
Statistical Process Control
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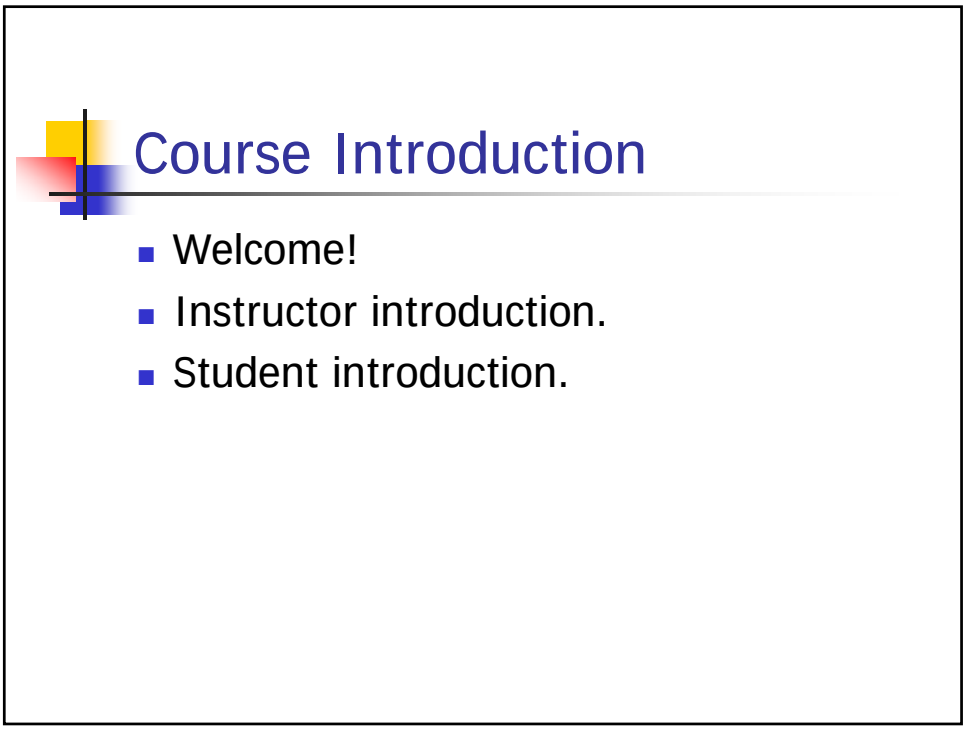

Course Introduction
Welcome!
Instructor introduction.
Student introduction.

## Learning Objectives

- Understand quality fundamentals.
- Differentiate between QC, QA, and TQM.
- Learn quality improvement tools.
- Learn SPC and reliability.
- Learn Cost of Quality.
- Understand ISO 9000:2000 QMS.
- Become aware of Excellence Models.
- Apply quality to oneself & organization.

## Our Objective

**You** Enjoy While **You** Learn

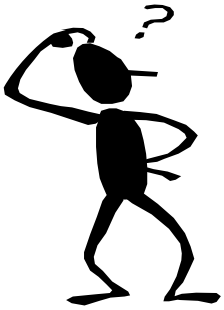
# CHAPTER ONE

## Introduction to Statistical Quality Control

## Meaning Of "Statistical Quality Control

| | |
|---|---|
| Statistical | With the help of numbers or data |
| Quality | We study the characteristics of the process |
| Control | In order to make it behave the way we want it to behave |

## What is Quality?



## What is Quality?

- "*fitness for use*" (Juran)
- "*conformance to requirements*" (Crosby)
- "*the totality of features and characteristics of a product or service that bear on its ability to satisfy given needs*" (ASQ)

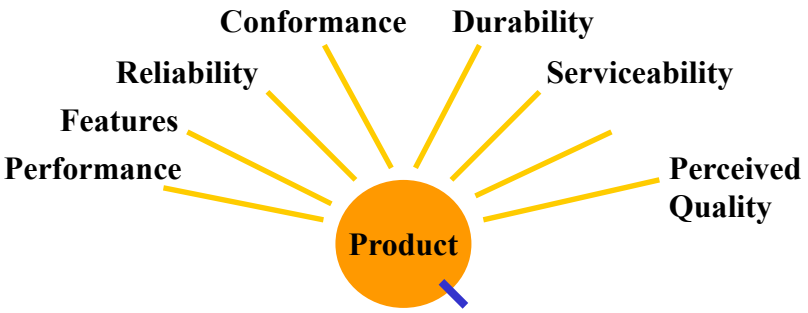
# Quality Aspects

- *Quality of design*
  - All goods and services are produced in various grades or various levels of quality.
- *Quality of Conformance*
  - How well the product conforms to the specifications and tolerances required by the design
- *Examples*
  - Car
  - Air condition

# Quality Characteristics

- *Physical*
  - Length, Weight, Voltage, Viscosity, etc.…
- *Sensory*
  - Taste, Appearance, Color, etc.…
- *Time Orientation*
  - Reliability, Maintainability, Serviceability, etc.…

# Quality Dimensions




*Source: Total quality and organization development by Lindsay and Petrick*

# Quality and Productivity

- *Example:*
- *100 product are produced in a machine, 75% is good and 25% is nonconforming. 60% out of 25% can be reworked at $4 per part. The direct manufacturing cost per part is approximately $20. Determine the cost/good part.*
- If you know that, a new process control procedure is implemented, the 25% is reduced to 5% nonconforming, and the 60% out of them can be reworked. Determine the cost/good part after the process control program is implemented.

# Quality Costs (1/4)

- *Prevention Costs*
  - Costs associated with efforts in design and manufacturing that are directed toward the prevention of nonconformance.
- *Examples*
  - Quality planning and engineering.
  - New products review.
  - Product/Process design

# Quality Costs (2/4)

- *Appraisal Costs*
  - Costs associated with measuring, evaluating, or auditing products, components, and purchased materials to ensure conformance to the standards that have been imposed.
- *Examples*
  - Inspection and test of incoming material.
  - Product inspection and test.
  - Materials and services consumed.
  - Maintaining accuracy of test equipment.

# Quality Costs (3/4)

- *Internal Failure Costs*
  - Costs are incurred when products, components, materials, and services fail to meet quality requirements and this failure is discovered prior to delivery of the product to the customer.
- *Examples*
  - Scrap
  - Rework
  - Retest
  - Failure analysis
  - Downtime

# Quality Costs (4/4)

- *External Failure Costs*
  - Costs occur when the product does not perform satisfactory after it is supplied to the customer.
- *Examples*
  - Complaint adjustment.
  - Returned product/material.
  - Warranty charges.
  - Liability costs.
  - Indirect costs.

## Quality & the Bottom Line

**Income Statement**

Right features
Competitive price
Higher Market share

**Revenue**

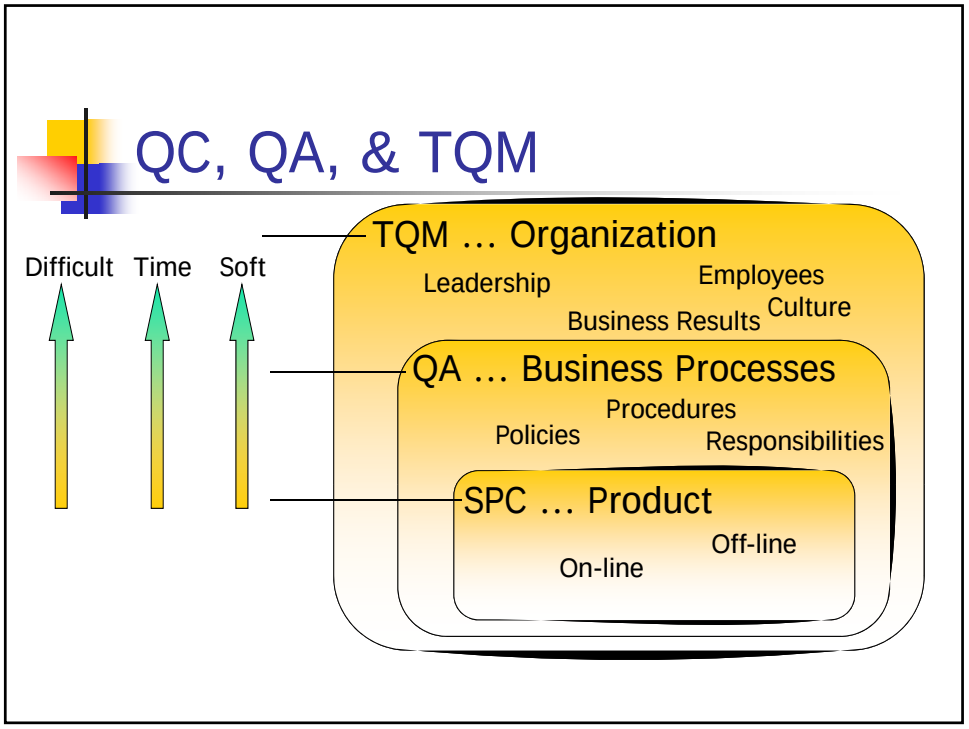
**- Cost**

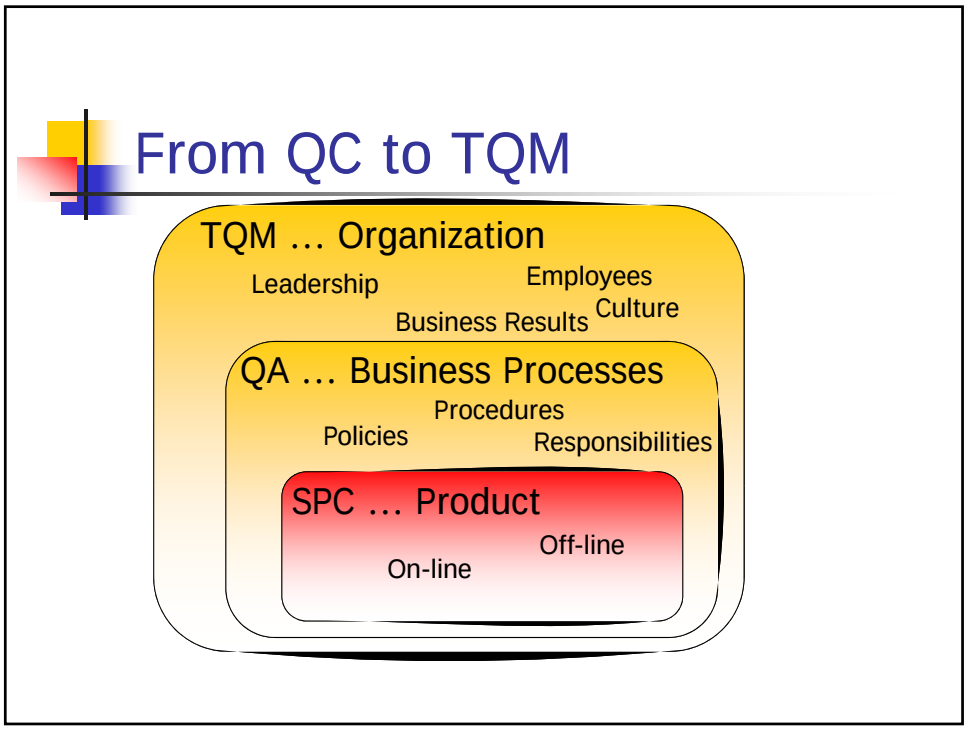
**= Profit**

Improved conformance
Reduced cycle time
Improved warranty
Less waste

## Quality Improvements

- *We may define quality improvement as a reduction in variability of processes and products.*
- *Variation can only be described in statistical terms.*


QC, QA, & TQM
Difficult
Time
Soft
TQM … Organization
Leadership
Employees
Culture
Business Results
QA … Business Processes
Procedures
Policies
Responsibilities
SPC … Product
Off-line
On-line

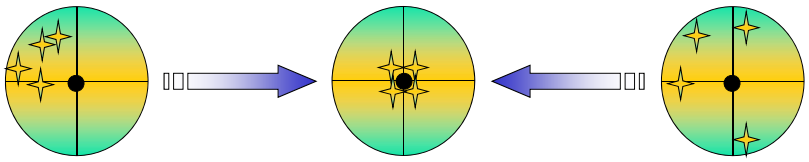

From QC to TQM
TQM … Organization
Leadership
Employees
Culture
Business Results
QA … Business Processes
Procedures
Policies
Responsibilities
SPC … Product
Off-line
On-line

# CHAPTER TWO

## Statistical Methods Useful in Quality Improvement

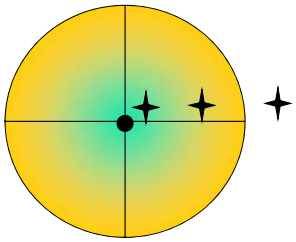
## Statistics: The Technical Language of Quality

- Quality is achieved if your product, service, and information are consistently on, or close to, target.

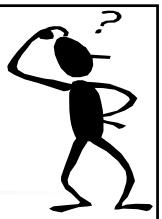


## Key Terms

- Specification/standard/requirement.
- Nominal/target value.
- Defective vs. non-defective.



## Examples: Standard, Target, & Defective

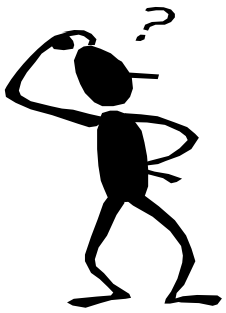


- Rod diameter spec. is 2 +/- 0.05 inch
- Satisfaction is above 3 on a scale from 1 to 5.

| Example | Target | Standard | Defective |
|---|---|---|---|
| Rod | | | |
| Satisfaction | | | |

## Who Sets the Standard?

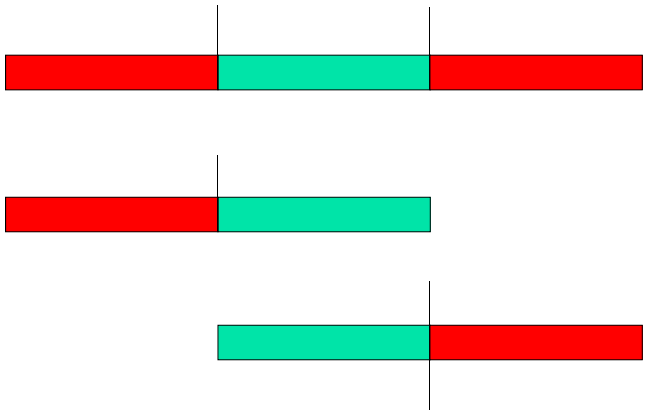
- _____
- _____
- _____
- _____
- _____
- _____



## Types of Standards

- Two-sided.
  - The shaft diameter (inches).
- One-sided … left is bad.
  - Time to failure (hrs) of electrical insulation material.
- One-sided … right is bad.
  - Cars exceeding the speed limit (mph).

