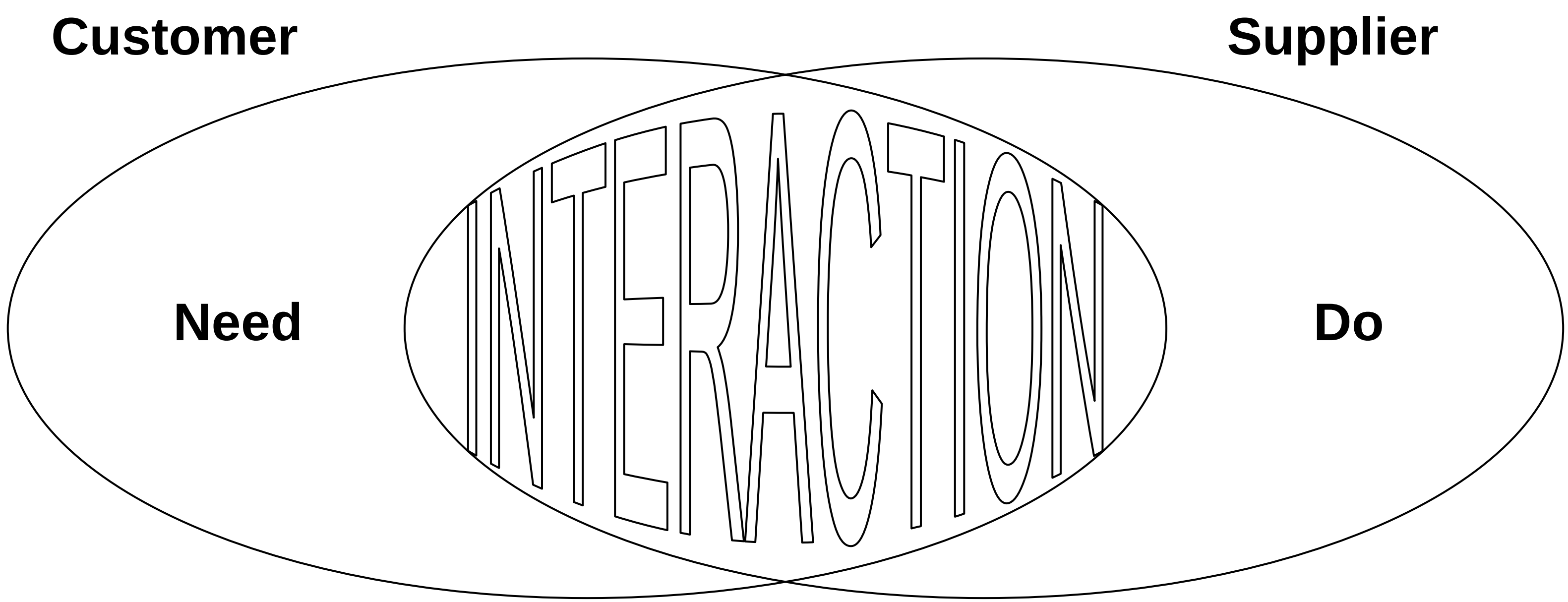
Driving value from the Need – Do interaction



Customers and Suppliers Exchange Value
Through the Need-Do Interaction

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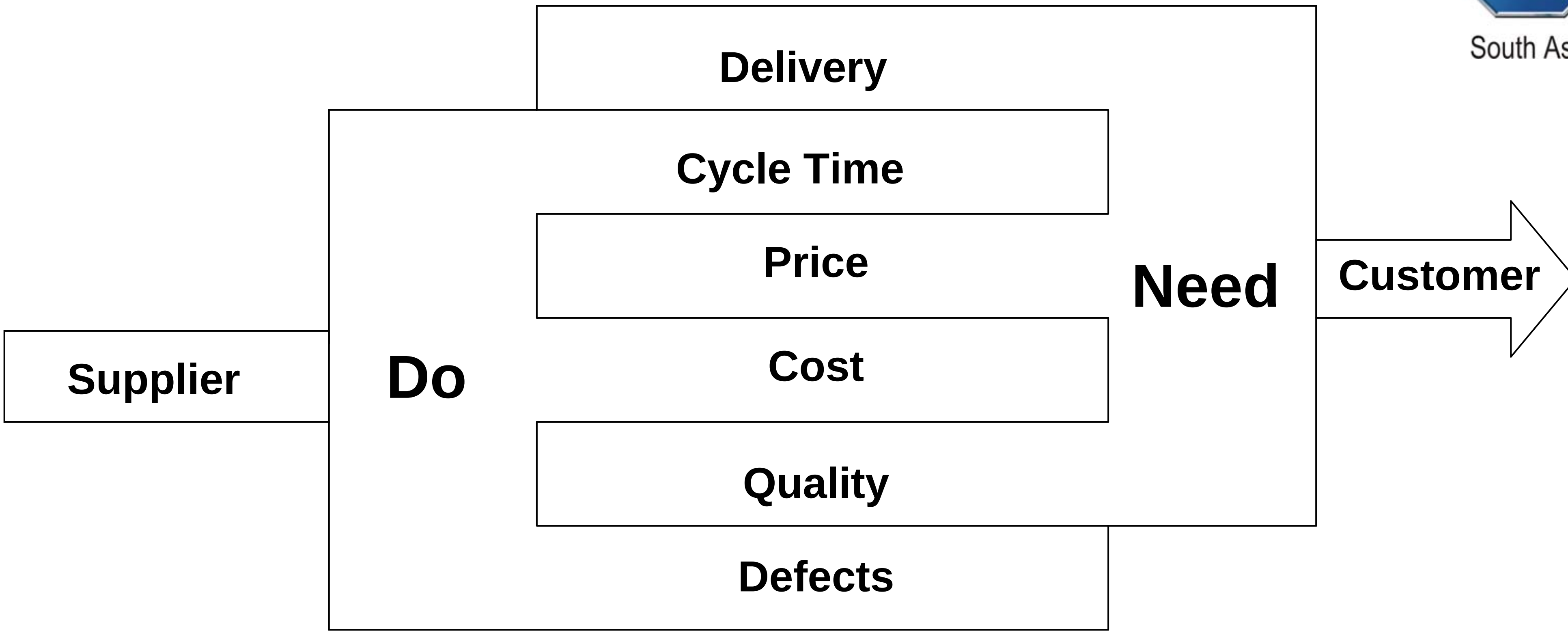
Maximizing the Need/Do Interaction



Supplier strives for performance in Cycle Time, Cost and Defects To Meet Customers expectations in Delivery, Price and Quality

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Critical To Matrix

CT's

Key Questions

- What does the phrase "critical to satisfaction" mean in terms of a customer? CTS
- What does the phrase "critical to quality" mean in terms of a product or service? CTQ
- What does the phrase "critical to delivery" mean in terms of a product service? CTD
- What does the phrase "critical to cost" mean in terms of a product or service? CTC
- What does the phrase "critical to process" mean in terms of a product or service? CTP

CT Concept

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Need	Quality	Delivery	Price
Do	Defect-free	Cycle time	Cost

CTQ1 -Critical to Quality **-Critical to Delivery** **-Critical to Cost**

CTQ2

CTQ3

Processes

CTP1 -Critical to Process 1

CTP2

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CTQ and CTP Characteristics

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CTQ1 -Critical to Quality ***Output*** Y_1

CTQ2

CTQ3

Processes

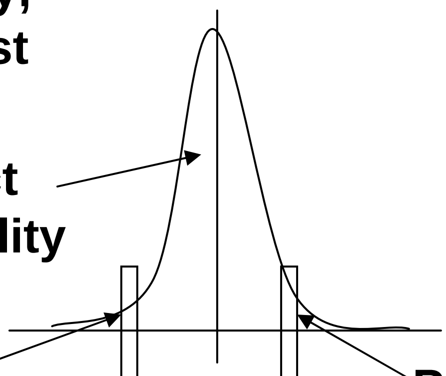
CTP1 - Critical to Process ***Input*** $f_1(X)$

CTP2

“Critical to” Characteristics

The inherent variation of any dependent variable (Y) is determined by the variations inherent in each of the independent variables f(x).

Product or Service requirement that impacts Quality, Delivery or Cost → $Y = f(X)$ ← **One of the “vital few” process variable (x) that significantly affect Y**



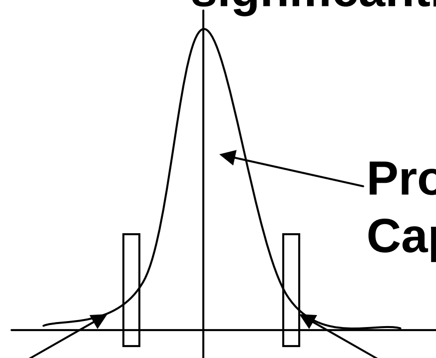
Product Capability

Probability of Defects

Probability of Defects

Critical-to-Quality characteristic
CTQ_1

Defect Opportunity



Process Capability

Probability of Defects

Critical-to-Process characteristic
CTP_1

Control Opportunity

The Focus of Six Sigma

$$Y = f(X)$$

Y

- **Dependent**
- **Output**
- **Effect**
- **Symptom Monitor**

$X_1 \ldots\ldots X_N$

- **Independent**
- **Input Variables**
- **Cause**
- **Problem Control**

CT Matrix Components

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$$Y = f\,(X_1, X_2 \ldots\ldots, X_N)$$

Y

- **Translation of customer needs into product or service requirements in terms of Quality, Delivery and Cost.**
- **These are the CTQ,CTD and CTC Characteristics**

f(X)

- **Breakdown of the processes required to produce the product or service.**
- **Identification of projects by understanding the relationship between product or service requirements and the processes used.**
- **Identification of the process parameters $f(x_1, x_2 \ldots\ldots x_N)$ that affect the requirements.**

Business Metrics

Business Metrics

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- **Following Business Metrics can be used in Six Sigma Projects.**
  - **Defect per Unit (DPU)**
  - **Defects per Million Opportunities (DPMO)**
  - **Throughput Yield (Yield)**
  - **Rolled Throughput Yield (RTY)**
  - **Parts per Million (PPM)**

Business Metrics

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- An example will illustrate the use of business metrics used in previous slides.
- <u>Example:</u>

A process produces 40000 pencils. Three types of defect can occur & number of occurrences are:

- Blurred printing – 36
- Wrong dimensions – 118
- Rolled ends - 11

Business Metrics

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- **Defect per Unit (DPU):**

  = Total number of defects / No. of units

  = 165 / 40000 = 0.004125

- **Throughput Yield (Yield):**

  $= e^{-DPU} = e^{-0.004125} = 0.996$

- **Parts per Million (PPM):**

  = DPU x 10,00,000

  = 0.004125 x 10,00,000 = 4125

Business Metrics

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- **Defect per Million Opportunities (DPMO):**

To Calculate the number of opportunities, it is necessary to find the number of ways each defect can occur on each item. In this product, blurred printing occurs in only one way (the pencil slips in the fixture), so in the batch there are 40,000 opportunities for this defect to occur. There are three independent places where dimensions are checked, so there are 3 x 40,000 = 1,20,000 opportunities for dimensional defects. Rolled ends can occur at the top and / or the bottom of the pencil, so there are 40,000 x 2 = 80,000 opportunities for this defect to occur. The total number of opportunities for defects is 40,000 + 1,20,000 + 80,000 = 2,40,000

DPMO = (Total no. of defects x 10,00,000) / (Total no. of opportunities)

= (165 x 10,00,000) / (2,40,000) = 687.5

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- **Rolled Throughput Yield (RTY):**

RTY applies to the yield from a series of processes and is found by multiplying the individual process yields. If a product goes through four processes whose yields are 0.994, 0.987, 0.951 & 0.990, then

RTY = 0.994 x 0.987 x 0.951 x 0.990 = 0.924

Exercise-1

- A car manufacturer produces 15000 cars per month . Three types of defect can occur at different stage & number of occurrences are:

  Initial Assembly – 50 (No. of Opportunities – 4)
  Intermediate Assembly – 95 (No. of Opportunities – 2)
  Final Assembly – 35 (No. of Opportunities – 3)

  Calculate the Defects per Unit (DPU), Defect per Million Opportunities (DPMO), Throughput Yield & Parts per Million (PPM).