## Defective & Non-Defective



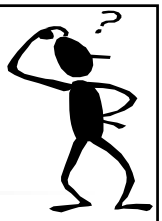
## Categories of Data

| Category | Meaning | Example |
|---|---|---|
| Nominal | Data is a code. | 0=Defective, 1=Non-defective. |
| Ordinal | Data is a rank. Data order is important. | 5=A, 4=B, 3=C, 1=D, 0=E. |
| Interval | Data is a measure; no true zero. | Temperature. |
| Ratio | Data is a measures; there is a true zero. | Weight. |

## Types of Data

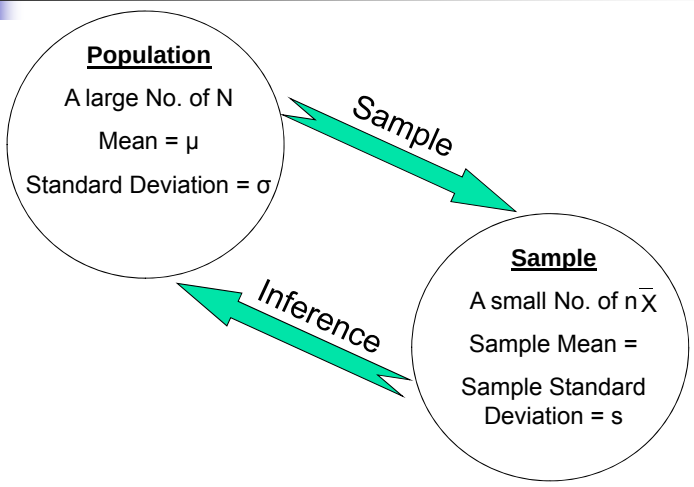
| Type | Meaning | Example |
|---|---|---|
| Continuous | Infinite values on an interval. | Temperature, Weight. |
| Discrete | Finite values on an interval. | Student letter grade, Traffic-light color. |

## Example: Categories & Types of Data



| Data | Category | Type |
|---|---|---|
| Customer satisfaction survey | | |
| Service time | | |
| Go/No-Go gauge | | |
| Percentage of purity | | |

# Statistical Overview



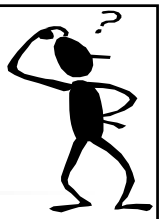

# Descriptive Statistics

- Centrality Measures
  - Mode
  - Median
  - Mean
- Dispersion Measures
  - Range
  - Variance
  - Standard Deviation
  - Coefficient of Variation

## Accuracy: Measures of Centrality

- **Mean** = add values ÷ number of values
- Median: is the value in the middle of ascendingly ordered data
- Mode: is most frequently occurring value(s)

## Example: Measures of Centrality

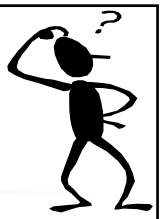


- Purpose: learn how to calculate measures of centrality
- Method: Hand-calculate the mean, median, & mode of boxes weights (kg):
  - 14, 16, 12, 18, 14, 10, 11, 14, 23, 18.
- Time: 25-30 minutes.

## Consistency: Measures of Spread

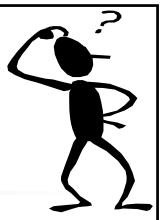
- Range = maximum value – minimum value.
- Variance: is the squared average deviations.
- Standard Deviation: is the average deviations.
- Coefficient of Variations : is the ratio between Standard deviation and Average.

## Example: Measures of Spread



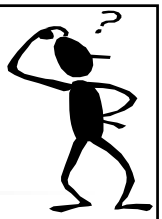
- Purpose: Learn how to calculate measures of spread.
- Method: Hand-calculate the range, variance, & standard deviation of boxes weights (kg):
  - 14, 16, 12, 18, 14, 10, 11, 14, 23, 18.

## Example:Why Need Both Types of Measures?



- If the passing grade is 75, evaluate the performance of the following 3-student classes:
  - Class 1 exam score: 0, 50, 100
  - Class 2 exam score: 48, 50, 52
  - Class 3 exam score: 78, 80, 82
- Rank the 3 classes from best to worst. Why?

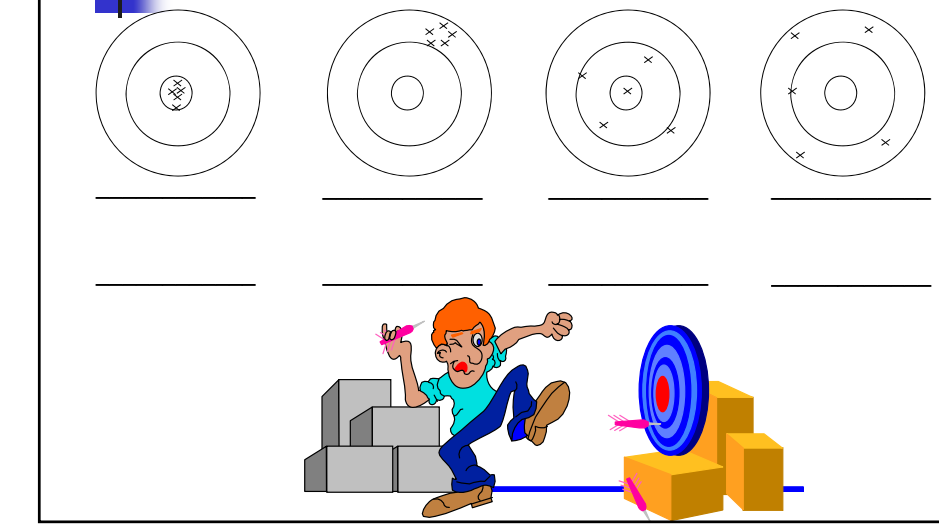
## Example:Why Need Both Types of Measures?



| Class | 1 | 2 | 3 |
|---|---|---|---|
| Accuracy | | | |
| Precision | | | |

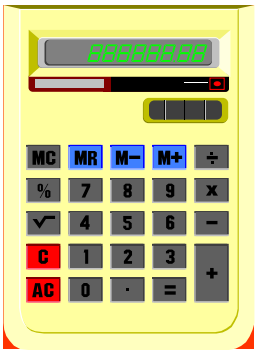
- Rank is _____

# Accuracy & Precision



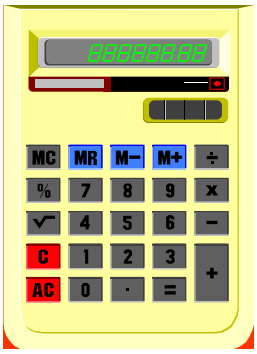
# Exercise: Centrality Measures

- Calculate the sample mode, median and the mean of the following data set.
  - Set A: 20, 20, 18, 17, 15, 17, 14, 17, 12, 10
  - Set B: 10, 20, 12, 13, 13, 16, 17, 12, 13, 17, 22



# Exercise: Dispersion Measures

- Calculate the sample range, variance, standard deviation and coefficient of variation.
  - Set A: 20, 20, 18, 17, 15, 17, 14, 17, 12, 10
  - Set B: 10, 20, 12, 13, 13, 16, 17, 12, 13, 17, 22




# Exercise: Descriptive Measures

- The following measurements were obtained for the analysis of isooctane in gasoline.
  - **Calculate $\bar{X}$, S, and the C.V**

| Sample | Percents Isooctane |
|---|---|
| 1 | 3.83 |
| 2 | 3.94 |
| 3 | 3.88 |
| 4 | 3.97 |
| 5 | 3.90 |
| 6 | 3.94 |

## Estimate of Standard Deviation from a Pair of Results (X1 and X2)

- In case of a single duplicate pair of measurements, the equation for the standard deviation can be significantly reduced as follows

$$S = \frac{D}{\sqrt{n}} = \frac{|X_1 - X_2|}{\sqrt{2}}$$

## Estimate of Standard Deviation from Duplicate Measurements

- For a set of measurements consisting of pairs of duplicate results, the standard deviation can be estimated as follows:

$$S = \sqrt{\frac{\sum D^2}{2k}}$$

- Where K = the number of sets of duplicates

## Graphical Representations

- Stem-and-leaf plot
- **Histogram**
- Box-plot

Data for boxes weights (in kg):

14, 16, 12, 18, 14, 10, 11, 14, 20, 18,
06, 10, 13, 24, 21, 18, 14, 15, 14, 16,
25, 18, 16, 20, 10, 24, 14, 12, 10, 14

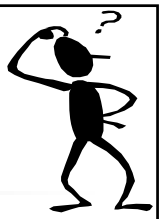
## Example: Stem-and-Leaf Plot

| | | |
|---|---|---|
| (0 – 4) | 0 | |
| (5 – 9) | 0* | 6 |
| (10 – 14) | 1 | 4 0 2 3 4 0 0 1 4 4 4 2 4 0 4 |
| (15 – 19) | 1* | 6 8 6 8 8 5 8 6 |
| (20 – 24) | 2 | 4 0 1 4 0 |
| (25 – 29) | 2* | 5 |

## Example: Ordered Stem-and-Leaf Plot

| | | |
|---|---|---|
| (0 – 4) | 0 | |
| (5 – 9) | 0* | 6 |
| (10 – 14) | 1 | 0 0 0 0 1 2 2 3 4 4 4 4 4 4 4 |
| (15 – 19) | 1* | 5 6 6 6 8 8 8 8 |
| (20 – 24) | 2 | 0 0 1 4 4 |
| (25 – 29) | 2* | 5 |

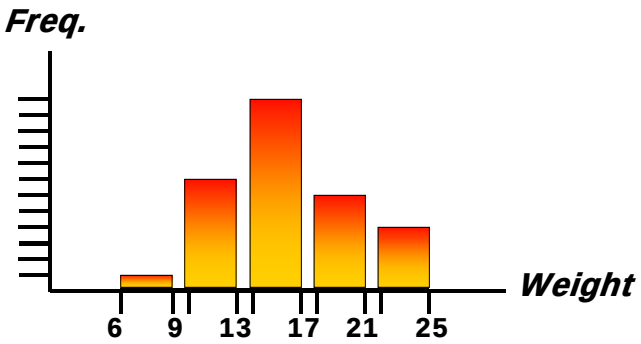
## Example: Distribution Table



- n = 30, cells = SQRT(n) = 5 or 6, cell width = (25 – 6)/5 = 4

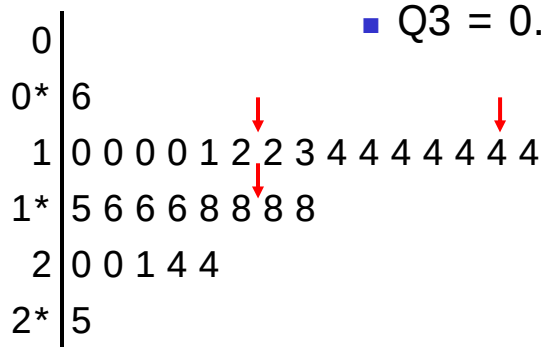
| Cell | Tally | Frequency |
|---|---|---|
| 6 to 9 | | |
| 10 to 13 | | |
| 14 to 17 | | |
| 18 to 21 | | |
| 22 to 25 | | |

## Example: Histogram

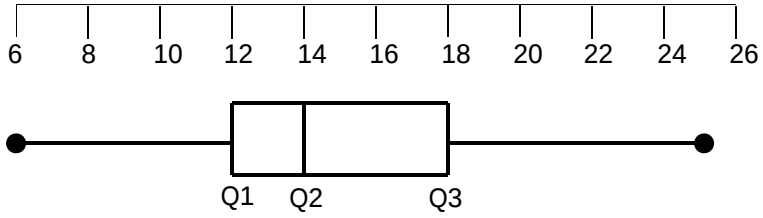



## Example: Box Plot

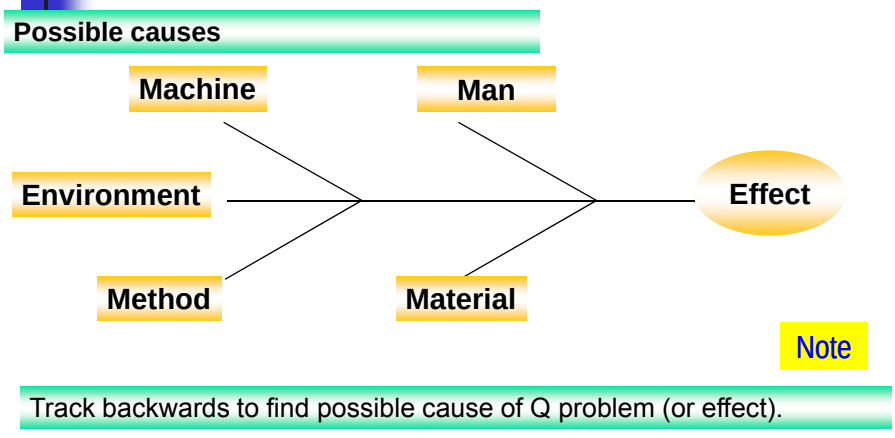
- Q1 = 0.25 x 30 = 7.5
- Q2 = 0.50 x 30 = 15
- Q3 = 0.75 x 30 = 22.5



# Example: Box Plot



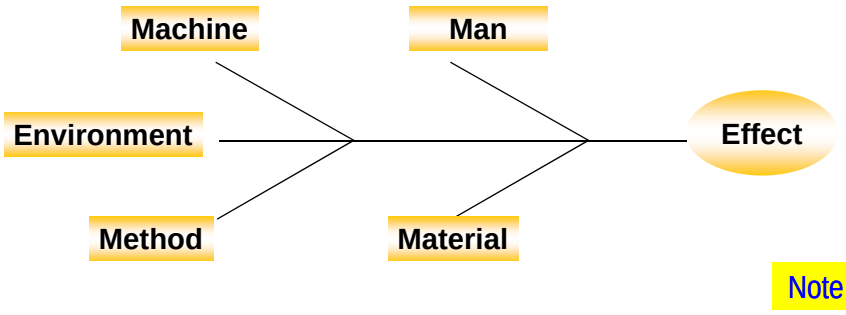

# Fish-bone or Cause & Effect Diagram



## Fish-bone or Cause & Effect Diagram

Solve the problem of Late deliveries of XYZ Company

**Possible causes**




Note

Track backwards to find possible cause of Q problem (or effect).