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Exercise-2

A → B → C → D

Process A – Mixing 100# in – 90# out 90%

Process B – Making 100# in – 80# out 80%

Process C – Converting 100# in – 90# out 90%

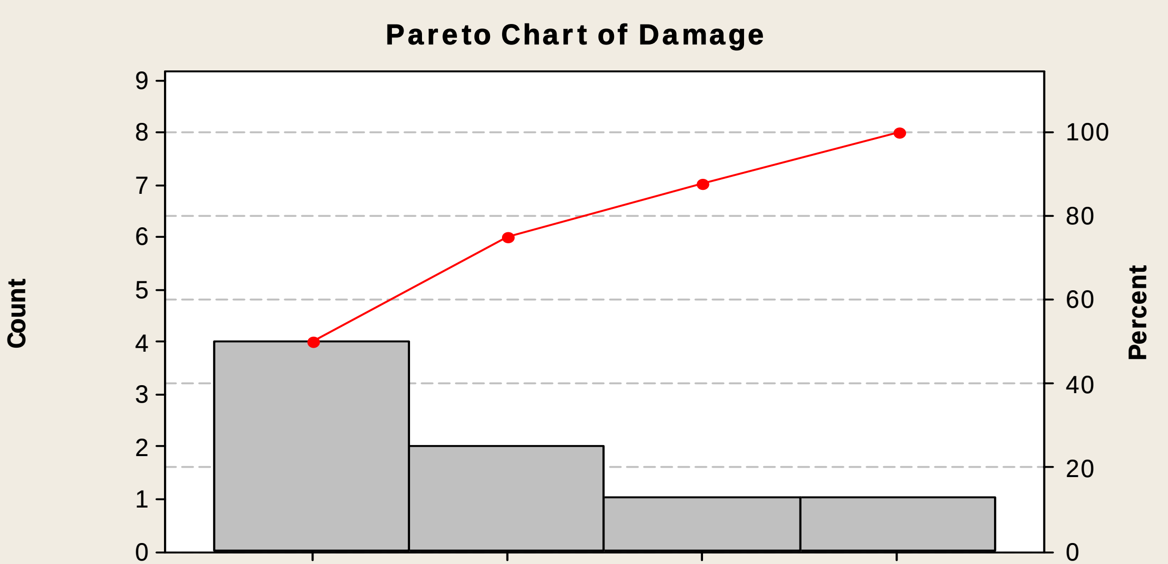
Process D – Inspection 100# in – 95# out 95%

Calculate the Rolled Throughput Yield (RTY) for the above process.

Pareto Charts

Pareto Charts

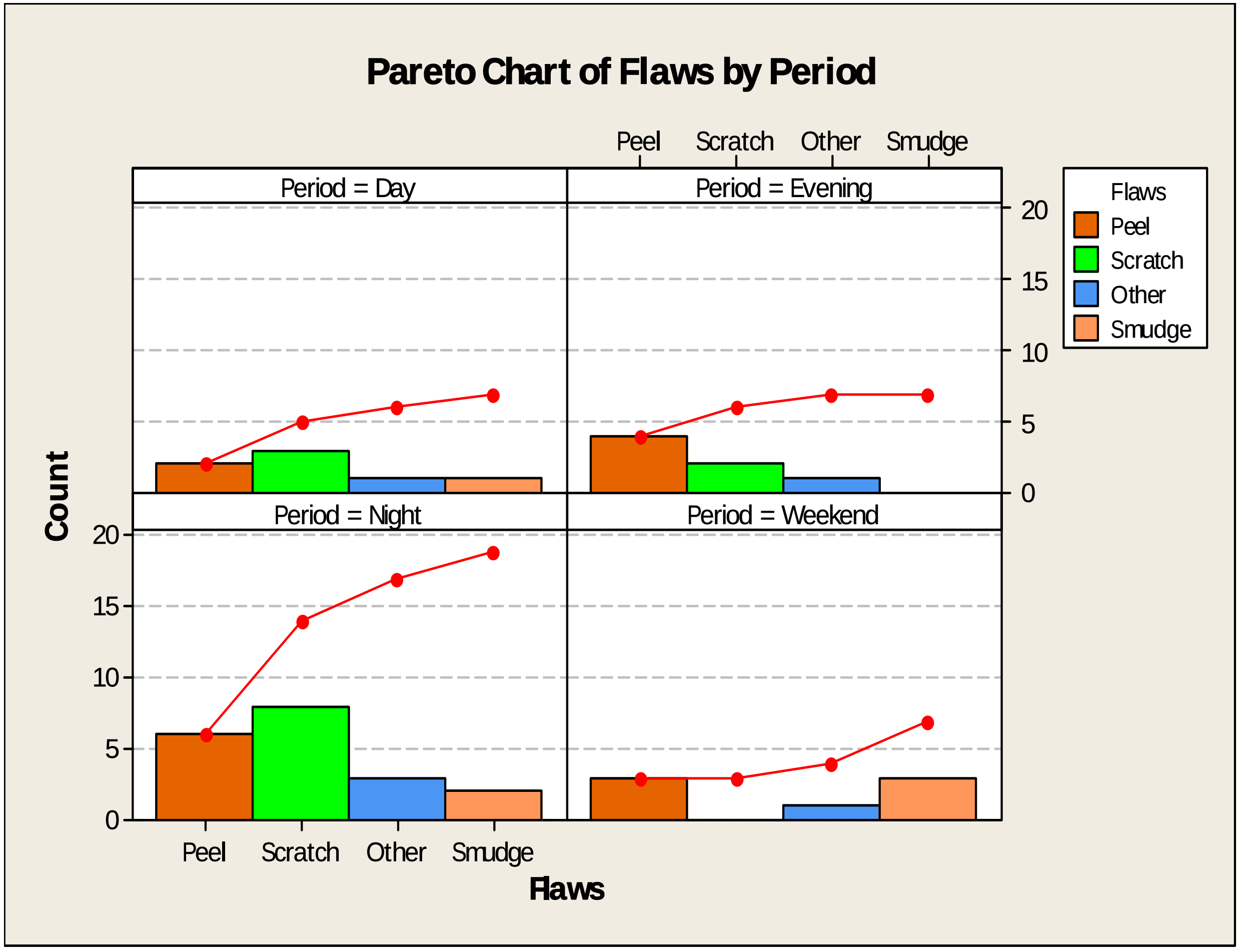
- Pareto Diagrams are an essential tools to help prioritize improvement targets. Paretos usually allow us to focus on the 20% of the problems that causes 80% of the poor performance.



Damage	Scratch	Chip	Bend	Dent
Count	4	2	1	1
Percent	50.0	25.0	12.5	12.5
Cum %	50.0	75.0	87.5	100.0

<u>Interpreting the results:</u>
Focus on improvements to scratches and chips because 75% of the damage is due to these defects.

Pareto Chart (Second Level)



Interpreting the results:
The night shift is producing more flaws overall. Most of the problems are due to scratches and peels. You may learn a lot about the problem if you examine that part of the process during the night shift.

You should drill down using third level, fourth level, etc., as far as it makes sense in solving your problem.

Project Charter

Project Charter

The Project should be defined through a Problem Description/ Project Objective and include:

- PPM or DPMO Baseline data
- Cost of Poor Quality (COPQ)
- Rolled Throughput Yield (RTY)
- Inventory or
- Other Appropriate Metric

SIX SIGMA PROJECT STATUS

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Project Status Summary Report

Project Details

Black Belt :	Arpit Upadhyay	Project No.	B 004
Company/Plant:	Bundy India Ltd., Baroda	Product:	DW tube
Process :	Double Wall tube manufacturing	Process Owner :	S.H. Pathak
Champion:	Vinod Dhar, Sukhdev Narayan	Master Black Belt	R. K. Arora
Process Team :	S.H. Pathak, Jogesh Shah, M. Prejith		
Problem Decsription:	To improve the produtivity on DW Line from 28471 to 47295 mtrs./shift		

Status Summary

Status:	In Progress
Status Date:	30.08.06
Review Date:	30.08.06
Last Review Date:	22.06.06
Start Date :	10.01.06
End Date :	

Metrics

	Business Metric(s):	Baseline	Current	Target
1	Critical to Delivery	28471 mtrs/shift	30442 mtrs/shift	47295 mtrs/shift
2	Critical to Cost		3.52 Lacs	99.06 Lacs/Annum
3				
	Z-Score			
	Projected Savings:		3.52 Lacs	99.06 Lacs/Annum

Y and Complementary Ys

1	Improve OEE
2	Increase Availability
3	Reduce Down time

Constraints/Special Conditions

1. Target Productivity calculated based on 90% Efficiency and 7.45 hrs working time(Mini clean time reduced).

MileStones

	Define	Measure	Analyze	Improve	Control
1	Team	MSA	1st level cause	Statistical Solutior	Monitoring
2	Metrics	Baseline Capability		Optimum Solution	Standardization
3	Process	Process Map	Root Cause	Implement Solutio	Train
4	Charter	X Shortlisting		Validate Solution	Maintain

Preliminary Plan

Phas	Target Date	Actual Date
D	13.01.06	21.01.06
M	03.02.06	18.02.06
A	20.03.06	01.04.06
I	20.06.06	
C	20.07.06	

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Team Selection (ARMI)

Team Selection (ARMI)

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The Six Sigma Team shall include following members.

- **A R M I**

Approver	Resources	Members	Interested Party
Champion	Maser Black Belt	Black Belt	Stake Holder
Executive		Green Belt	Customer
		Process Owner	Supplier

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Top Level Process Map (SIPOC)

Top Level Process Map

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Top Level Process Map – the basic steps or activities that will produce the output – the essentials, without any extras. Everyone does these steps – no argument.

- **The Top Level Flow Map is the minimum level of process flow mapping required in order to begin a FMEA**

Top Level Process Map

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List General Input and major Customer Key Output Variables

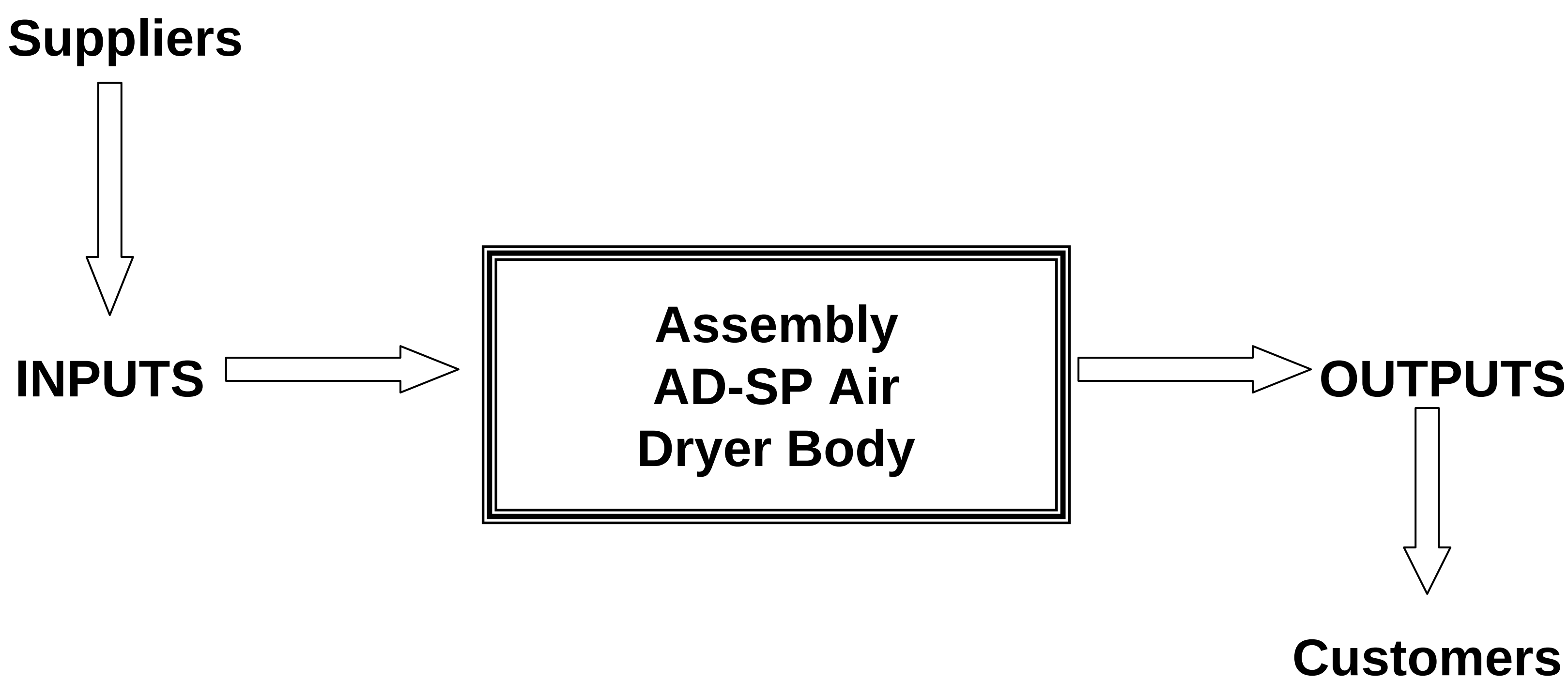
INPUTS → **Assembly AD-SP Air Dryer Body** → **OUTPUTS**

Inputs:
- Assembly Labor
- Procedures
- Materials
- Equipment, Fixtures
- Environment
- Cleanliness
- Rework

Outputs:
- Part to Print
- Performance to Spec
- Visually acceptable
- Leak Free
- Identified
- Clean
- Packaged for use
- Consistent standard

Top Level Process Map

Remember that processes are also affected by elements that feed into and receive from the process



This is known as the SIPOC Model

Basic Statistics

Statistics

- **The Science of:**
  - **Collecting,**
  - **Describing,**
  - **Analyzing,**
  - **Interpreting data…**

And Making Decisions

Type of Data

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- Attribute Data (Qualitative)
  - Categories like Machine 1, Machine 2, Machine 3
  - Yes, No
  - Go, No Go or Pass/Fail
  - Good/Defective
  - On-Time/Late
  - Discrete (Count) Data
    - # of Maintenance Equipment Failures, # of freight claims
- Variable of Continuous Data (Quantitative)
  - Decimal subdivisions are meaningful
  - Cycle Time, Pressure, Conveyor Speed

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Measures of Central Tendency

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- What is the Middle Value of Distribution?
  - Median
- What value represents the distribution?
  - Mode
- What value represents the entire distribution?
  - Mean ($\bar{x}$)
- What is the best measures of central tendency?

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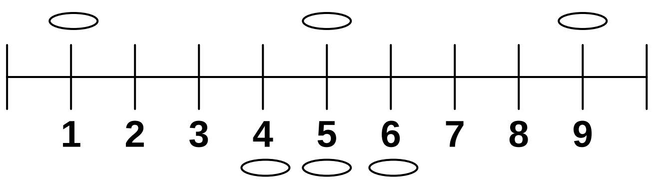
Data Distributions

- Mean: Arithmetic average of a set of values
  - Reflects the influence of all values
  - Strongly Influenced by extreme values
- Median: Reflects the 50% rank – the center number after a set of numbers has been sorted from low to high.
  - Does not include all values in calculation
  - Is “robust” to extreme scores
- Mode: The value or item occurring most frequently in a series of observations or statistical data.

Measure of Central Tendency - Mean

- Find the value of "n" and "$\overline{X}$" for the following 2 distribution.



n = $\overline{X}$=

n = $\overline{X}$=

Are the 2 Distributions Same?

What is the Difference?

Measures of Variability - Spread

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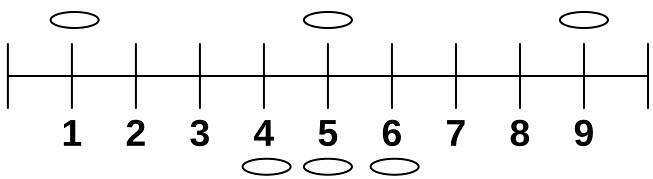
- **Range "R" = Max – Min is an easy measure of Spread**



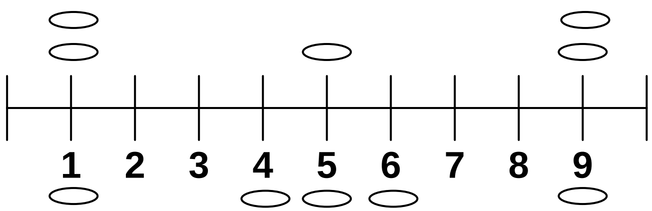
n = $\bar{X}$= R=

n = $\bar{X}$= R=

Is Range a good Measure of Variability?

- Find the value of "n", "$\bar{X}$" and "R" for the following 2 distribution.

Do the 2 distributions have same Variability?



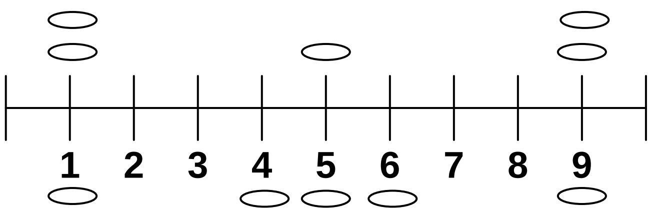
n = $\bar{X}$= R=

n = $\bar{X}$= R=

How do we measure average variability from the Center?

Measures of Variability (Spread)

- **Calculate Variance & Standard Deviation for these 2 Distributions.**



n = $\bar{X}$= R= V= S=

n = $\bar{X}$= R= V= S=

Measures of Variability

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- The Range is the distance between the extreme values of data set. (Highest – Lowest)
- The Variance(S^2) is the Average Squared Deviation of each data point from the Mean.
- The Standard Deviation (s) is the Square Root of the Variance.
- The range is more sensitive to outliers than the variance.
- The most common and useful measure of variation is the Standard Deviation.

Sample Statistics vs. Population Parameters

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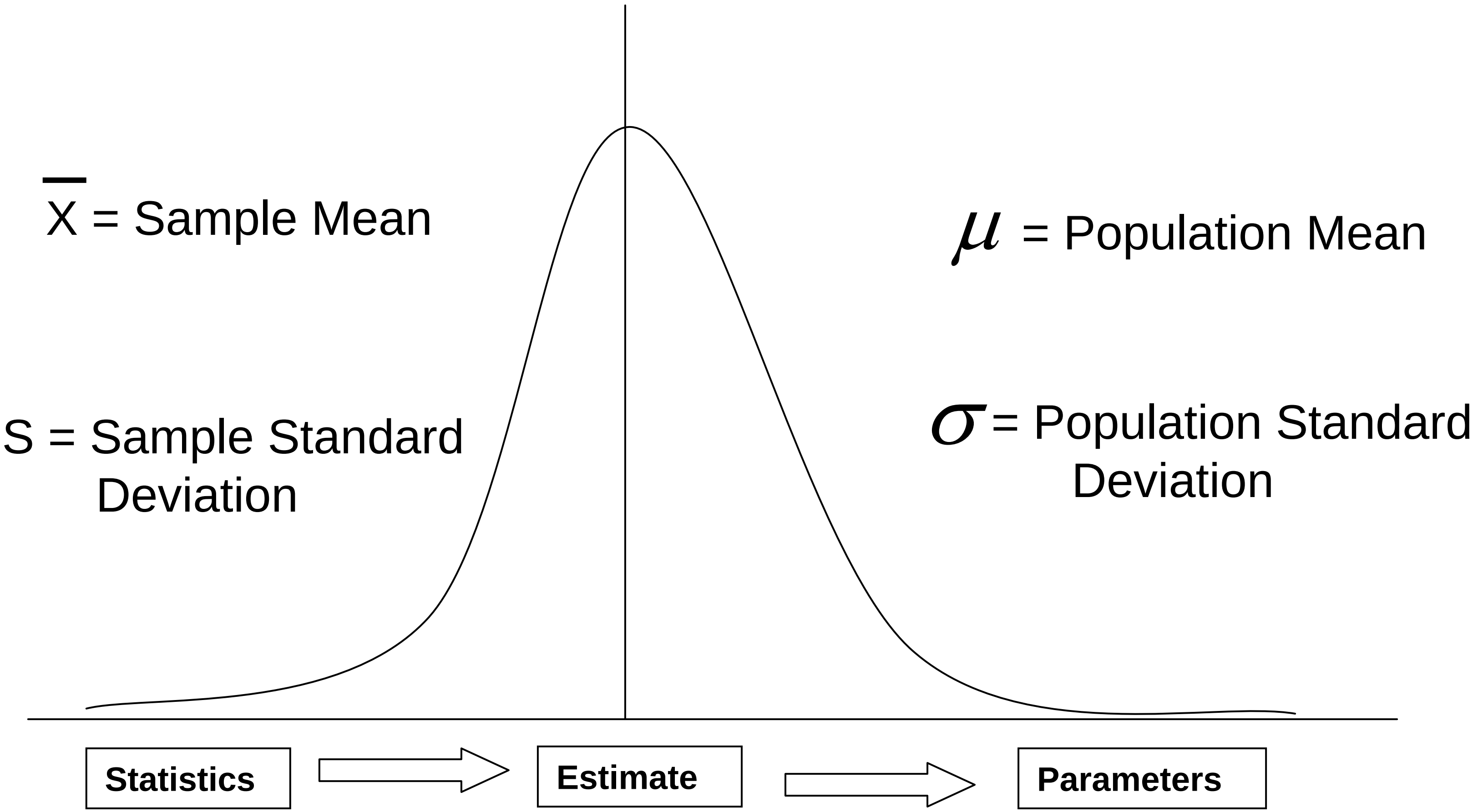

Statistical Calculations (Sample)

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Mean

$$\overline{X} = \frac{\sum_{i=1}^{n} Xi}{n}$$

Variance

$$S^2 = \frac{\sum_{i=1}^{n} (Xi - \overline{X})^2}{n-1}$$

Standard Deviation

$$\sigma = \overline{R} / d_2$$

N	d_2
2	1.128
3	1.693
4	2.059
6	2.326

Standard Deviation

$$S = \sqrt{\frac{\sum_{i=1}^{n} (Xi - \overline{X})^2}{n-1}}$$

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Statistical Calculation (Population)