## Check sheet

track defects or collect data

**Wednesday**

**Invoicing errors**

| | |
|---|---|
| Wrong Account | 𝍸 \|\| |
| Wrong Amount | \|\|\| |

**Accounts payable errors**

| | |
|---|---|
| | \|\| |
| Wrong Account | 𝍸 |
| Wrong Amount | |

# Pareto Analysis (20-80%)

## Steps of making the Pareto Analysis

- Select the measurement parameter
- Rank the parameter in descending order
- Calculate the percentage
- Calculate the cumulative percentage
- Construct a bar graph for each category and a line graph for the cumulative percentage .

# Pareto Analysis ( Example, Step1 )

At the end of 1st Quarter of 2003, XYZ Company surveyed the performance of 4 suppliers and put the result in the following table :

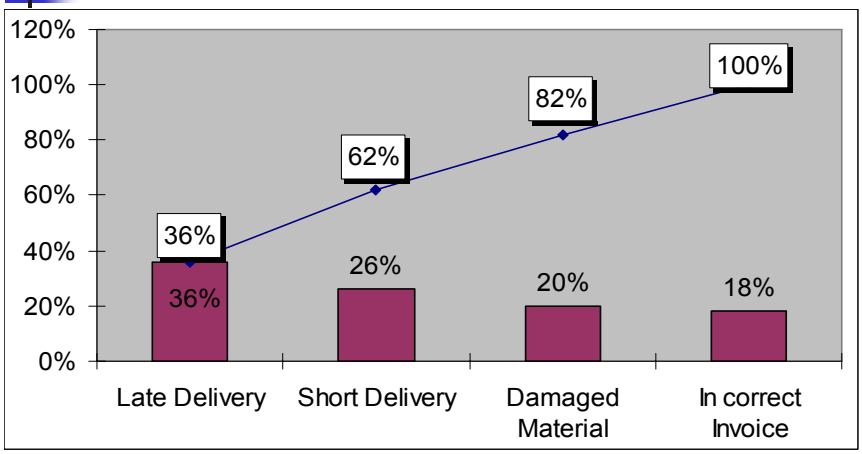
| Problems | Suppliers | | | | TOTAL |
|---|---|---|---|---|---|
| | A | B | C | D | |
| Incorrect Invoice | 3 | 4 | 0 | 2 | 9 |
| Late Deliveries | 3 | 4 | 5 | 6 | 18 |
| Damaged Material | 2 | 5 | 1 | 2 | 10 |
| Short Delivery | 2 | 5 | 3 | 3 | 13 |
| Totals | 10 | 18 | 9 | 13 | 50 |

## Pareto Analysis (Example, Step 2 )

% of each problem was calculated , and the result put in descending order in the following table

| Problems | Suppliers | | | | TOTAL | % | Accum. % |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | | | |
| Late Deliveries | 3 | 4 | 5 | 6 | 18 | 36% | 36% |
| Short Delivery | 2 | 5 | 3 | 3 | 13 | 26% | 62% |
| Damaged Material | 2 | 5 | 1 | 2 | 10 | 20% | 82% |
| Incorrect Invoice | 3 | 4 | 0 | 2 | 9 | 18% | 100% |
| Totals | 10 | 18 | 9 | 13 | 50 | 100 % | 100% |

## Pareto Analysis ( Example, Step3 )



# Hypothesis Testing

- Common questions that can be answered using the null hypothesis approach:
  - Is the mean of the data set significantly different from the true value?
  - Are the means of two different sets significantly different?
  - Are the precisions of two different data sets significantly different?

# Test 1: Comparing the Mean With the True Value

- The largest difference that could be expected as a result of indeterminate error is given by:

$$\pm t\left(\frac{s}{\sqrt{n}}\right)$$

$$H_o : (\bar{X} - \mu) \prec \pm t\left(\frac{s}{\sqrt{n}}\right)$$

$$H_1 : (\bar{X} - \mu) \succ \pm t\left(\frac{s}{\sqrt{n}}\right)$$

## Test 2: Comparing Two Means

- There are two occasions when we wish to determine if two independently obtained results are essentially the same.

$$H_o : (\bar{X}_1 - \bar{X}_2) \prec \pm ts_p \sqrt{\frac{n_1 + n_2}{n_1 n_2}}$$

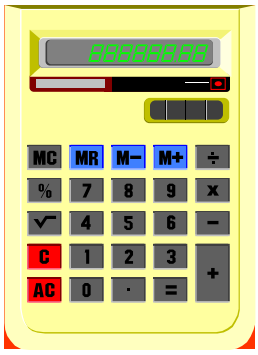
$$H_1 : (\bar{X}_1 - \bar{X}_2) \succ \pm ts_p \sqrt{\frac{n_1 + n_2}{n_1 n_2}}$$

Where $S_p$ is the pooled standard deviation of the two samples.

$$S_p = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

## Exercise: Comparing Two Means

- Compare the two means, of the following data set.
  - Set A: 20, 20, 18, 17, 15, 17, 14, 17, 12, 10
  - Set B: 10, 20, 12, 13, 13, 16, 17, 12, 13, 17, 22



## Test 3: Comparing Two Precisions

- To determine if the standard deviation from one data set is significantly different from the standard deviation of another data set

$$H_o : F_c \prec F_t$$

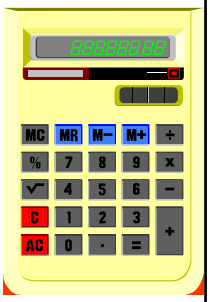
$$H_1 : F_c \succ F_t$$

$$F_c = \frac{Var_1}{Var_2} = \frac{S_1^2}{S_2^2}$$

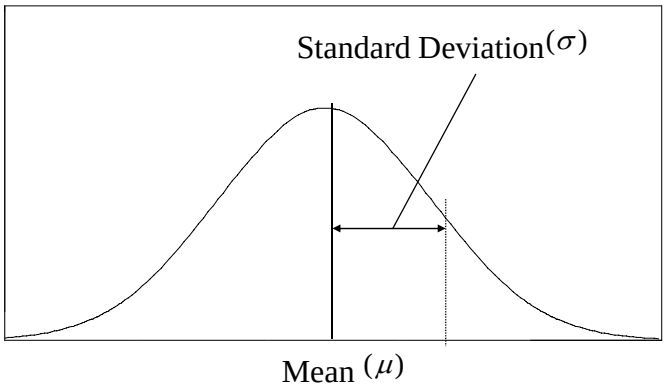
- **The larger variance is always numerator.**
- **$F_t$ is the expected tolerance base on Normal distribution.**

## Exercise: Comparing Two Precisions

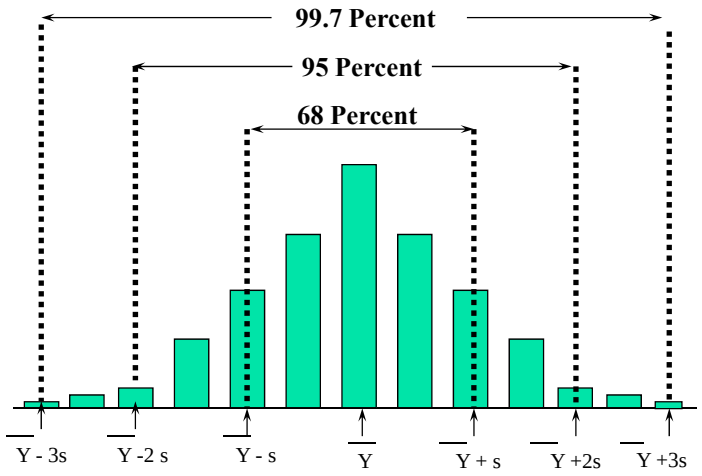
- A ship of copper ore was purchased by a local metal refiner. The analysis certificate made out while the ship was being loaded, show that %Cu =14.66 with a standard deviation of 0.07% for 5 measurements. When the ore arrived at the refinery, it was analyzed and the following results were obtained: %Cu = 14.58, 14.61, 14.69, 14.69, and 14.64. Should the refiner accept the ore?



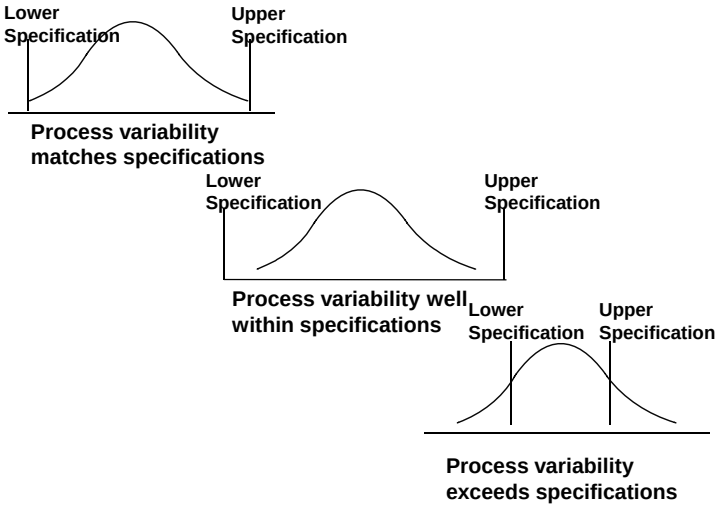
## Normal Distribution




## Normal Distribution Principle



## Process Capability




## CHAPTER THREE

# Methods and Philosophy of Statistical Process Control

## Statistical Methods for Quality Improvement

- Acceptance Sampling
- Statistical Process Control Charts (SPC)
- Design of Experiments
- Process Capability studies

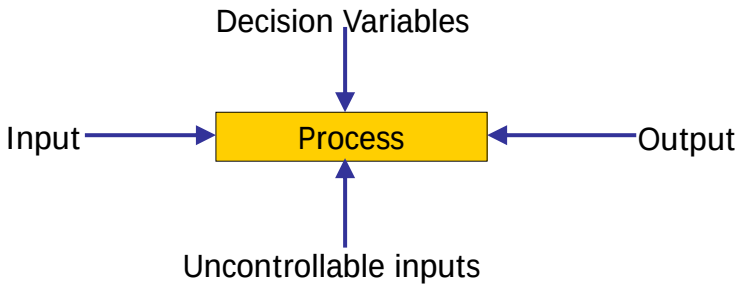
## Statistical Quality Control

**Can be applied to:**

- Engineering Problems
- Inspection Problems
- Operating Problems
- Management Problems
- Accounting and Clerical Problems

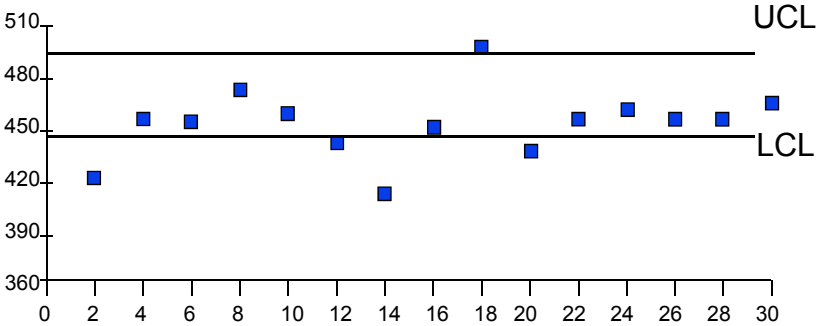
# Process

- Is any set of conditions, or set of causes, which work together to produce a given results.




# Control Chart

***Purpose:*** *To monitor and analyze variation of a process to determine whether the variation is normal or abnormal.*

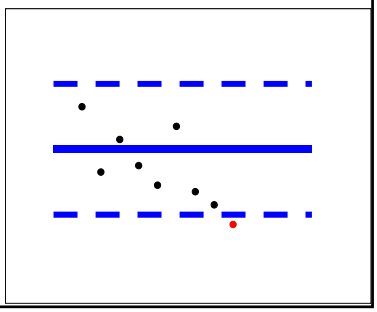



US System ⟶ 3.09 Sigma Limits

ES System ⟶ 3.00 Sigma Limits

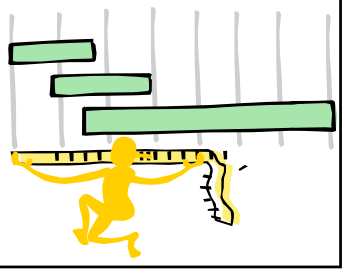
## Control Charts Type

- Variables Control Chart
  - X-bar and R Charts
  - X-bar and S Charts
  - MA Control Charts
- Attributes Control Charts
  - P-Chart
  - np-Chart
  - C-Chart
  - U-Chart



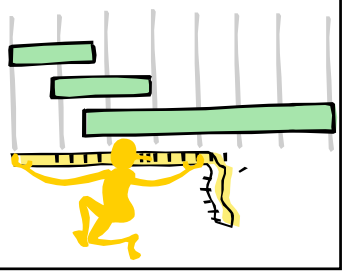
## Type of Variations in Production

- Within-Piece Variation
- Piece-To-Piece Variation
- Time-To-Time Variation

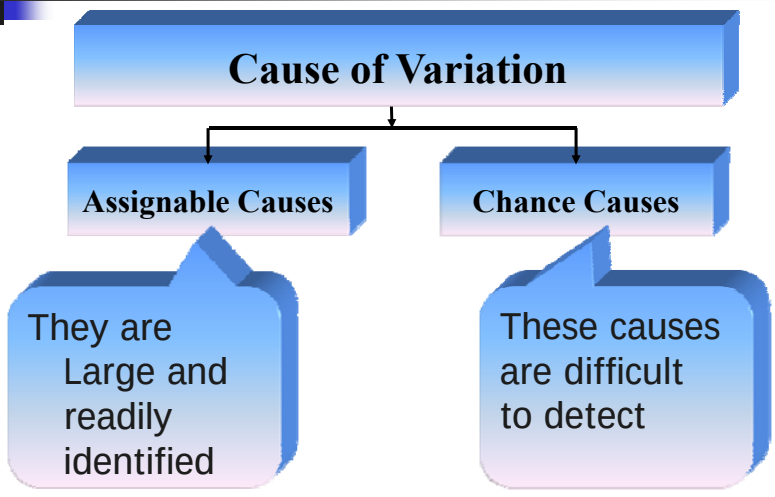


## Sources of Variation

- Equipment
- Material
- Environment
- Operator
- Inspection Activity

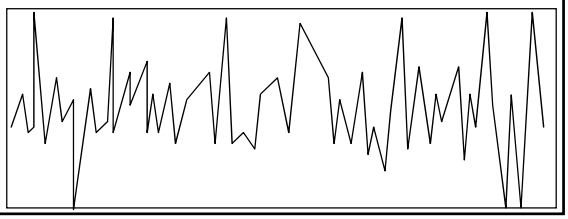


## Causes of Variation



## The Control Chart Method

- A graphical record of the quality of a particular characteristics
- It shows if the process is in a stable state with chance causes of variation or not.