Mean

$$\mu \approx \overline{X}$$

Variance

$$\sigma^2 = \frac{\sum_{i=1}^{n} (Xi - \overline{X})^2}{n}$$

Standard Deviation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (Xi - \overline{X})^2}{n}}$$

Probability Density Functions (Shape)

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- The Shape of the distribution is shown by the probability Density Function.
- The Y axis is Probability Density and the X axis is Data Values
- Area Under the curve Represents the probability of finding a data point between 2 Values.
- Probability Density Function Defines the interrelation between the center and the spread.
- The distributions with known function are called Parametric and those with unknown functions are called Non-Parametric

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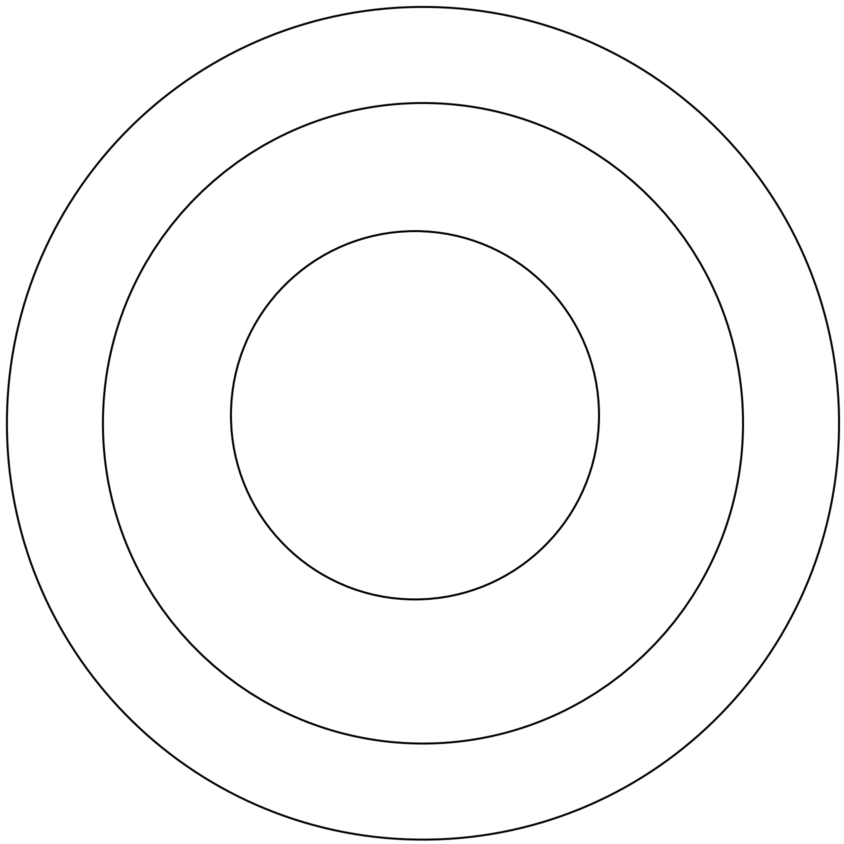
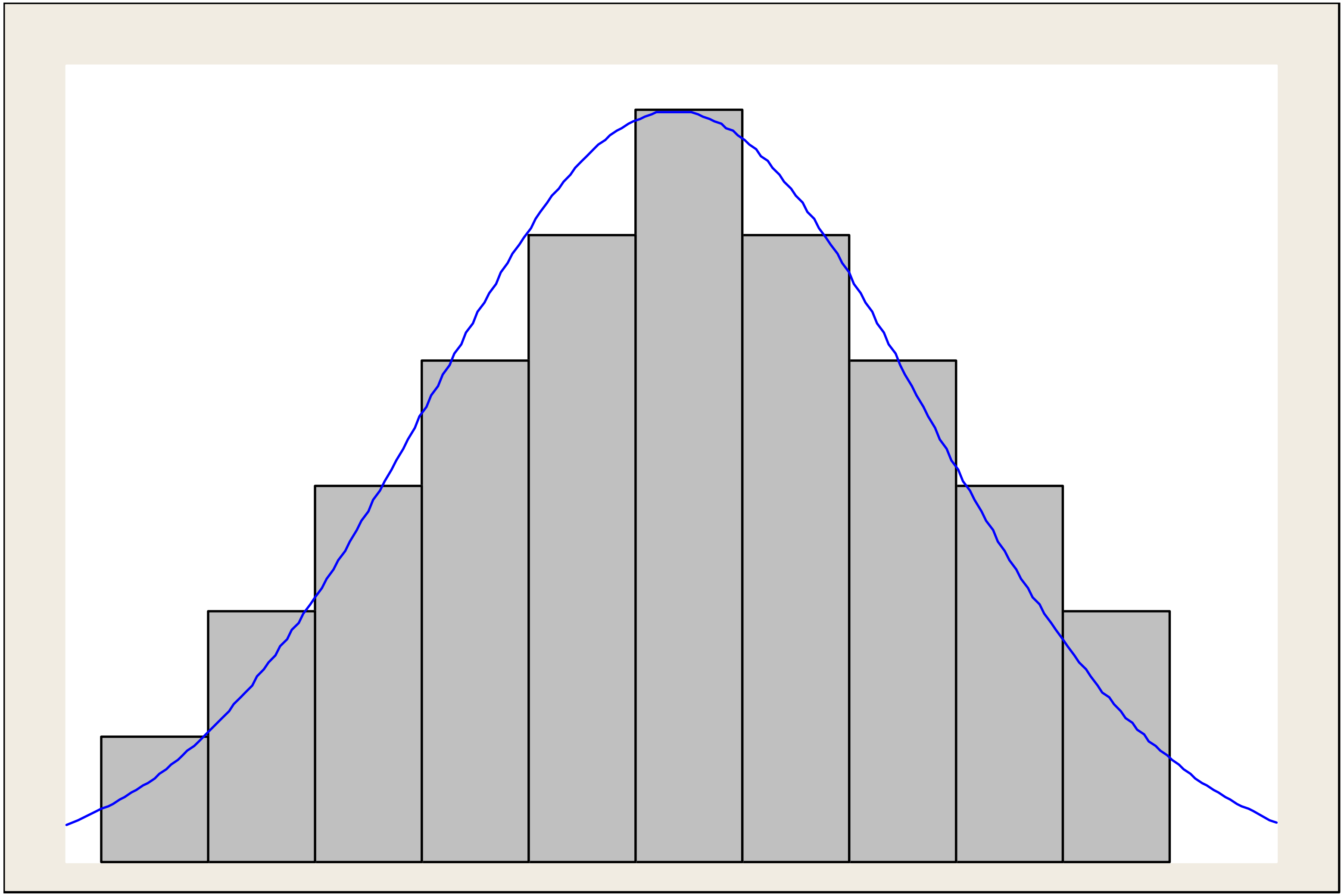
Distribution for a Targeted Process

- **If an Expert Marksman is Shooting, what place has the Highest Probability of getting a hit?**



Distribution for a Targeted Process



Properties of Normal Distribution

- **Normal Distribution is Symmetric**
  - Has equal No. of Points on both Sides
  - Mean Median and Mode Coincide
- **Normal Distribution is Infinite**
  - The chance of finding a point outside tolerance is not absolutely Zero.
  - We need to define a practical Limit of the Process

Properties of Normal Distribution

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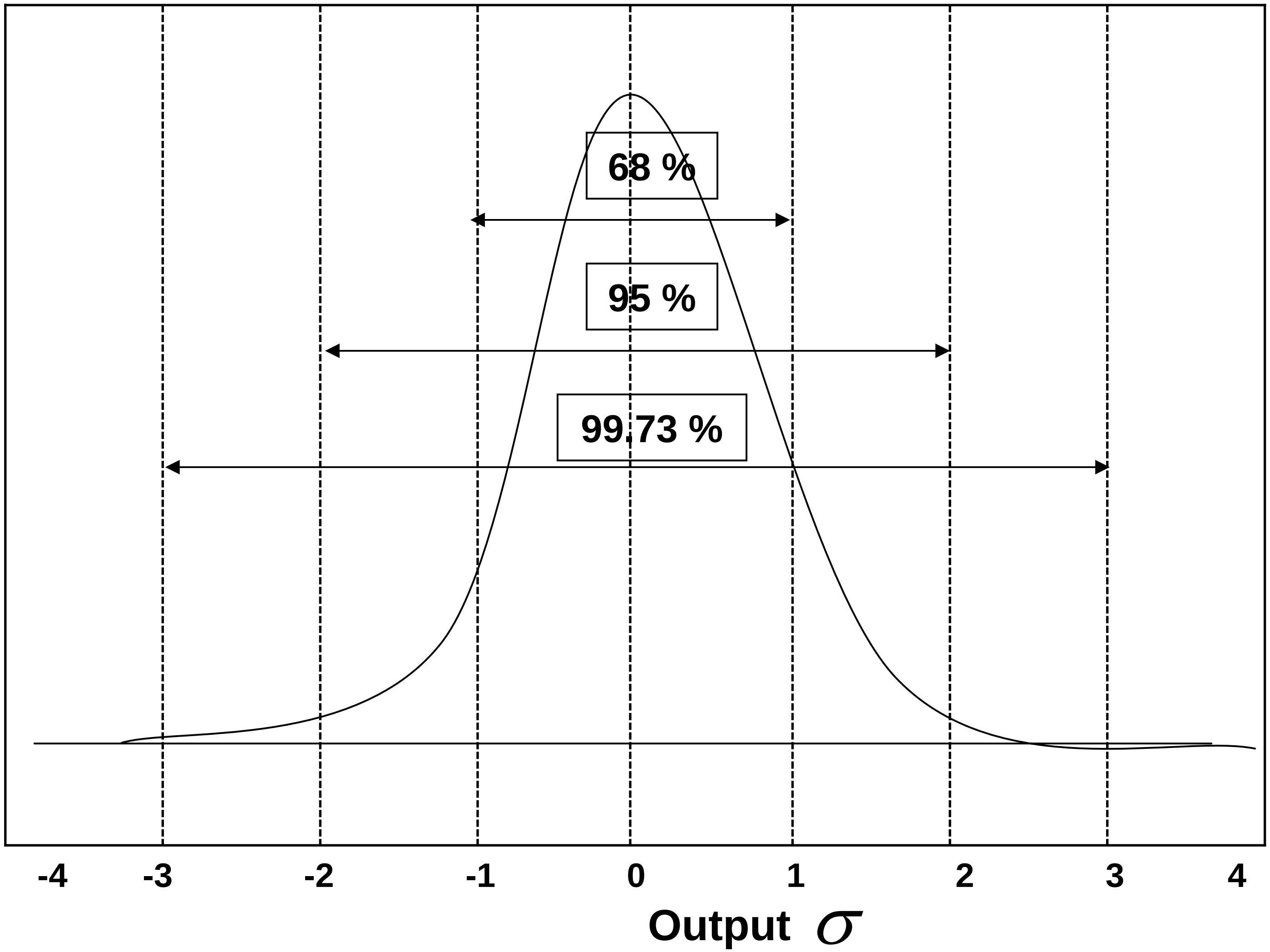
- **Normal Curve & Probability Areas**



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Let's Summarize…

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- We need data to study, predict and improve the processes.
- Data may be Variable or Attribute.
- To understand a data distribution, we need to know its Center, Spread and Shape.
- Normal Distribution is the most common but not the only shape.