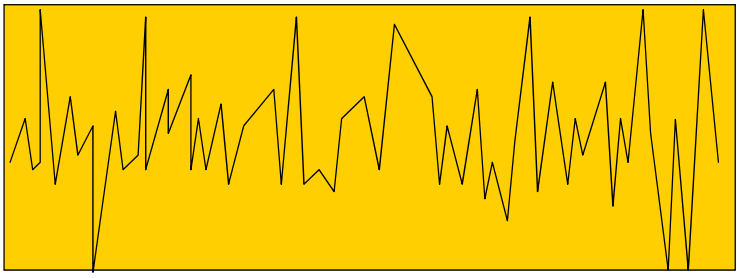


## CHAPTER FOUR

**Variable Control Charts**

## Variables Control Charts

- X-bar and R Charts
- X-bar and S Charts
- MR Control Charts



## Objectives of Variable Control Charts

- Quality Improvement
- Determine the Process Capability
- Setting Effective Specification Limits
- Deciding to release the product to the next phase or not

## Control Chart Building Technique

- Select the Quality Characteristics
- Choose the Rational Subgroup
- Collect the Data
- Determine the Trial Central Line and the Control Limits
- Establish the revised Central Line and the Control Limits
- Achieve the Objectives

## Selection of Quality Characteristics

- Must be measurable and expressed in numbers
- Seven basic units were used
  a) Lengths
  b) Mass
  c) Current
  d) Temperature
  e) Substance
  f) Time
  g) Length intensity
- Variables can be treated as Attribute
- One Characteristic only is selected

## Choosing the Rational Subgroup

- The Inspection Cost
- Test (Inspection) Type
- Pre-Control Rule
- Keep The results in tighter and sensitive Control Limits

**Usually sample of 5 is taken and sampling frequency is every half hour.**

## Establish X-bar and R Charts

$$\sigma_{\bar{x}} = \sigma / \sqrt{n}$$

$$UCL = \overline{\overline{X}} + z\sigma_{\bar{x}} \qquad CL = \overline{\overline{x}} \qquad LCL = \overline{\overline{X}} - z\sigma_{\bar{x}}$$

-OR-

$$UCL = \overline{\overline{X}} + A_2\overline{R} \qquad CL = \overline{\overline{x}} \qquad LCL = \overline{\overline{X}} - A_2\overline{R}$$

**خريطة المدى (R)**

$$UCL = D_4\overline{R} \qquad CL = \overline{R} \qquad LCL = D_3\overline{R}$$

## Establish X- bar and *S* Charts

$\bar{X}$ **Chart**

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_3\sigma$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_3\sigma$$

$$\bar{S} = \Sigma \frac{s}{n}$$

$$UCL_S = B_6\sigma$$

$$CL_S = C_4\sigma$$

$$LCL_S = B_5\sigma$$

Use S, B4, and B3 if sigma is unknown, and CLs = $\bar{S}$

## Establish MR (Individual) Chart

In some cases, especially in destructive test, The QE can't take more than one sample each time.

$$UCL_{\bar{X}} = \bar{X} + 3\frac{\overline{MR}}{d_2}$$

$$LCL_{\bar{X}} = \bar{X} - 3\frac{\overline{MR}}{d_2}$$

$$UCL_{MR} = D_4\overline{MR}$$

$$LCL_{MR} = D_3\overline{MR}$$

## State of Control

1. Process in Control
2. Process out of Control
   - ♦A point is outside the 3σ limits Plus AT & T rules.
   - ♦A nonrandom behavior is observed in the points

## Interpretation of the Control Charts

Western Electric Rules (AT&T Rules) are used to decide about out of control condition.

There are 10 rules were used.

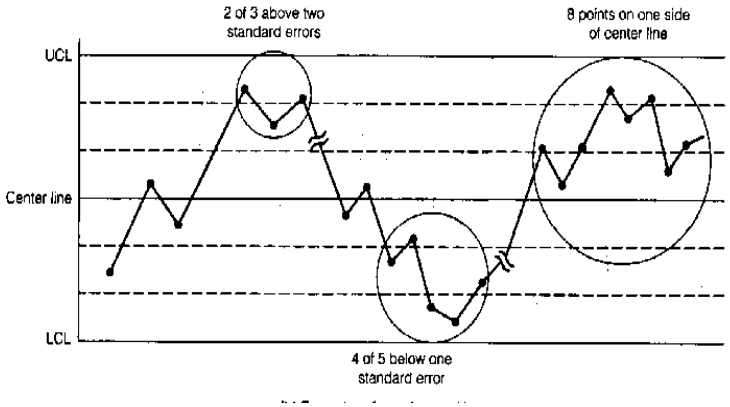
## AT&T Rules

- One or more points outside Control Limits
- Two of three consecutive points outside of $2\sigma$ limits
- A run of 8 consecutive points on one side of the center line
- Six points in a row steadily increasing or decreasing

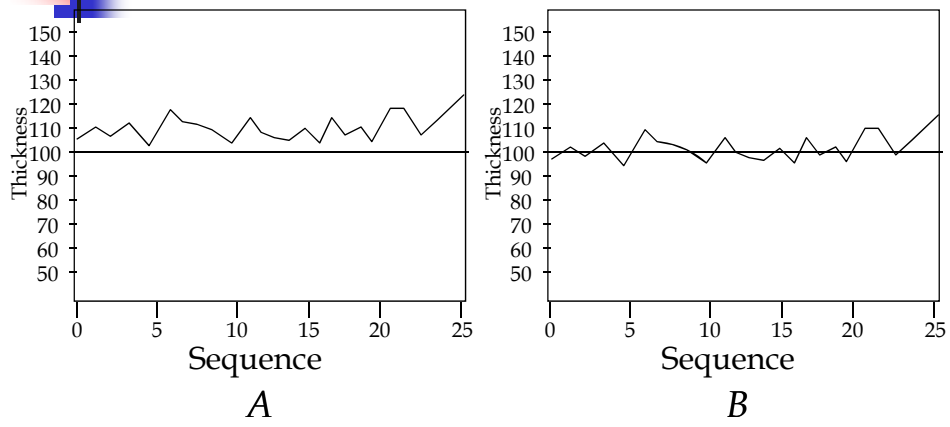
## AT&T Rules Continued

- Eight points in a row in zone C or beyond
- Eight points in a row in both sides of the center line with none in zone C
- Four points in a row alternating up and down
- Fifteen points in a row in zone C
- An unusual and nonrandom pattern

## Two of three consecutive points outside of 2σ limits

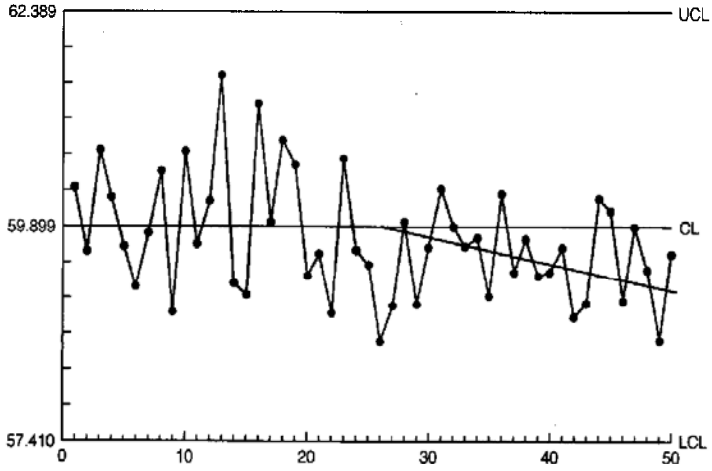



## A run of 8 consecutive points on one side of the center line

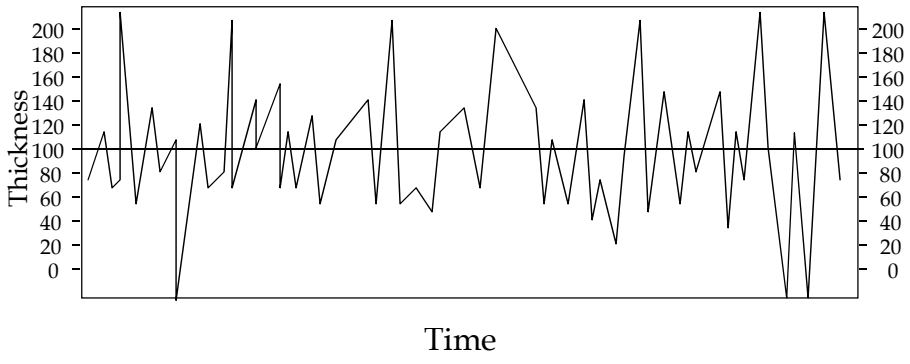



Which process has better quality?

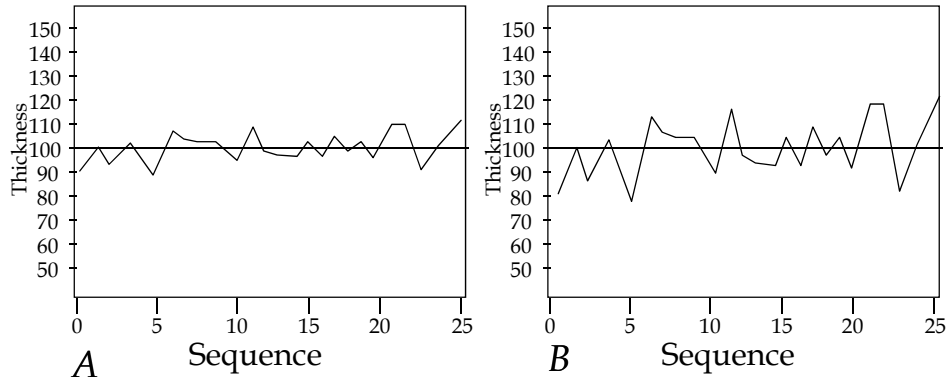
## An unusual and nonrandom pattern




## An unusual and nonrandom pattern

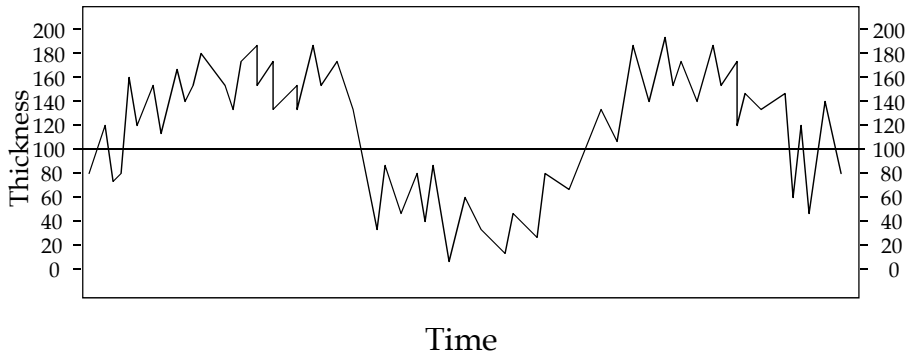


## An unusual and nonrandom pattern




Which process has better quality?

## An unusual and nonrandom pattern



# CHAPTER FIVE

## Attribute Control Charts

## SPC "Attributes Charts"

**Types of Attributes**

- Non-measurable Characteristics
- Measurements that could not be made due-to:

  a) Time  b) Cost

  c) Easier to use "go-no-go" gage

## Non Conformity

**Definition**

Departure of quality characteristics from required

## The Objectives of Attribute Charts

- Determine the average quality level
- Bring to the attention of any changes in the average level
- Improve the product quality
- Evaluate the quality performance
- Determine the acceptance criteria of a product

## Attribute Charts Type

- P-Chart
- np-Chart
- C-Chart
- U-Chart

## P- Chart

- P- Chart can be produced to measure the quality produced by:
  a) A Work Center
  b) A Department
  c) A Shift
  d) The entire Plant
- Also used to report the quality performance of an operator, a group of operators, or management.

# P-Chart Construction

- **Constant Sample Size**
  At least 25 subgroups should be collected

$$\overline{P} = \frac{\sum nP}{n}$$

Where $nP$ is the number of Nonconforming units in each subgroup
$n$ is the sample size for each subgroup

$$UCL = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}} \qquad LCL = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$$

If *LCL* is negative, replace it with zero value

# P-Chart Construction

- **Variable Sample Size**

$$\overline{P} = \frac{\sum P}{N}$$

where $P$ = Fraction of nonconforming in a single subgroup
N = Number of subgroups

$$UCL = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{\bar{n}}} \qquad LCL = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{\bar{n}}}$$

where $\bar{n}$ is the average sample size of the subgroups

## *nP* - Chart

- *nP*-Chart is similar to *P*-Chart
- It is easier for personnel to understand
- Sample size must be constant

Center Line = $\overline{nP}$

Control Limits = $\overline{nP} \pm 3\sqrt{\overline{nP}(1-\overline{P})}$

## C-Chart

**Example for C-Chart**

- No. of nonconforming rivets on an airplane
- Imperfections in a large roll of paper
- Rust sports on a steel sheet
- Billing errors
- Errors in forms
- Seeds or air pocket in a glassware

## C-Chart Construction

Center Line = $\overline{C}$

$$UCL = \overline{C} + 3\sqrt{\overline{C}}$$

$$LCL = \overline{C} - 3\sqrt{\overline{C}}$$

Where $\overline{C}$ = Average number on nonconformities for a number of subgroups

## U-Chart

If subgroup size varies, U-Chart would be appropriate to use.

$$U = \frac{C}{n} \qquad \overline{U} = \frac{\sum C}{\sum n}$$

$$UCL = \overline{U} + 3\sqrt{\frac{\overline{U}}{n}} \qquad LCL = \overline{U} - 3\sqrt{\frac{\overline{U}}{n}}$$

Where *C* = Count of nonconformities in a subgroup

*n* = Number of unit inspected in a subgroup

## A Quality Rating System of Nonconformities (MIL-STD-105D)

1. Critical Nonconformities
2. Major Nonconformities
3. Minor Nonconformities

A weight of 9, 3 and 1 points are assigned to critical, major and minor nonconformities.