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Exercise-3

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- **Calculate the Mean, Median, Range, Variance & Standard Deviation for following data set.**

2, 2, 5, 6, 7, 9, 9

Capability Analysis

Do we NEED Metrics and Baseline?

- If we cannot measure it, we cannot improve it.
- Metrics Help us understand where we stand
- Metrics help us move in the right direction.
- Metrics provide objectivity to peoples' feelings and perceptions.
- Metrics provide a common language and help us share information without subjectivity, biases and confusions.
- Metrics help us set a common goal.

Baseline

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- When we start a long journey, we look at the mile stones to find out how far we have come…
- But, suppose, we did not know where we started, can we tell how far we have come?
- Base line sets a starting point of our journey.
- It is the first measure and tells us about as-is State.
- It also helps us to set targets and scope out project.

What do we need to Measure?

- We need to measure whatever is important to the project.
- We need to track the following metrics

1. Y
2. Business Metrics
3. Z Score

Why we need to Measure - Y

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- Y is the metric (CTQ/CTD/CTC) that we are focusing on. E.g.
  - PPM, No. of mistakes in a form, Dia Variation, Power Factor, etc.
  - Cycle Time, Lead Time, Inventory Level etc.
  - Maintenance cost, Utility cost etc.

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What we need to Measure - Business

- Business metrics are the justification for taking up a six sigma project and are required for management buy-in.
- Since Management is committing resources to the project, it needs to know what will be the business impact.
- One or more business metrics are required to maintain management focus on the project. Or else, it will be Six Sigma for the sake of Six
- Business metrics are best expressed in terms of money but could be any that give the big picture e.g.
  - COPQ, Customer Satisfaction Index, RTY exc.

What we need to Measure – Z Score

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- Z Score is the sigma level of the process.
- This is a common metric.
- It is used as common scale for measuring the extent of improvements.
- It also helps us benchmark against world class processes.
- A world class or Six Sigma process operates at 6 Sigma Levels or a Z Score = 6

While Setting The Metrics, Remember…

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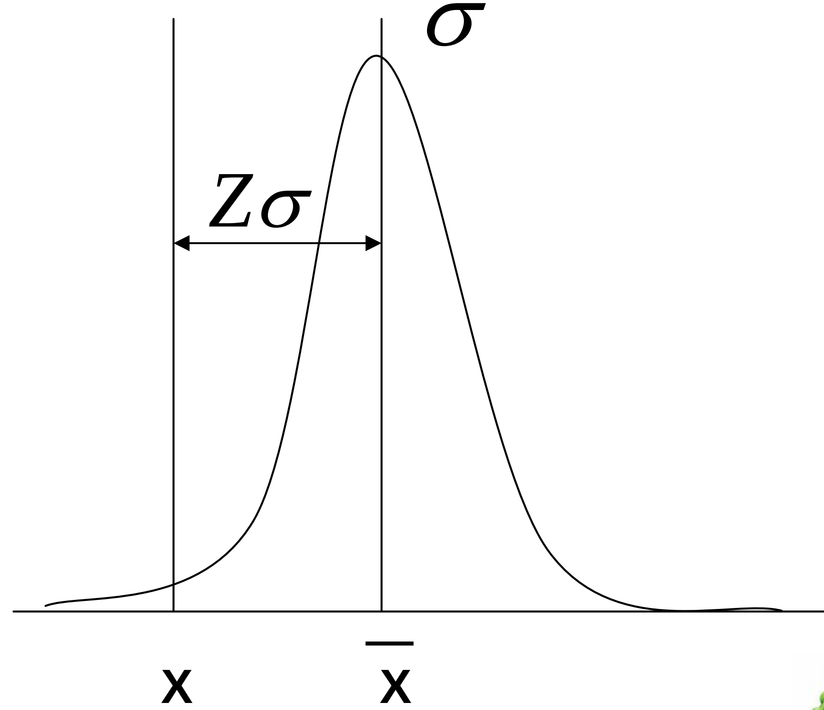
- The metrics Should be relevant to the Problem Statement.
- If both Variable and Attribute Metrics are available, prefer Variable metric.
- If your metric is a lean metric (inventory, cycle time etc.) first consider Lean tools.
- Sometimes counter-metrics are required to ensure proper output.
  - E.g. While Improving the metric – "Cycle Time", Counter-metric – "Defect rate" needs to be tracked so that the cycle time is not reduced at the expense of Quality

The Z - Transform

- **Z – Transform is used for a Normally Distributed process.**
- **It expresses how far value X is from the Center $\bar{X}$ in terms of σ**
- **E.g. for a normal distribution with $\bar{X}$ =70 and σ=10, a the value X=30 has z=(30-70)/10=-4**
- **In other words the point X=30 is 4σ away From the mean on –ve Side**

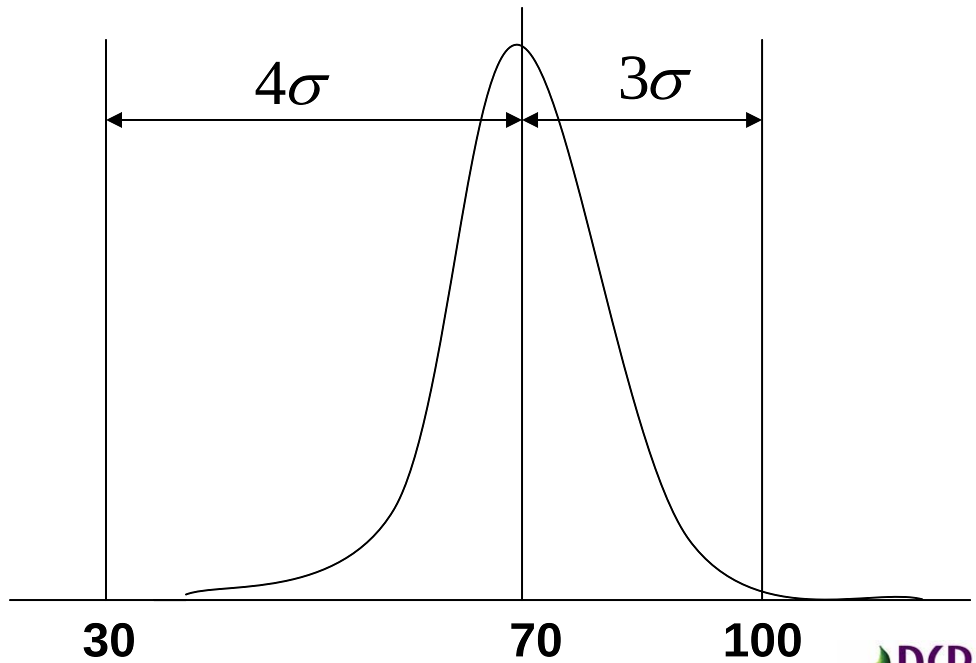
$$Z = \frac{X - \bar{X}}{\sigma}$$



The Z - Score

- If X was substituted by the Tolerance Limits (LSL & USL), Z will tell how many σs are there between Tolerance Limits and the center of the process.
- This is the Sigma level or the Z Score
- E.g. for normal distribution with $\bar{X}$ =70 and σ=10, LSL=30, Z_L=(30-70)/10=-4
- For USL=100,Z=3

$$Z = \frac{SL - \bar{X}}{\sigma}$$



But Wait….

- Every time we make a batch, do we get the SAME amount of Variation?
- Why does the process VARY from batch to batch?
- Can we prevent Batch to Batch variation TOTALLY?
- Data from WHICH of these batches should be taken for calculating Z Score?
- How much data is SUFFICENT?
- If I get different Z Scores for data collected at different times which of them is CORRECT?

Well

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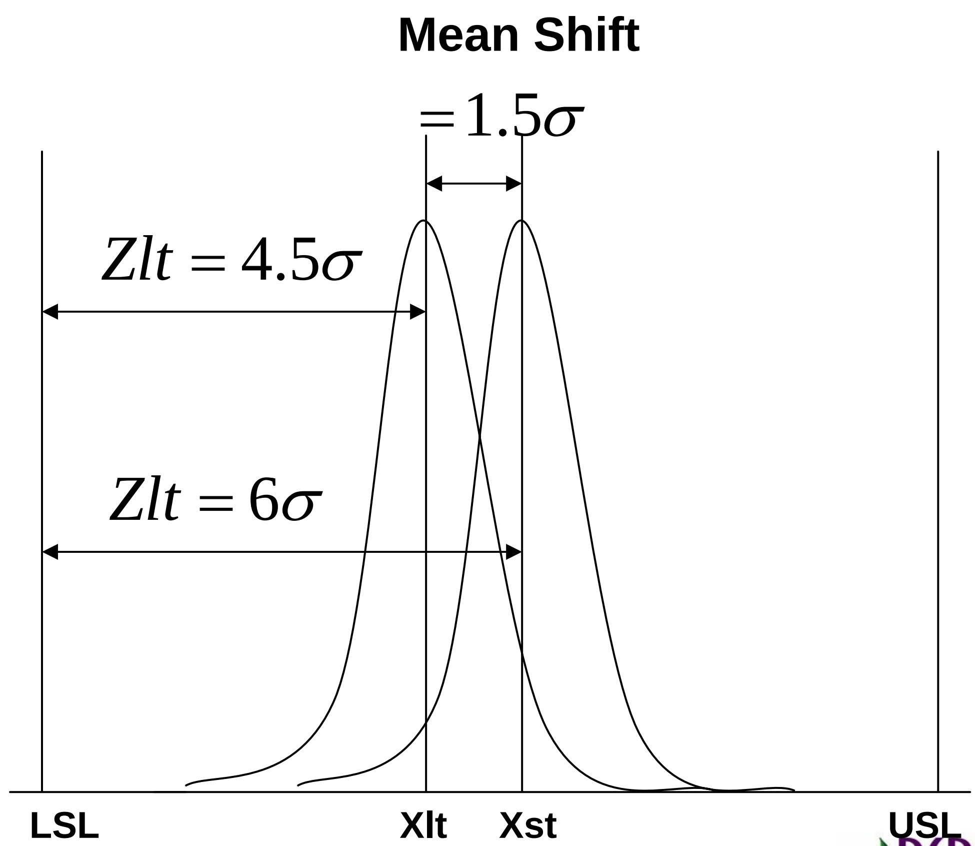
- Every time we make a batch, we may NOT get the same amount of Variation.
- The process varies from batch to batch due to MEAN SHIFT over a period of time.
- We can MINIMIZE this but not prevent it.
- This means that process will have more variation in LONG TERM when compared to SHORT TERM variation.
- A process is Six Sigma process when the short term Z Score is 6

Shot Term vs Long Term

- Mean of a process shifts over a period of time.
- This Shift is empirically observed to be 1.5
- So Zlt = Zst-1.5 Approx.
- And Zst =Zlt+1.5 Approx.
- A Six Sigma Process has Zst =6
- So a Six Sigma Process has Zlt =4.5



Capability vs Performance

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- Zst represents the CAPABILITY of the process whereas Zlt represents the PERFORMANCE over a period of time
- What is Capability?
  - Inherent ability
  - Due to Common Causes of Variation
- What is Performance?
  - Final Output
  - Due to Common as well as Special Causes of variation

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Causes of Variation

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- **Common Cause of Variation**
  - **Are an intrinsic part of the process**
  - **Give consistent Variation**
  - **Affect each data point equally**
  - **Are reflected in Unit to Unit Variation**
- **Special Causes of Variation**
  - **Are usually outside the process**
  - **Appear some time and not at the other times**
  - **Affect some data points more than others**
  - **Are reflected in Time to time Variations**

Causes of Variation - Examples

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- **Common Cause of Variation**
  - Usual Traffic on Road
  - Usual Play in the Slides of machine
  - Human Attentiveness
  - Variation in dimensions in a lot manufactured together.
- **Special Causes of Variation**
  - Accident on Road
  - Excess Play in Slide due to wear over time.
  - Illness
  - Variation due to Change in lot or supplier.