## Guidelines for Implementing Control Charts

- Determine which process characteristics to control
- Determine where the charts should be implemented
- Apply control charts to important characteristics
- Add new charts if necessary
- Implement and maintain control charts as close to the work center as possible

# CHAPTER SIX

## ACCEPTANCE SAMPLING

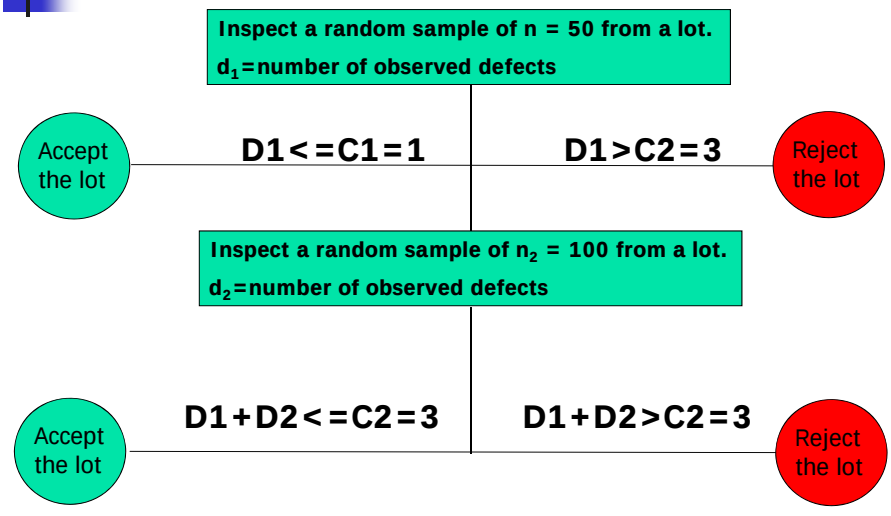
## When are Using Acceptance Sampling

- When testing is destructive.
- When the cost of 100% inspection is extremely high.
- When 100% inspection is not technologically feasible or need much time.
- When the vendor has an excellent quality history.
- When there are potentially serious product liability risks.
- When there are many items to be inspected and the inspection error rate is sufficiently high.

## Types of Sampling Plans

- A single sampling Plan
  - N = sample size, and c = acceptance number
- Double sampling plans
  - N1 = sample size on the first sample, c1 = acceptance number of the first sample.
  - N2 = sample size on the second sample, c2 = acceptance number for both samples.
- A multiple sampling plan

## Operations With the Sampling Plan



## MILITARY Standard 105 D (ANSI/ASQC Z1.4) Procedure

1. Choose the acceptance Quality Level (AQL).
2. Choose the inspection level.
3. Determine the lot-size.
4. Find the appropriate sample size code letter
5. Determine the appropriate type of sampling plan to use.
6. Enter the appropriate table to find the type of plan to be used.
7. Determine the corresponding normal and reduced inspections plans to be used.

## *The Cost Of Quality (COQ):*

# *Concepts*

## Definition: Cost of Quality.

**Cost** to **Improve Quality** +

**Costs due to Lack of Quality (not right at the first time).**

## Quality Product Costs More ??

- Buy a 500 $ car breaks (original)!
  - No replacement.
  - Good performance.
  - Full control.
  - A peace of mind.

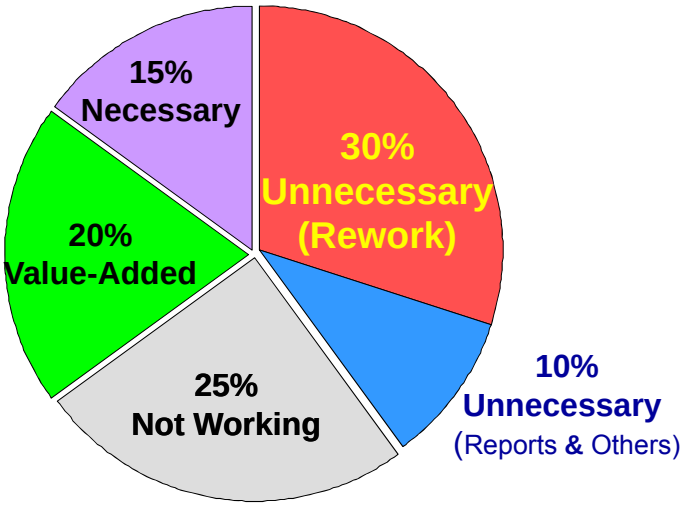
Total cost =.

- Buy a 100 $ car breaks (clone)!
  - 100 SR replacement.
  - 80,000 $ car loss in an accident.
  - 15 days hospitalized.
  - Death of a child.

Total cost =.

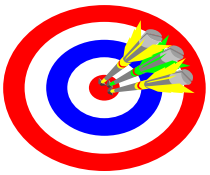
I've been doing it for years nothing happened

## The Way We Work **(W. Conway)** :

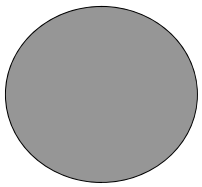



## Tolerance and Acceptability

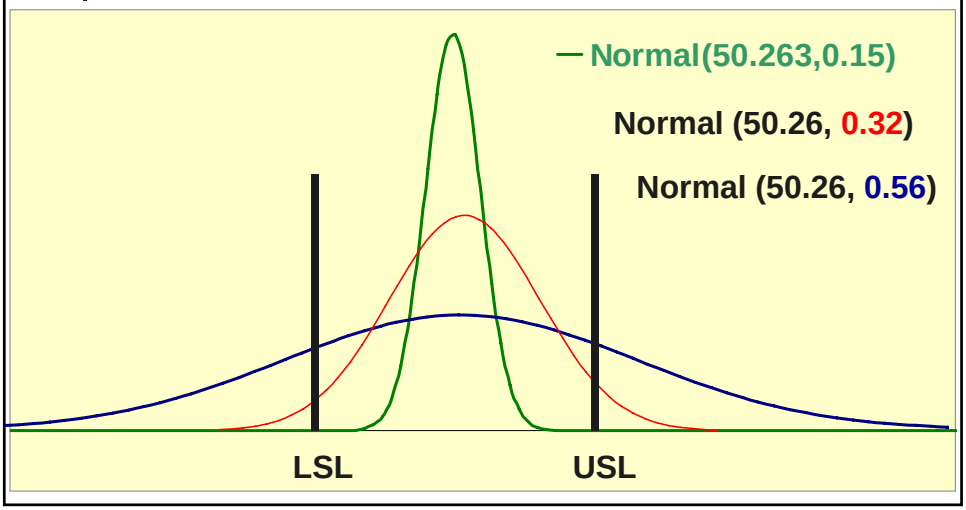
- The Japanese target.
  - Taguchi loss function.



- The American target.
  - Any where is fine (Deming).

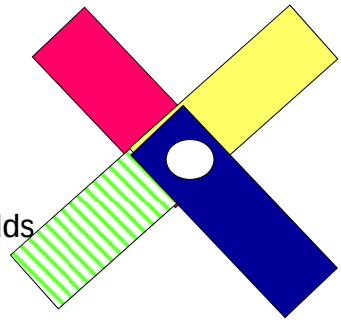


## Change in Variation:



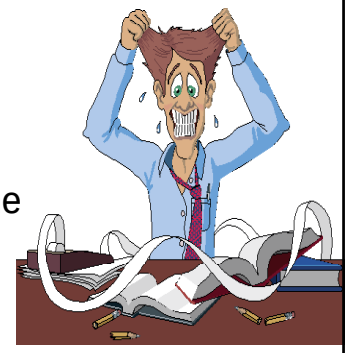

## Cost of Poor Quality:

- All holes are within tolerance.
- They are not aligned.
  - Drill -- adds cost.
  - Collapse on the road -- adds cost.
  - Fix it -- adds cost.
  - Loss of next sale -- etc.



## Poor Quality System Cost$

- **11 days to fill an order.**
  - The whole batch has to be ordered from the mother company, before handling the customer's order.
  - Branch is rated on **speed** of filling orders, mother company is rated on **inventory** cost.



## Poor Quality System Cost$ (Cont.1):

- It costs $100 to buy $3 battery.
  - Paperwork.
  - Who is involved?
    - Manager/supervisor.
    - Accounting.
  - Building a wall for the other guys.

## Poor Quality System Cost$ (Cont.2):

- **T**racing **discrepancies** between purchasing & receiving.
- Most tasks are simply to satisfy the internal demands (management, accounting ..Etc..) , In many cases not needed.

## Poor Quality System Cost$ (Cont.3):

- **High backorders**: conflicting measures.
  - Headquarters :**inventory cost.**
  - Branch: **speed** of filling orders.

## Performance Measure(poor Q System):

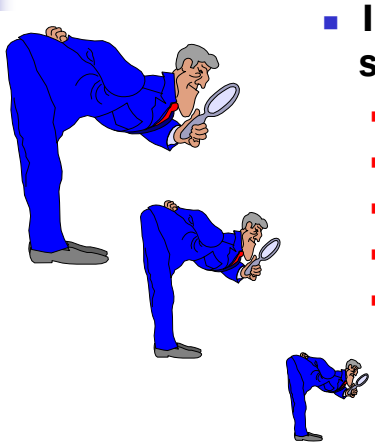
| Bank: | Airline Reservation: |
|---|---|
| 800 tellers. | 1200 agents. |

- **Measure**: **Number of customers served / month.**
- **Policy**: **Fire if < average for last 3 months.**
- **Results:**
  - Pr.(**< average in the last 3 month**)= (0.5)(0.5)(0.5)=0.125
  - No of **tellers fired** (**each month**) = 0.125 (800) =**100**
  - No of **agents fired** (**each month**) = 0.125 (1200) =**150**

## Performance or Loss Measure?

- **Hiring costs.**
- **Training cost.**
- **Loss of morale cost.**
- **Loss of customer:**
  - **Rushed,**
  - **Transferred to customer service,**
  - **Call again, system is down (it is not),**
  - **Hang up on customer.**

## Inspect the Inspector (Poor Q System):



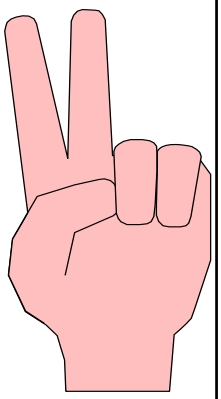
- **Incoming inspection of spare parts (example):**
  - Warehouse worker.
  - Add another workers.
  - Add an accountant.
  - Add a programmer.
  - … What's next?

## Cost of Quality Estimates:

- **35% of operating expenses in service companies (Crosby).**
- **44% of work time (Paul revere insurance) .**
- **30% of sales (Juran).**
- **20% of sales (Baldrige awar applicants) .**
- **20-40% of hospital costs.**
- **25% non interest banking .**

## What Is a Good Level For The COQ?

2% of sales is ***a good level for Costs of Quality*** (Crosby)



## Quality Costs

1. Quality Costs identify opportunities for quality improvement
2. Quality Costs are the basic data for Total Quality Management (TQM)

**Quality Costs Exceeds:**

- 20% of sales dollar in manufacturing
- 30% of sales dollar in service

## Quality Costs Categories

**Preventive Costs**

1. Marketing/customer/user
2. Product/Service/Design development
3. Purchasing
4. Operations
5. Quality Administration
6. Others (Rent, Telephone, Travel, etc.)

## Quality Costs Categories

**Appraisal Costs**

1. Purchasing Appraisal Costs
2. Operation Appraisal Costs
3. External Appraisal Costs
4. Review of test and Inspection data
5. Miscellaneous Quality Evaluations

## Quality Costs Categories

**Internal Failure Costs**

1. Product Design Failure Costs
2. Purchasing Failure Costs
3. Operations Failure Costs

## Quality Costs Categories

**External Failure Costs**

1. Complaint Investigation of Customer
2. Returned Goods-Evaluate & Repair
3. Recall Costs. Recall of products due to quality problems
4. Warranty Claims
5. Liabilities
6. Penalties
7. Lost Sales

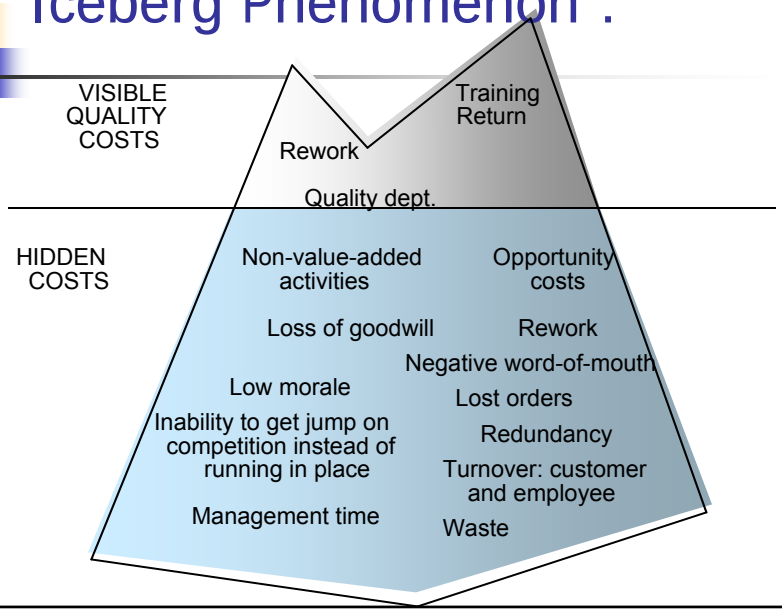
## Quality Costs Categories

**Base line is needed to relate the quality costs to other costs such as:**

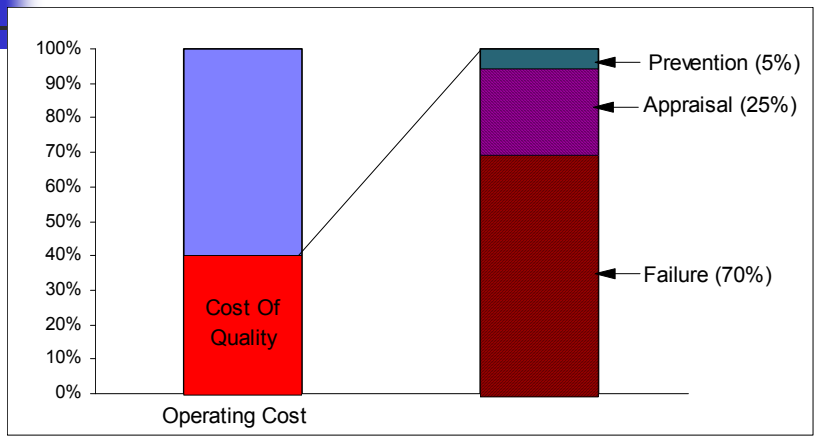
1. Labor (Quality Cost/Hour of Labor
2. Production (Quality Cost/$ of Production Cost)
3. Sales (Quality Cost/$ of Net Sales)
4. Unit (Quality Cost/Unit)

Optimum costs with respect to conformance percentage can be determined.

## Iceberg Phenomenon :



## Costs of Quality Categories:



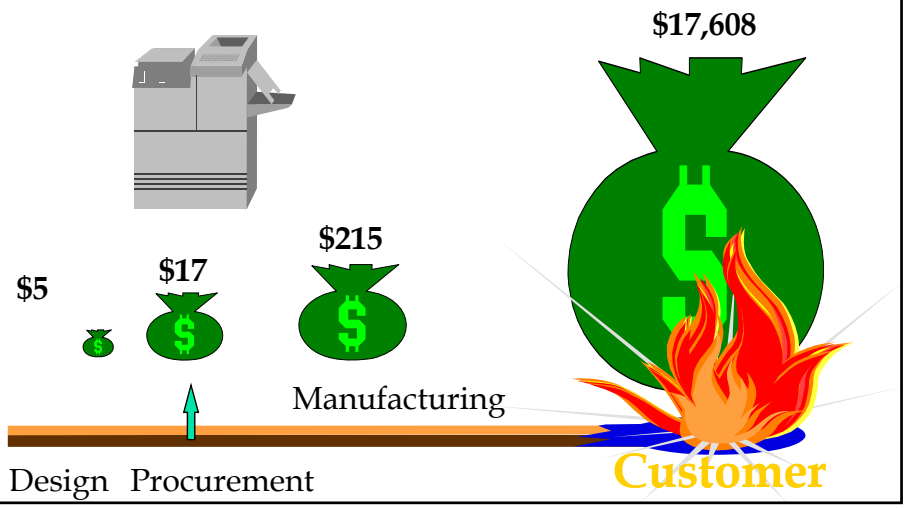

**Prevention + Appraisal+ Failure = Total Quality Costs**

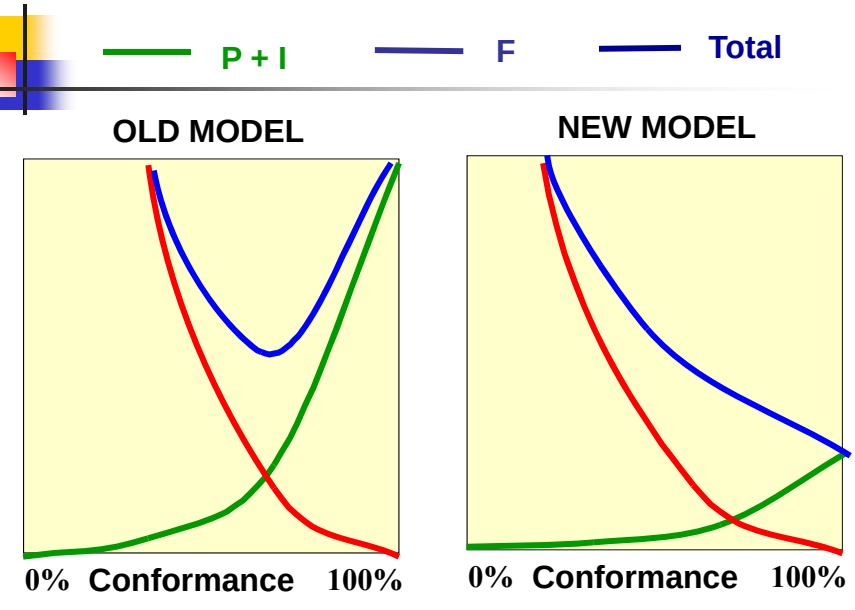
## Exercise (Classify Activities As): Prevention, Appraisal, Failure and Red Flag.

*1-Complaints handling*
*2-Customers surveys*
*3-Internal audits*
*4-Quality education*
*5-Review of work*
*6-Meeting*
*7-Customer report*
*8-Worker's compensation*
*9-Management training*
*10-Reports*
*11-Strategic planning*
*12-Trouble-shooting accounting*
*13-Logging rework time*
*14-Marketing research*
*15-EEO Lawsuits*
*16-Inter functional design team*

# Behavior of Costs Of Quality:

(Ricoh Example)



# The Cost Of Quality (COQ):

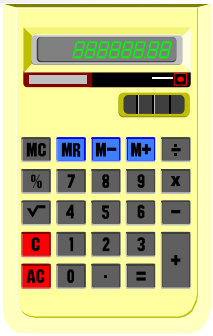
# Estimates

## Contents:

- Four Techniques.
- Estimating Service, Non-Service & Hidden Costs.
- Sources.
- Flowcharting.
- Things to Avoid / Problems with COQ.

## Four Techniques for Estimating Overall COQ:

- **Whole Account.**
- **Whole Person.**
- **Activity Analysis.**
- **Labor / Resource Claiming.**




## Whole Account:

- **Training.**
- **Audit.**
- **Legal.**
- **Rework / Returns.**

**Each is classified (P , A , F).**

## Whole Person:

- Inspectors.
- Expeditors (Purchasing / Custom Clearing / Dept collectors … etc.).
- Lawyers.
- Complaint Handling personnel.
- Warranty personnel.
- Software Debugging Engineers.

Each is to be classified (P , A , F).

## Activity Analysis:

**Self reported time spent on quality.**

**Advantages**

- **Increases Awareness.**
- **Requires ≤ 1 hour.**
- **Simple spreadsheet.**
- **Interdepartmental comparisons.**
- **Easily replicated.**

**Disadvantages**

- **Requires Education.**
- **Disruptive.**
- **Lots of Analyses.**
- **Workers comparisons.**
- **Requires dictionary.**

## Activity Analysis(Cont.1):

- 1) Requirements:
  - Dictionary of activities.
  - Data collection instrument.
  - Analyst.
  - Software.

## Activity Analysis(Cont.2):

- 2) Results
  - Categorized as:
    Prevention, Appraisal, and Failure.
  - Associated dollars.
  - Percentages.
  - Specify to where costs reside.
  - Priority ranking.

## Labor/ Resource Claiming:

- **It differs from activity analysis:**
  - Time is actually tracked rather than estimated.
- **The cost requires** analyzing time & resource allocations.
  - Overtime,
  - Supplies,
  - Equipment,
  - …..etc.

## Estimating Non-Service Costs:

- Reworked Units.
- Material.
- M/C time lost.
- Utility (Electricity / Oil / Gas ….).

## Estimating Hidden Costs:

- **Find Whole person / whole account then, x 2, 3 or 4.**
  - Although well documented, it may not be convincing to some.
- **More than 25%** of non-manufacturing (**service**) **is reworked (Crosby).**
  - Exclude whole person to avoid duplication.

## Estimating Hidden Costs (Cont.) Lost customers (TARP):

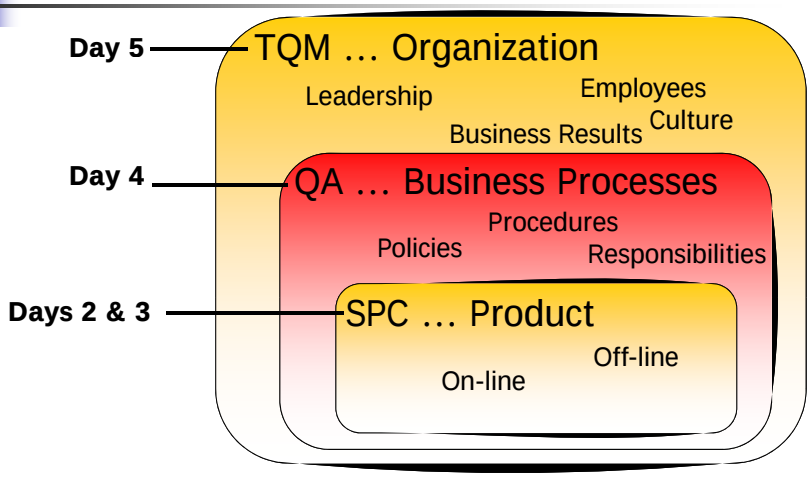
- **Unhappy customer tells 10-12 people.**
  - **13% of unhappy customer tell 20 people.**
- **2%** of potential customers will not do business **(based on negative word-of-mouth).**
- **96%** of customers do not complain.
- Surveys why they are dissatisfied & leaving.
- In banks:
  - **40%** leave due to poor service,
  - **60%** leave for other reasons.

## Problems with Quality Costs:

- Lack of agreement on definitions & components.
  - Even departments within companies tend to develop their own definitions.
- Lack of comparability over time or between industries.
- Difficult to build systems to capture data.
- Financial measures for short-term, while quality is definitely a long-term strategy.

## Overcoming Obstacles:

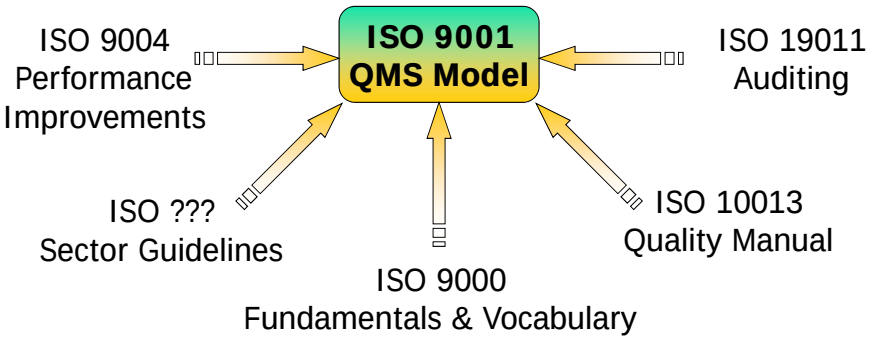
## From QC to TQM



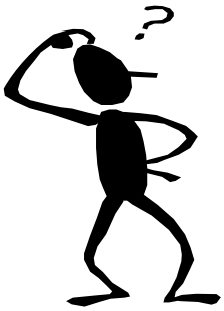

## What is ISO 9000:2000 QMS ?

- ISO = International Organization for Standards
- 9000 = code to denote QMS Family
- 2000 = year of last revision
- Is a family of standards for implementing a Quality Management System (QMS)

## The ISO 9000 Family



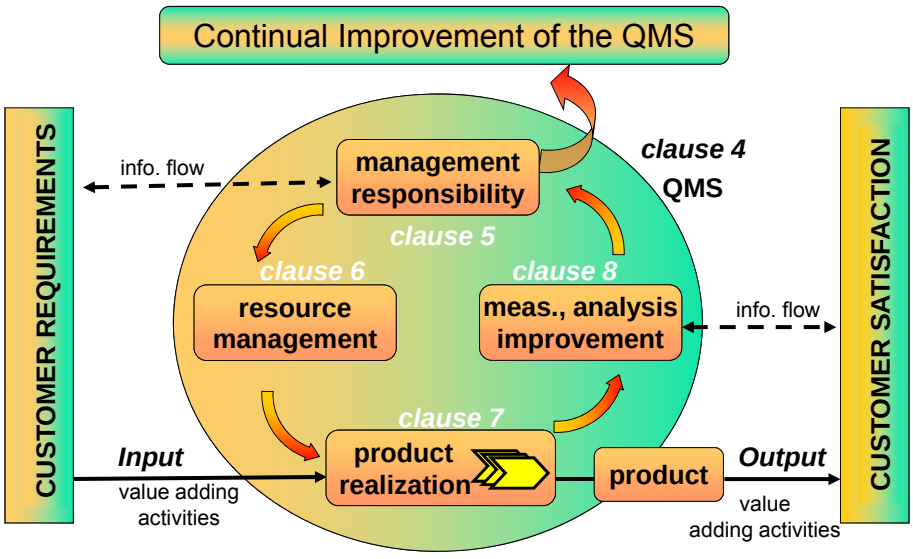

## Why ISO 9001:2000 QMS ?



# What is QMS?

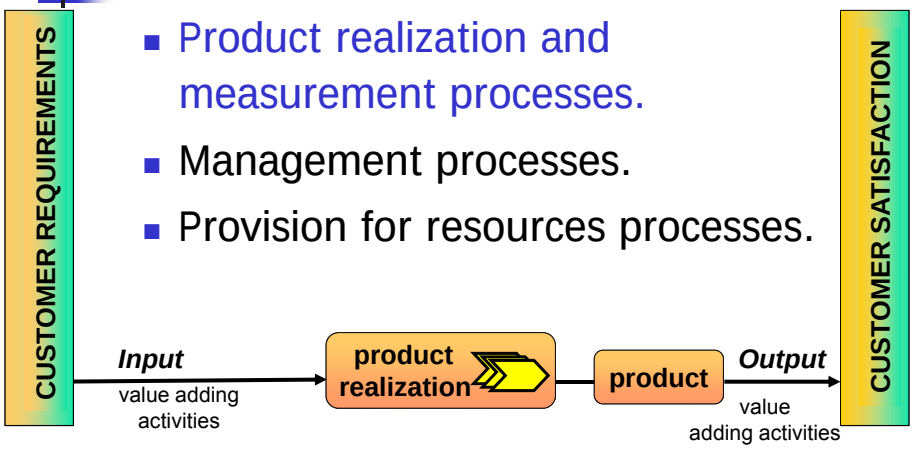
- QMS is a:
  - System: a set of logically related processes that turn input into output.
  - For Managing: administering activities and resources to achieve an objective.
  - Quality: customer/user satisfaction.