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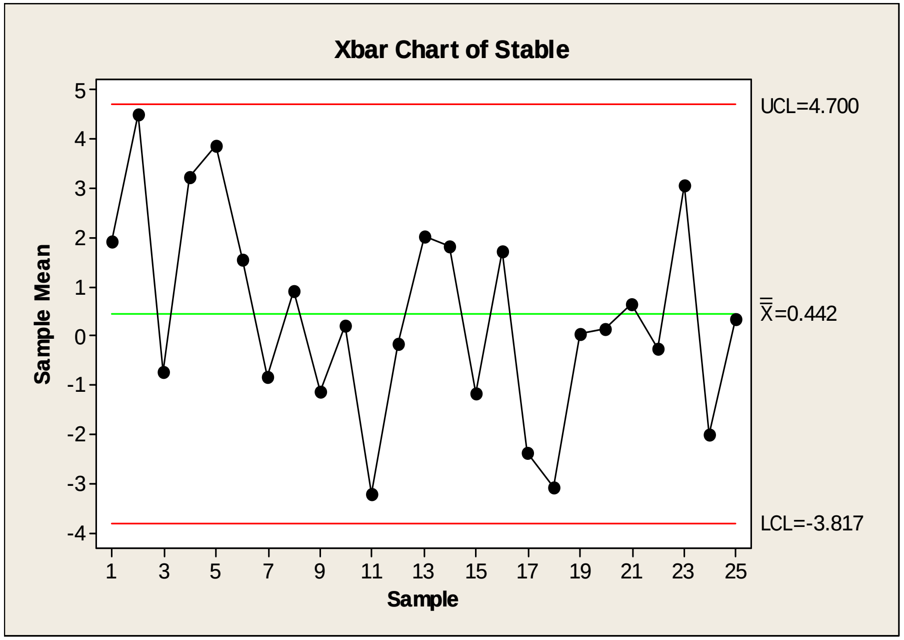
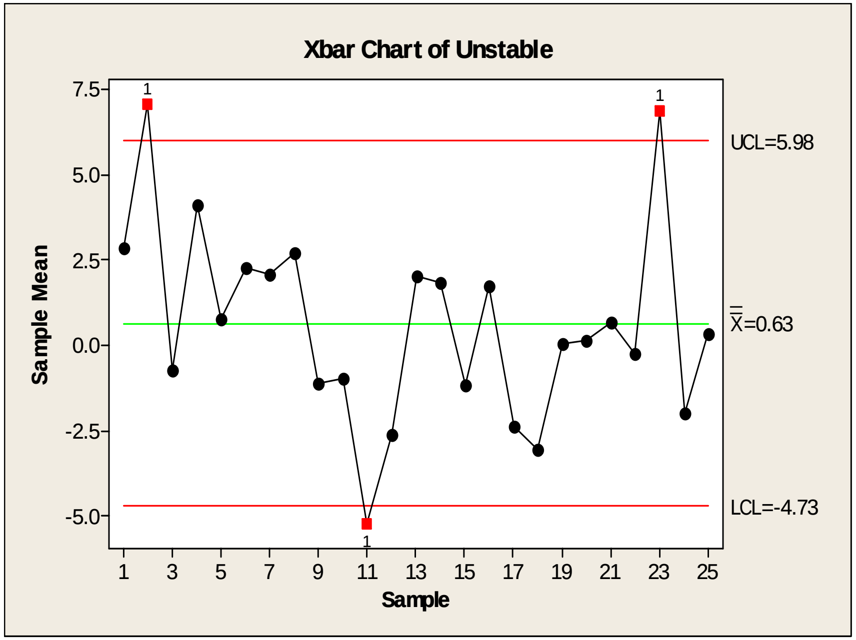
Stability

- When the variation is only due to common causes, the process is said to be Stable.
- A Stable Process has predictable variation.
- Special causes disturb the stability of the process due to which the Variation becomes unpredictable.
- A Stable process is also called a process in “Control”



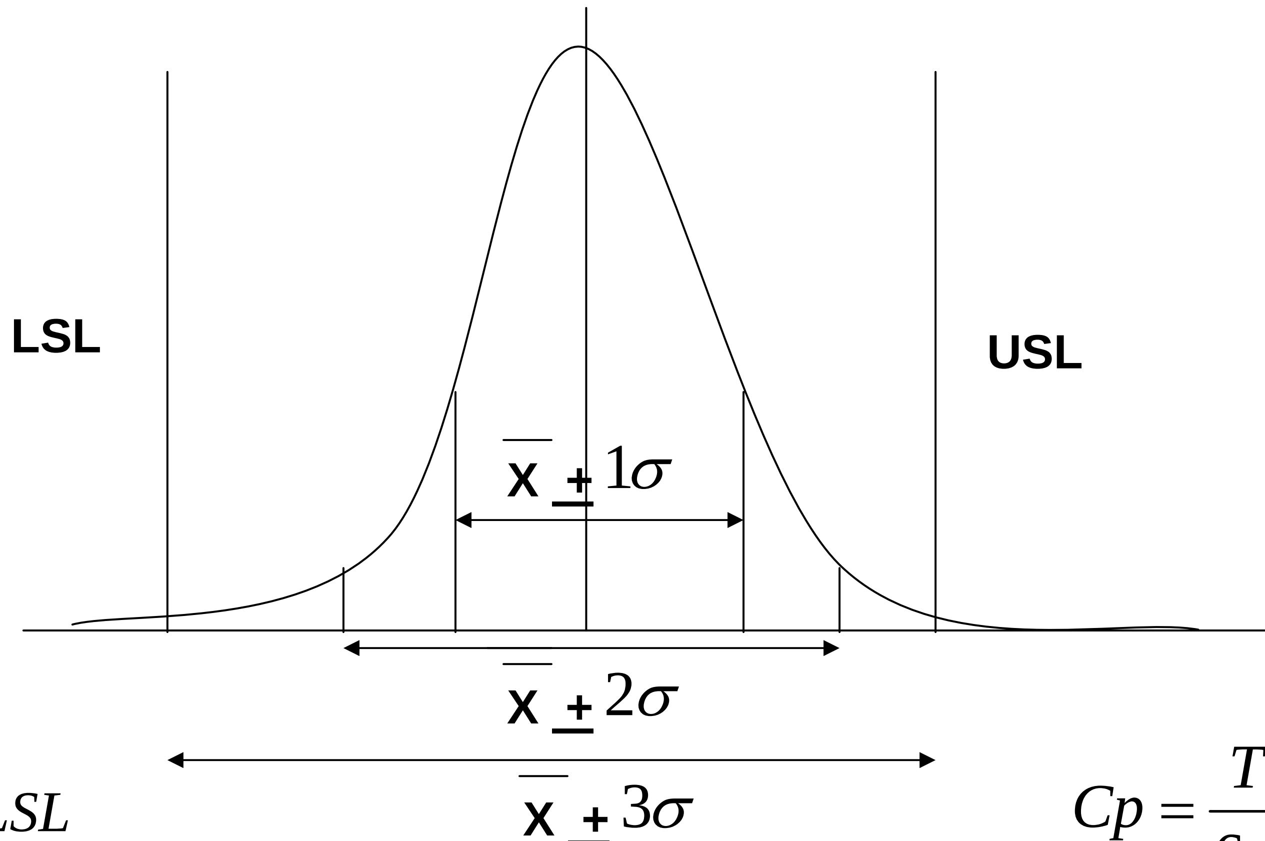


Capability vs Stability

- Capability has a meaning only when a process is stable.
- If a process is out of control, first we need to stabilize the process.
- Improvement in the inherent variation can be made only when the process is stable.
- Control Charts are used to study stability
- The first job of Six Sigma practitioner is to Identify and remove Special Causes of Variation.
- Once the process is made predictable, the next job is to identify the causes of inherent variation and remove them.

Calculating Capability

- **Capability Can be defined as** $\dfrac{\textbf{Tolerable Variation}}{\textbf{Process Variation}}$

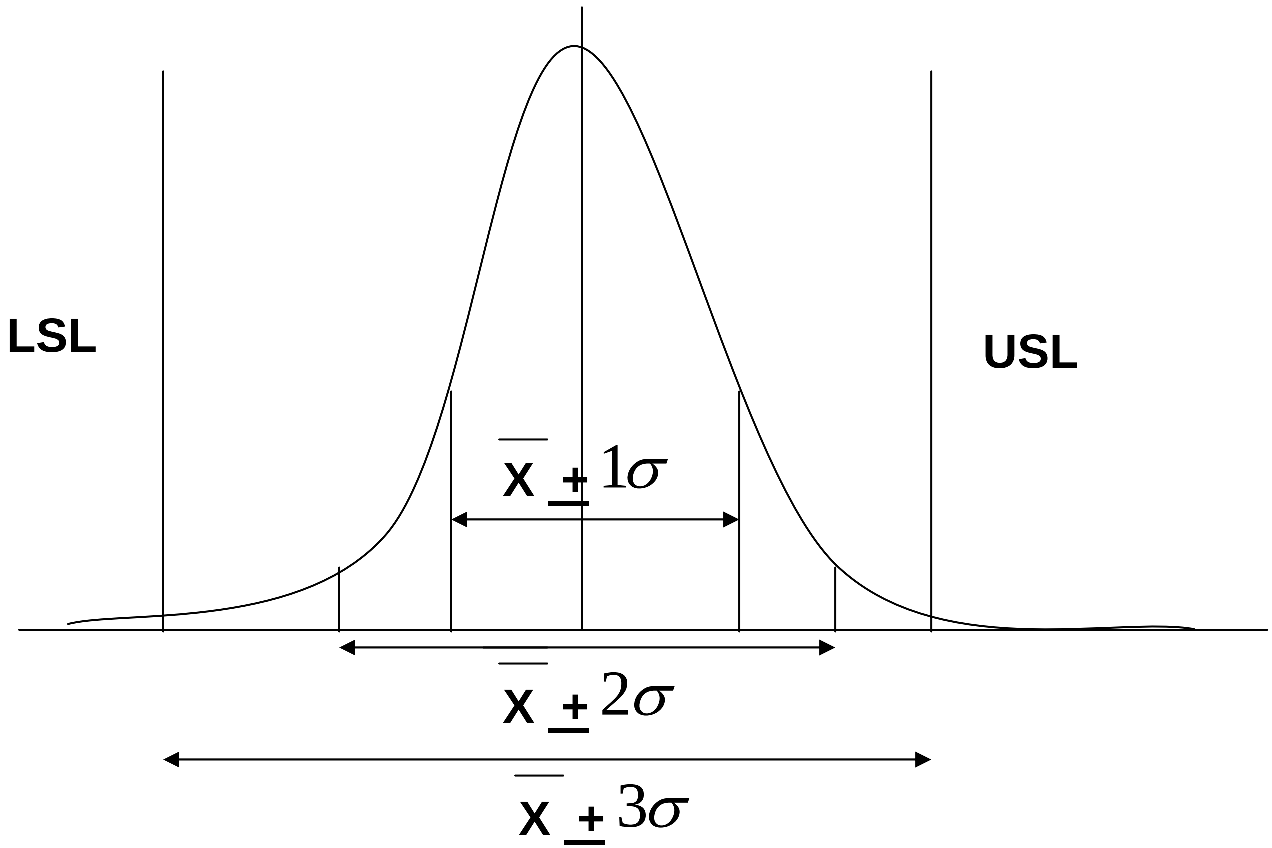


$$Cp = \frac{USL - LSL}{6\sigma}$$

$$Cp = \frac{T}{6\sigma}$$

Calculating Capability

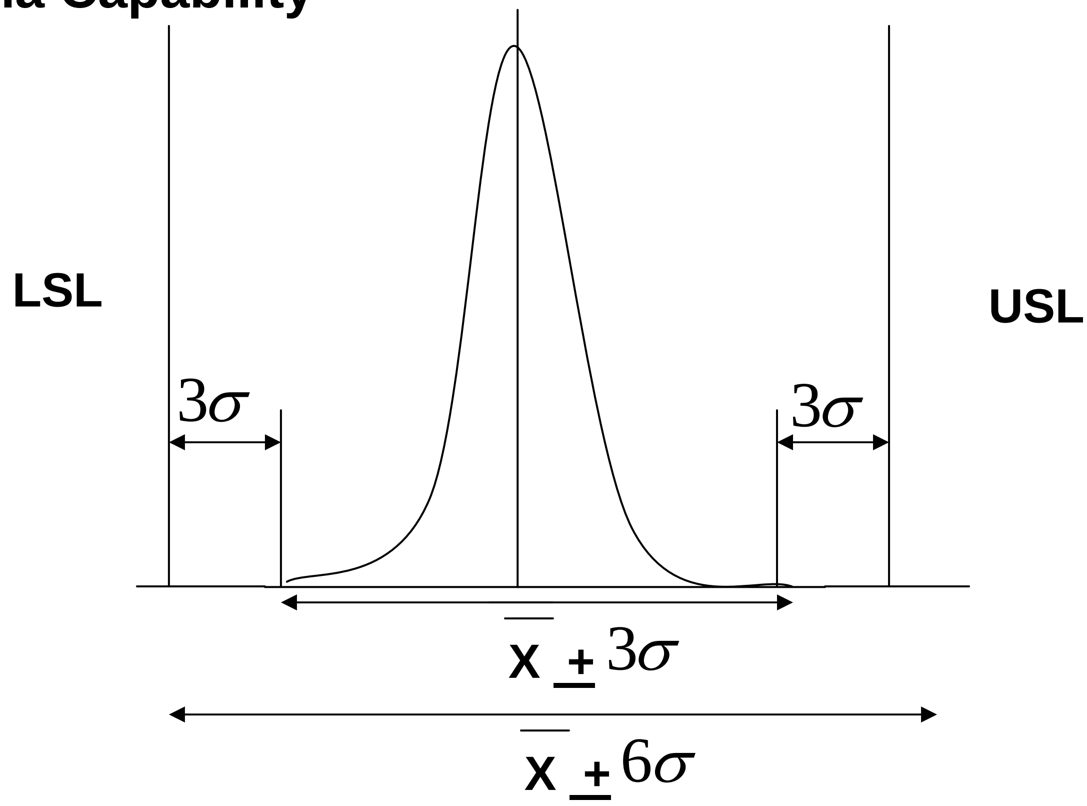
- **Marginal Capability**



$$Cp = \frac{T}{6\sigma} \qquad Cp = \frac{6\sigma}{6\sigma} \qquad Cp = 1$$

Calculating Capability

- **Six Sigma Capability**



$$Cp = \frac{T}{6\sigma} \qquad Cp = \frac{12\sigma}{6\sigma} \qquad Cp = 2$$

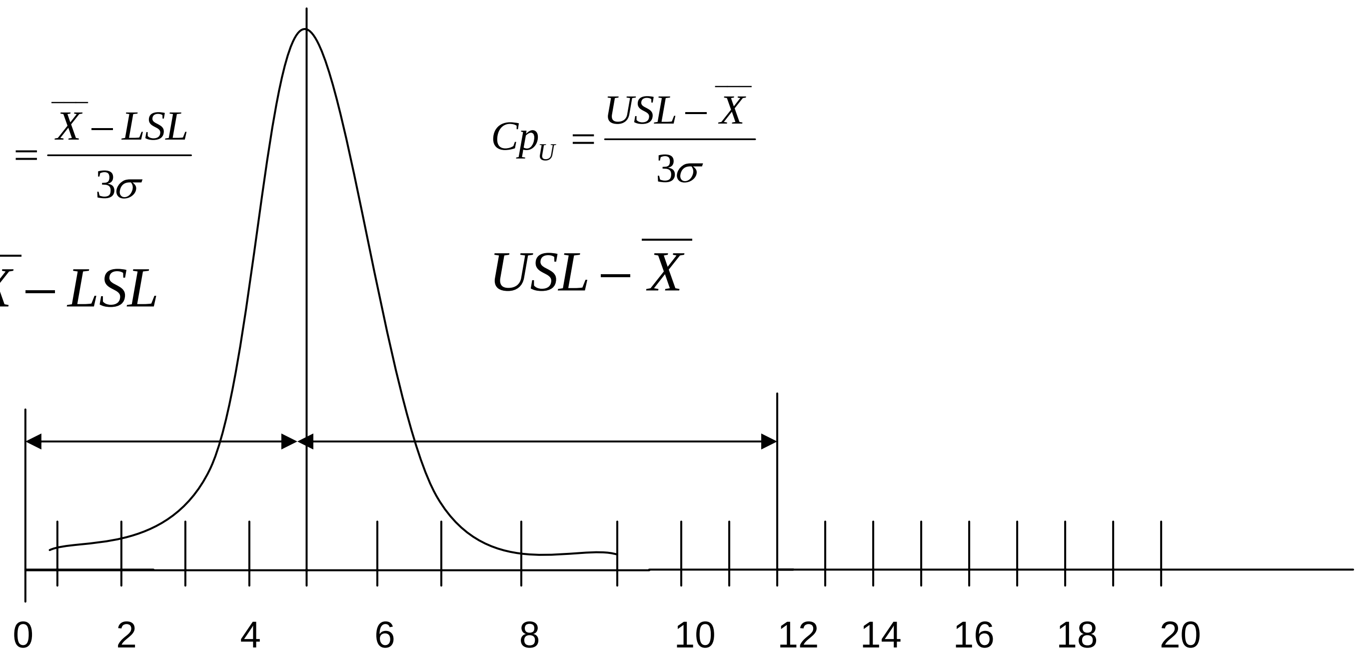
Calculating Capability

- **Calculate Cp from Upper & Lower Side**

$$Cp_L = \frac{\overline{X} - LSL}{3\sigma}$$

$$Cp_U = \frac{USL - \overline{X}}{3\sigma}$$

$$\overline{X} - LSL \qquad USL - \overline{X}$$



$$Cp_K = Min\left[\frac{\overline{X} - LSL}{3\sigma}, \frac{USL - \overline{X}}{3\sigma}\right]$$

Calculating Performance

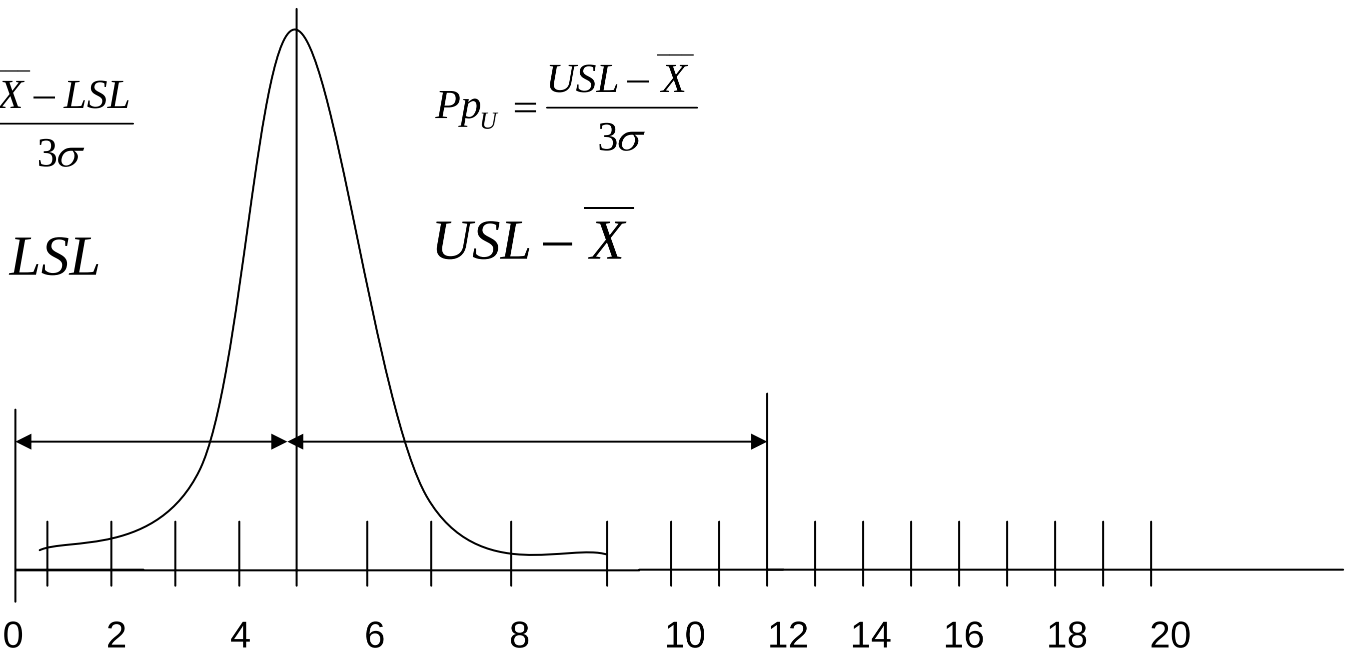
- **Calculate Cp from Upper & Lower Side**

$$Pp_L = \frac{\overline{X} - LSL}{3\sigma}$$

$$Pp_U = \frac{USL - \overline{X}}{3\sigma}$$

$$\overline{X} - LSL$$

$$USL - \overline{X}$$



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

$$Pp_K = Min\left[\frac{\overline{X} - LSL}{3\sigma}, \frac{USL - \overline{X}}{3\sigma}\right]$$

Capability vs Performance

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

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

$$Cp_K = Min\left[\frac{\overline{X} - LSL}{3\sigma}, \frac{USL - \overline{X}}{3\sigma}\right]$$

$$Pp_K = Min\left[\frac{\overline{X} - LSL}{3\sigma}, \frac{USL - \overline{X}}{3\sigma}\right]$$

- **If the formula are same, what is the difference?**
- **The difference is in Sigma calculation!**
- **Sigma in Capability covers Short Term Variation.**
- **Sigma in Performance covers Long Term Variation.**
- **How is the Data collection Different?**

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Capability Calculation

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- Capability covers short term variation.
- It requires data collected over short period of time.
- Small Subgroups of data (Generally 3-7 sample size) are taken.
- Data points within a subgroup need to be of consecutive output.
- Many subgroups are collected over a period of time.
- The average variation within a subgroup is considered to be present the inherent Variation.
- Sigma is calculated using $\sigma = \frac{\overline{R}}{d_2}$
- Should be used only when process is stable

Performance Calculation

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- Performance covers long term variation.
- It required data collected over long period of time.
- Data should represent more than one day, if possible more than a month of variation.
- If Data points are too many, one may randomly sample the data to represent all days and batches.
- The Root Mean Square variation is considered to to represent the Overall Variation.
- Sigma is calculated using

$$\sigma = \sqrt{\frac{\left(x_i - \overline{X}\right)^2}{n-1}}$$

- Should be used only when data is available over a long period of time.