# ISO 9001 Model: Process-Based QMS

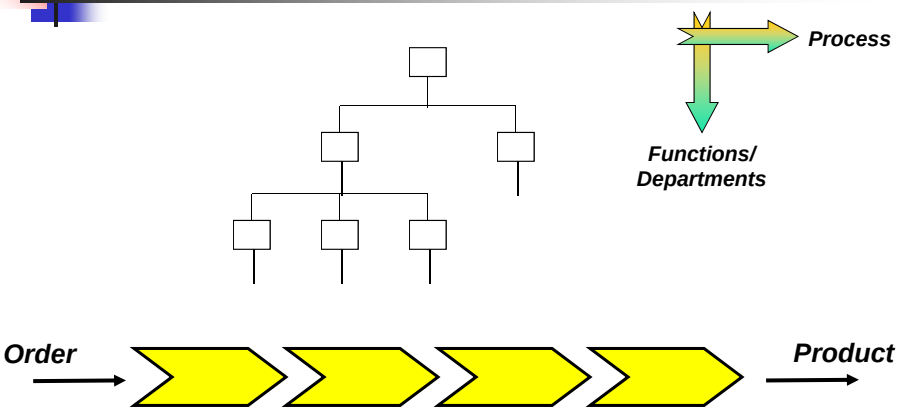


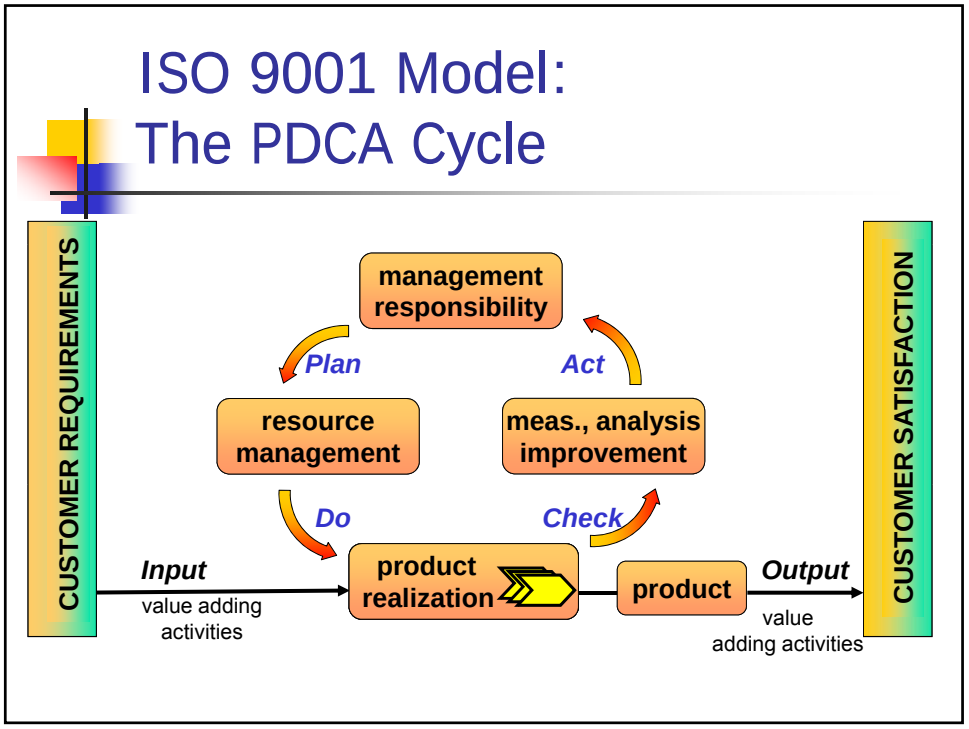
# ISO 9001 Model: Key Processes

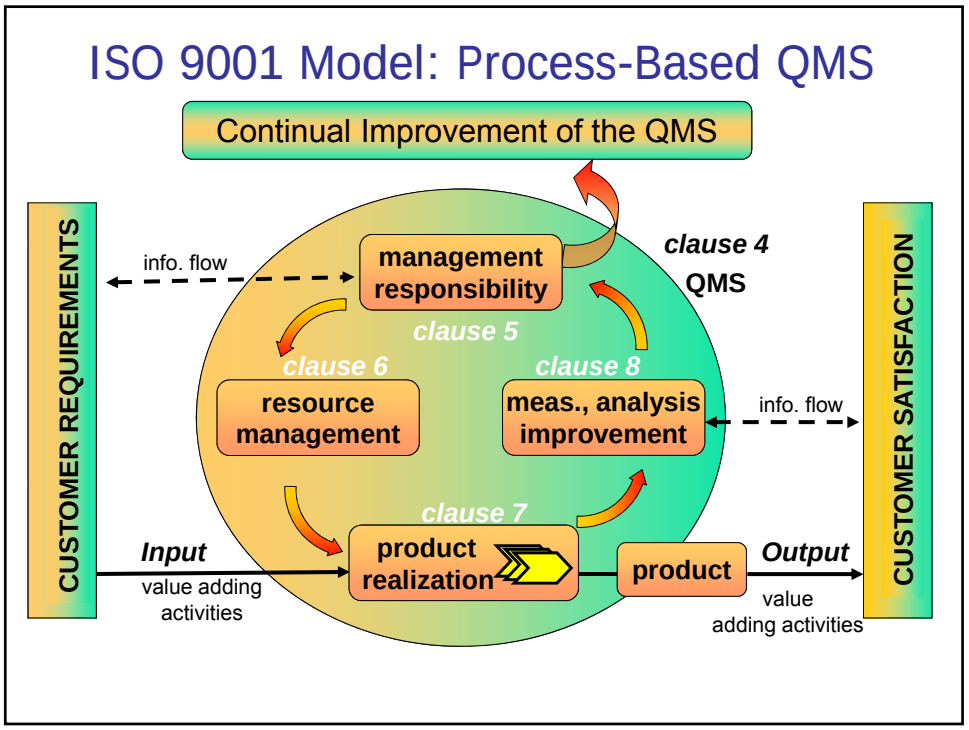
- Product realization and measurement processes.
- Management processes.
- Provision for resources processes.



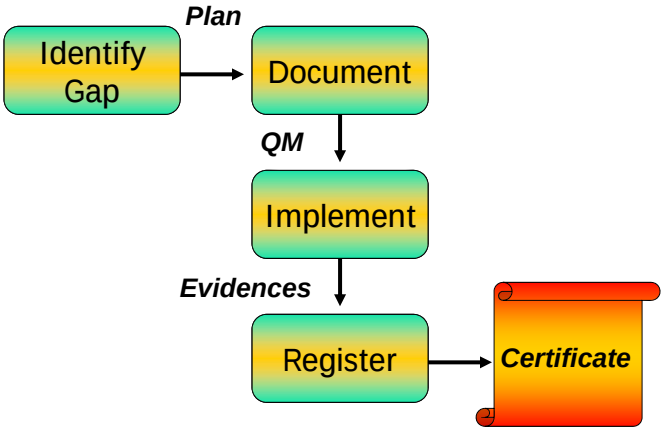

# Process Versus Function Approach




ISO 9001 Model:
The PDCA Cycle
CUSTOMER REQUIREMENTS
management responsibility
Plan
Act
resource management
meas., analysis improvement
Do
Check
Input
value adding activities
product realization
product
Output
value adding activities
CUSTOMER SATISFACTION

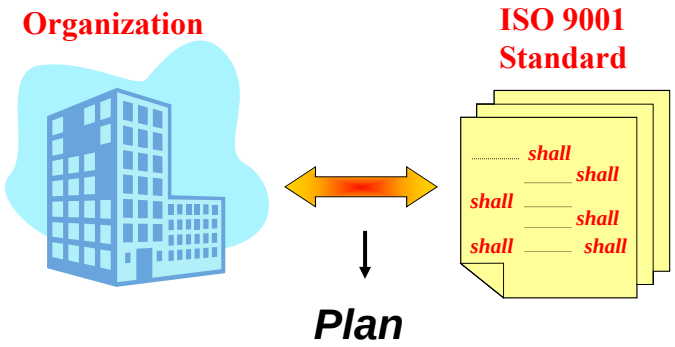

ISO 9001 Model: Process-Based QMS
Continual Improvement of the QMS
CUSTOMER REQUIREMENTS
info. flow
management responsibility
clause 4
QMS
clause 5
clause 6
clause 8
resource management
meas., analysis improvement
info. flow
clause 7
Input
value adding activities
product realization
product
Output
value adding activities
CUSTOMER SATISFACTION

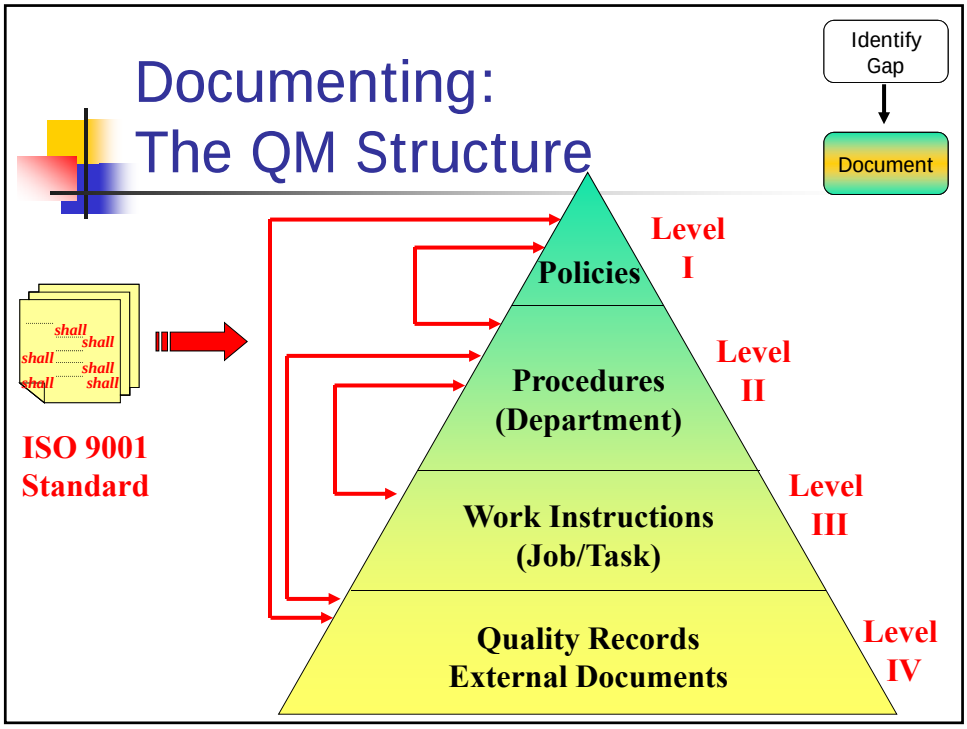
# ISO 9001 Certificate Realization Process