Capability, Performance and Z Score

$$Cp_K = Min\left[\frac{\bar{X} - LSL}{3\sigma}, \frac{USL - \bar{X}}{3\sigma}\right]$$

$$Pp_K = Min\left[\frac{\bar{X} - LSL}{3\sigma}, \frac{USL - \bar{X}}{3\sigma}\right]$$

$$Z = Min\left[\frac{\bar{X} - LSL}{\sigma}, \frac{USL - \bar{X}}{\sigma}\right]$$

So

Z_{LT}=3 X Pp_k

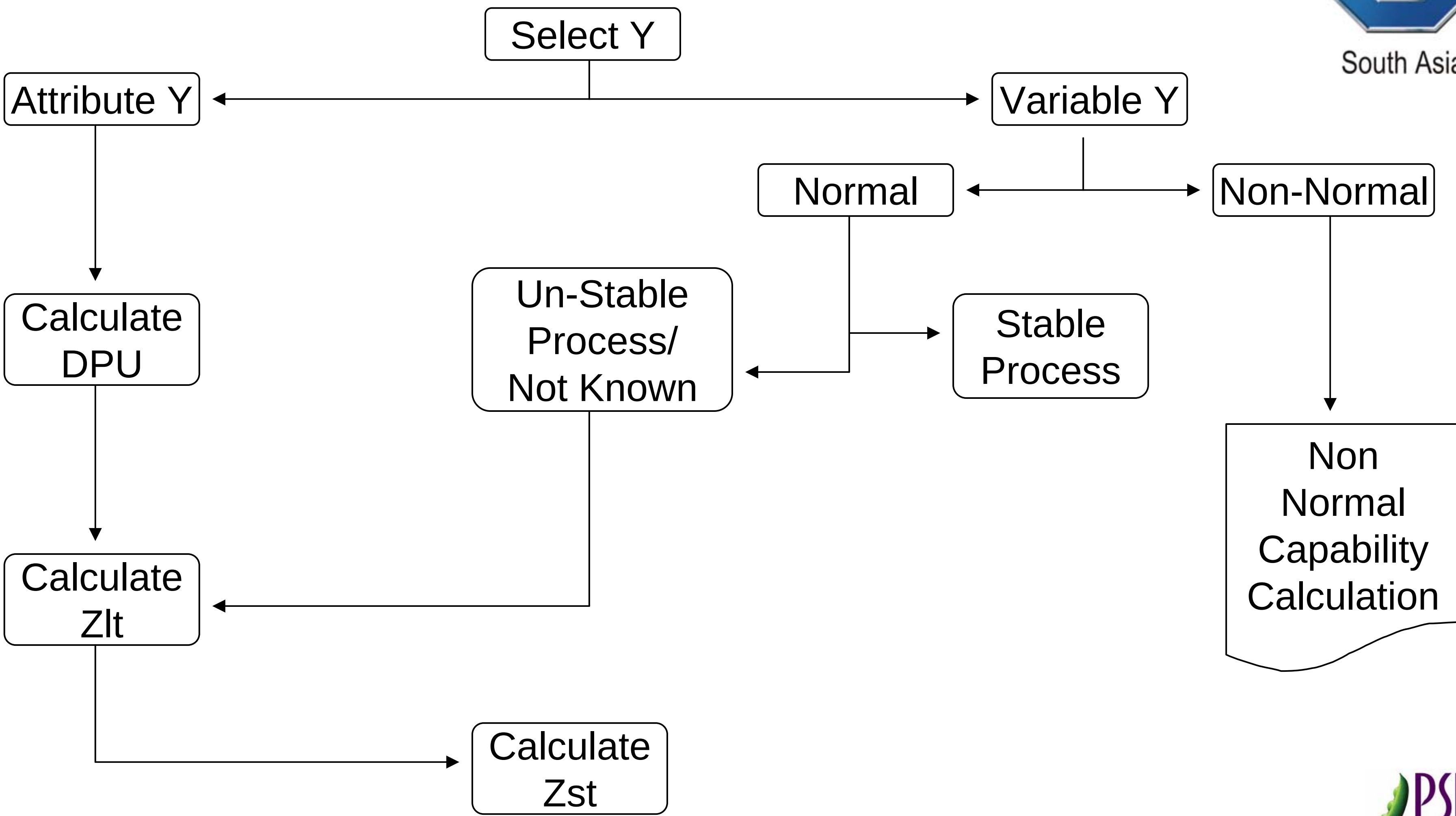
&

Z_{ST}=3 X Cp_K

- **If the process is Stable, Collect Short term data using Subgroups, Calculate Cpk and Zst=3xCpk**

- **If the process is Unstable or Stability is not known, Collect Long term data by random sampling, Calculate Ppk and Zlt=3xPpk. Convert it into Short Term bench mark Z by Zst=Zlt+1.5**

Z Score Calculation Road Map



Zst is the baseline Z score

Exercise-4

- Calculate the Z Score for the following processes.

1. Data of Length in machining process has been collected. The required length is 555 max. The Process has been behaving consistently for last 6 months. The data was collected for the first 5 pieces for each of last 35 batches. The mean of the data is 540.26857 & Standard deviation is 10.38606.

2. Data for Cycle Time of a molding process has been collected. The specification is 60-65 sec. The Process has been behaving erratically for last 8 months. The data collected for the first 5 pieces for each of last 30 shifts. The mean of the data is 64.03827 & Standard deviation is 0.54618.

Implementation of Six Sigma

Phases of Breakthrough Strategy

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Characterization
- Phase I: Process Measurement
- Phase II: Process Analysis

Optimization
- Phase III: Process Improvement
- Phase IV: Process Control

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Phase of Breakthrough Strategy

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Phase I: Process Measurement
- Identify KPIV's and KPOV's on Process Map/FMEA
- Establish Measurement System Capability
- Establish Process Capability Baseline

Phase II: Process Analysis
- Update Process Map, FMEA, Control Plan & Capability
- Identify Critical Input Variable
- Analyze Process data using Six Sigma Tools

Phase III: Process Improvement
- Verify and optimize Critical Input Variables
- Identify and Test Proposed Solutions
- Implement Solutions and Confirm Results

Phase IV: Process Control
- Standardization / Mistake Proofing
- Implement Process Controls and Verify Effectiveness
- Monitor Process by Control Plan—HOLD the Gains

Phase I: Process Measurement

Plan Project and Identify Key Process Metrics, Inputs and Outputs

- Project Selection Justification
- Business Metrics (RTY, COPQ, PPM)
- Process Mapping / Data Collection Process/Control Plan
- Cause & Effect Matrix / FMEA

Quantify Variation on Vital Few Variation Sources

- 3 Level Pareto charts
- Vital Few Variation Sources
- Gage Studies (GR&R)

Perform Short-term Capability Study

- Short-term and Long-term Capability
  - CpK, PpK
  - SPC Charts
  - Sigma (Z) Calculations

Phase II: Process Analysis

TÜV SÜD South Asia

Update Project Baseline and Status

- Project Status From
- Metric Graph with Goal Line
- Process Map / FMEA / Control Plan

Identify Root Causes of Variation

- Multi-Vari and Horizontal Root Cause Charts
- SPC Charts
- Fishbone Chart, Documenting Input Variables
- Hypothesis Tests to Verify Critical Input Variables
- List of Critical Input Variables
- List of Containment Actions

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Phase III: Process Improvement

Update Project Baseline and Status

- Project Status From
- Metric Graph with Goal Line
- Process Map / FMEA / Control Plan

Optimize Process

- Test and Verify Critical Input Variables
- Use Statistical Tools to Optimize Process
- Identify, Plan and Test Proposed Solutions
- Select Solutions and Confirm Results
- Implement Solutions and Improvement Plans
- Document Improvement Plans and Actions

Phase IV: Process Control

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Update Project Baseline and Status

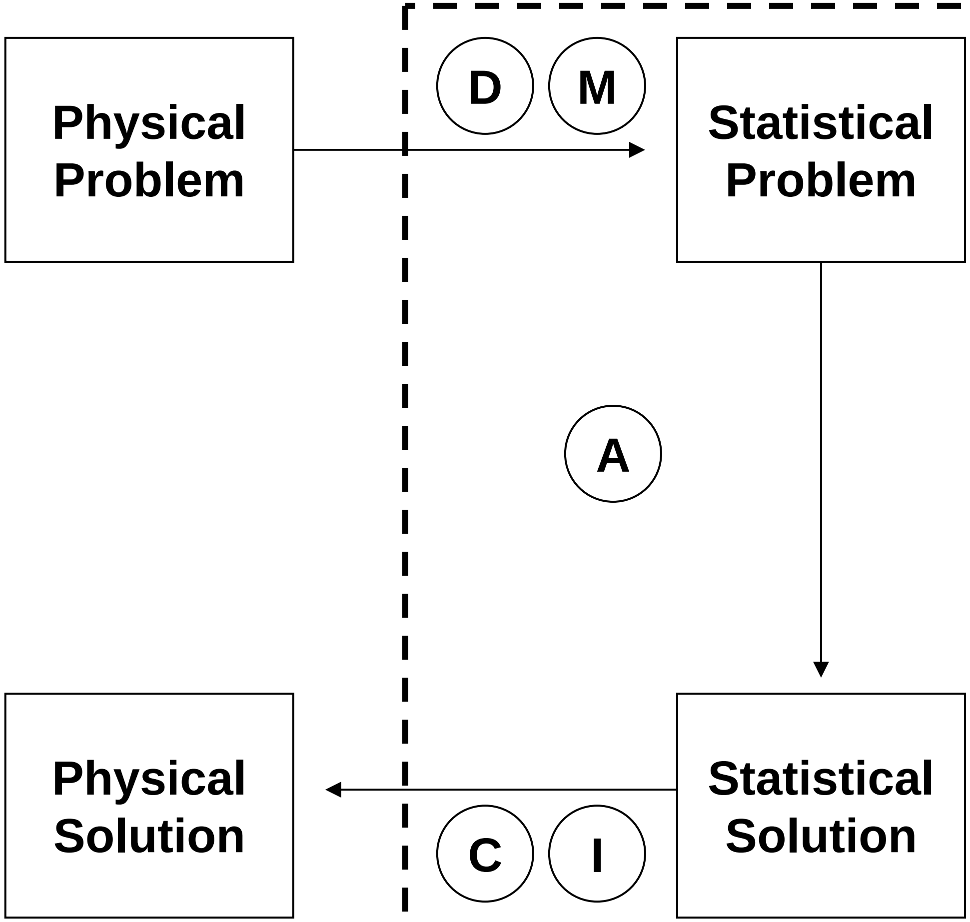
- Project Status From
- Metric Graph with Goal Line
- Process Map / FMEA / Control Plan

Optimize Process

- Each Standardization and Mistake Proofing
- Implement Process Controls
- Verify Effectiveness of Process Controls and System Improvements
- Monitor Process by Control Plan
- HOLD and GAINS

Statistical Problem Solving

South Asia



- Define the Problem in terms of Y and Probable Xs
- Measures the Extent of Problem

- Shortlist the Xs for analyses
- Collect Data
- Eliminate Xs that are not important
- Finalize Xs for Optimization

- Confirm the short listed Xs
- Find Y=f(X) or Best case for the selected Xs
- Identify Physical controls based on constraints
- Verify and Maintain new controls

THANK YOU