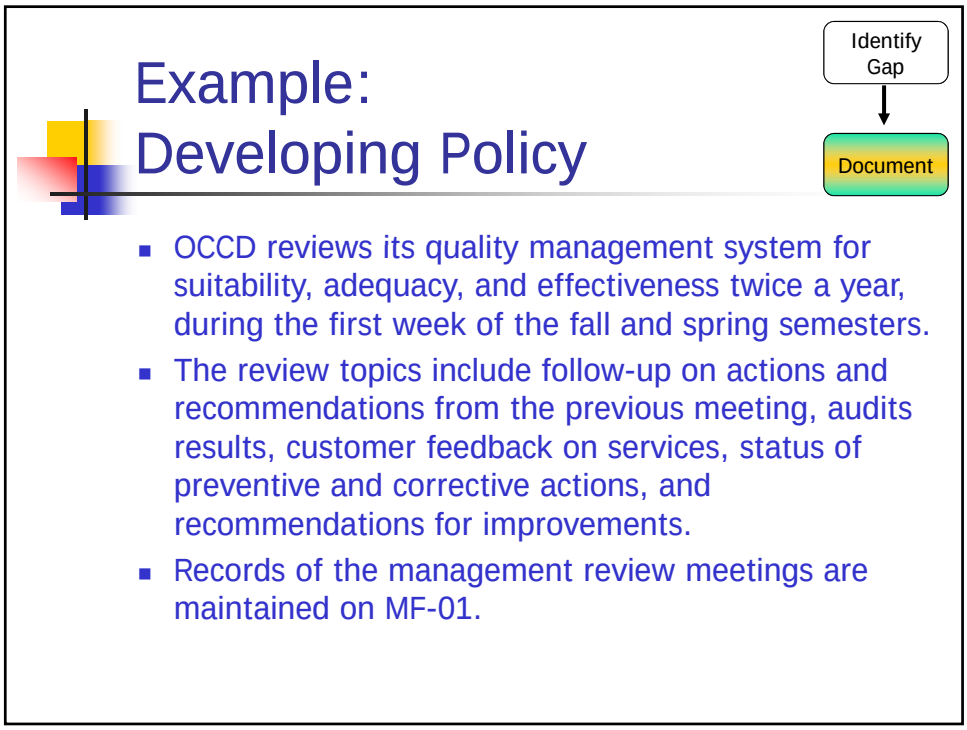


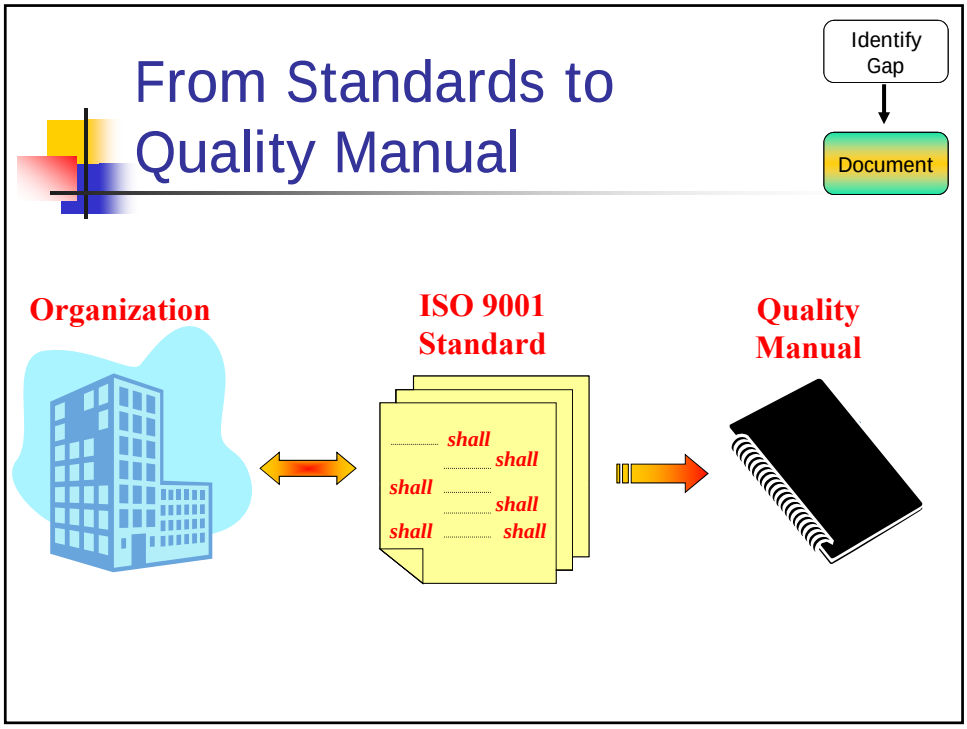

Identify Gap

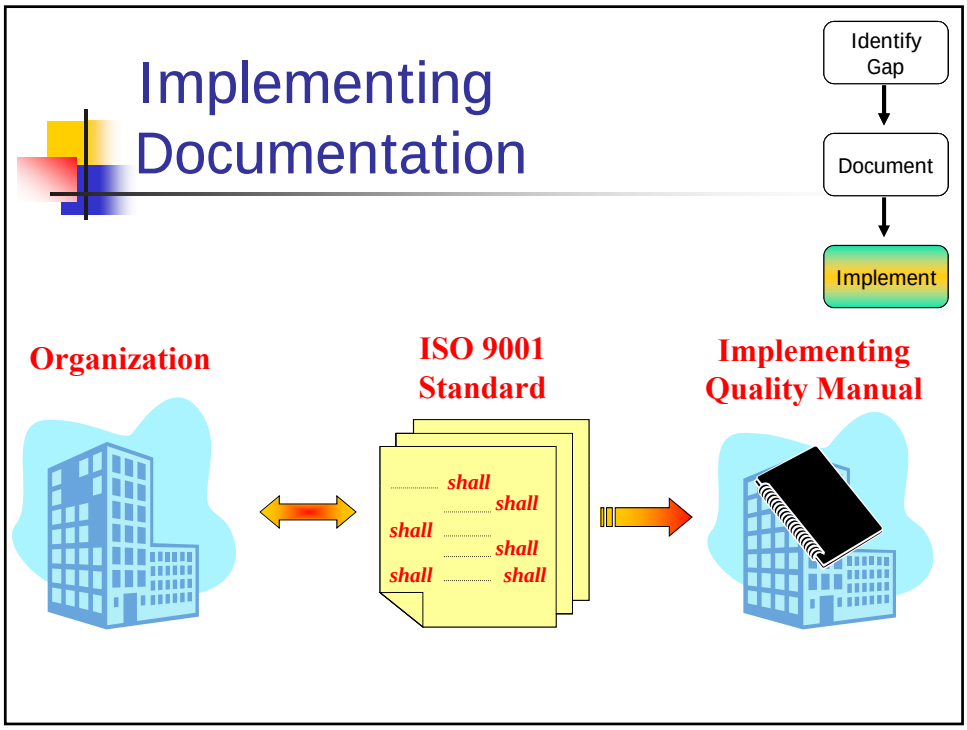
# Identifying the Gap



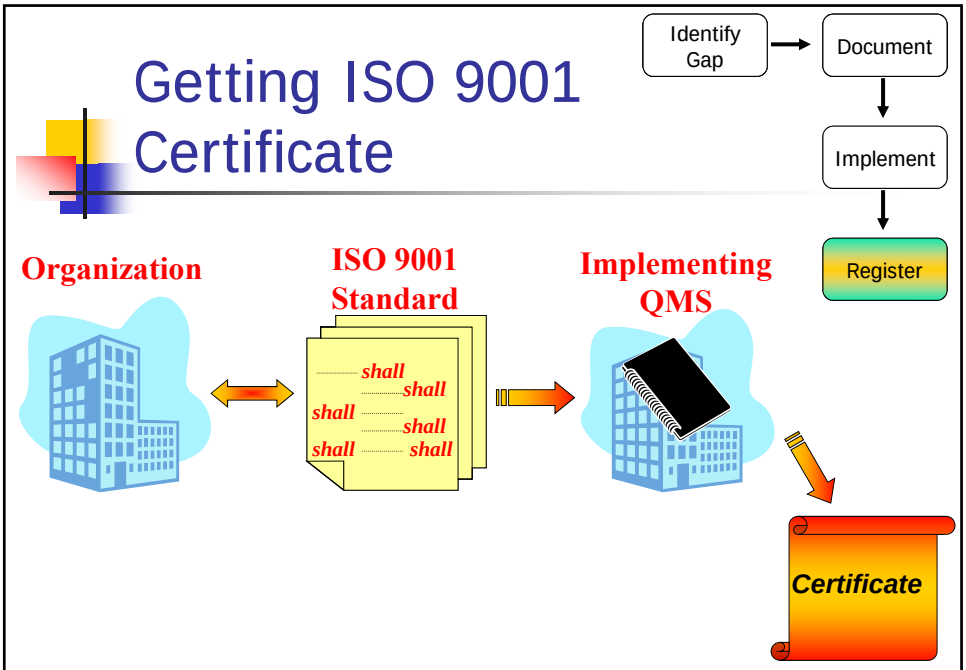

Identify Gap
Document
Documenting:
The QM Structure
shall
ISO 9001
Standard
Level I
Policies
Level II
Procedures
(Department)
Level III
Work Instructions
(Job/Task)
Level IV
Quality Records
External Documents


Identify Gap
Document
Example:
Developing Policy
OCCD reviews its quality management system for suitability, adequacy, and effectiveness twice a year, during the first week of the fall and spring semesters.
The review topics include follow-up on actions and recommendations from the previous meeting, audits results, customer feedback on services, status of preventive and corrective actions, and recommendations for improvements.
Records of the management review meetings are maintained on MF-01.

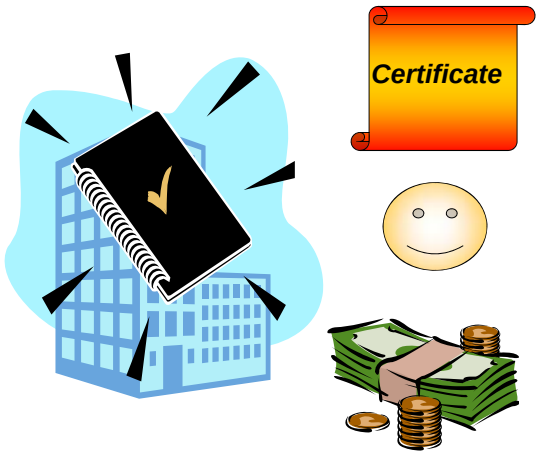

From Standards to Quality Manual
Identify Gap
Document
Organization
ISO 9001 Standard
Quality Manual
shall
shall
shall
shall
shall
shall


Implementing Documentation
Identify Gap
Document
Implement
Organization
ISO 9001 Standard
Implementing Quality Manual
shall
shall
shall
shall
shall
shall

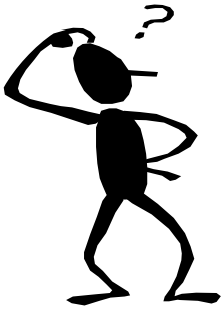
# Getting ISO 9001 Certificate



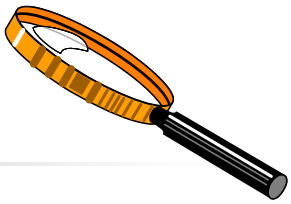

# Effective QMS: Beyond Certificate



## Why Audit?

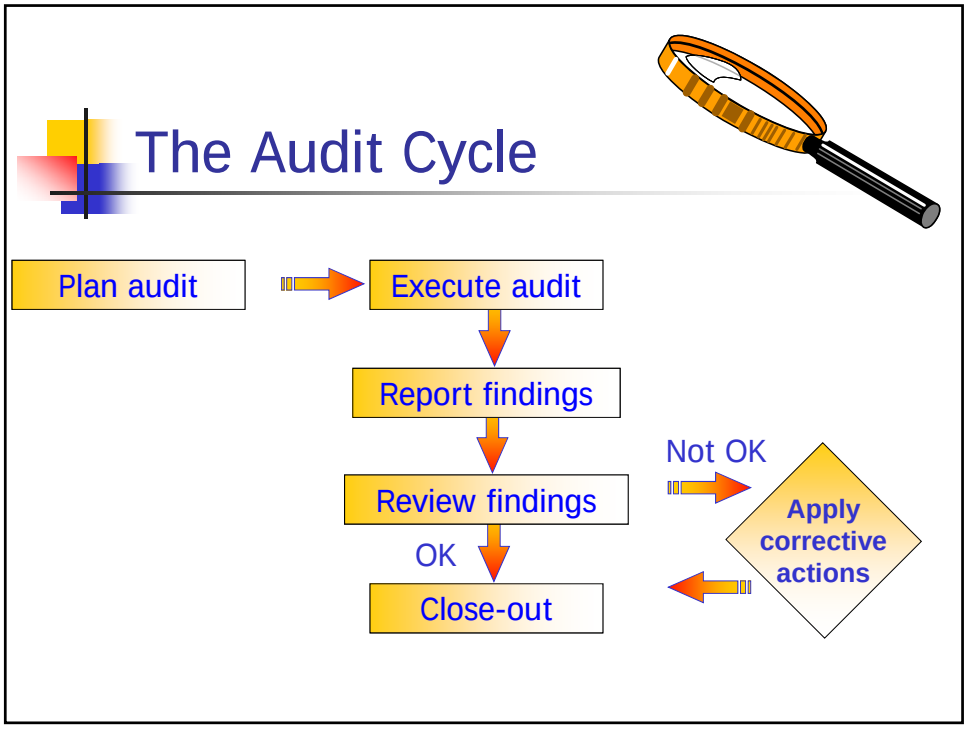


## Who Audits?



- Organization.
- Customer.
- Registrar.

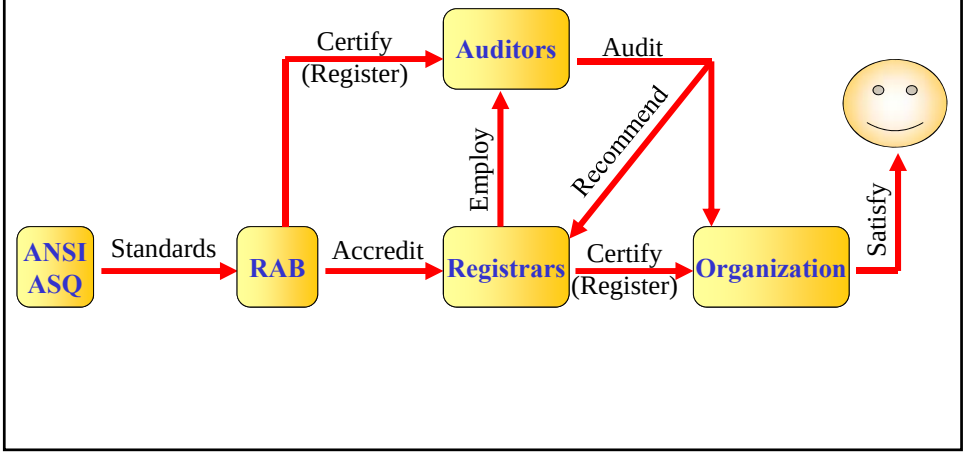
# The Audit Cycle



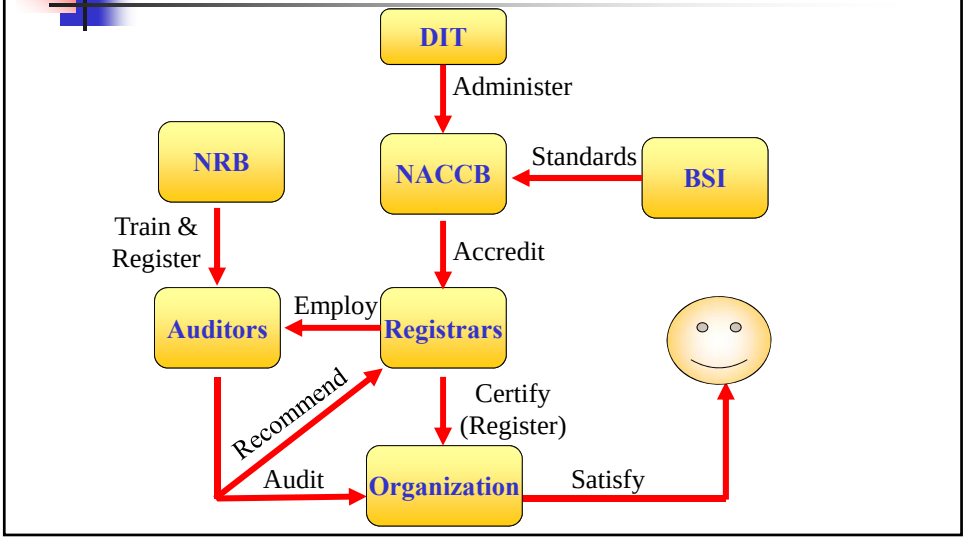

# Corrective versus Preventive Action

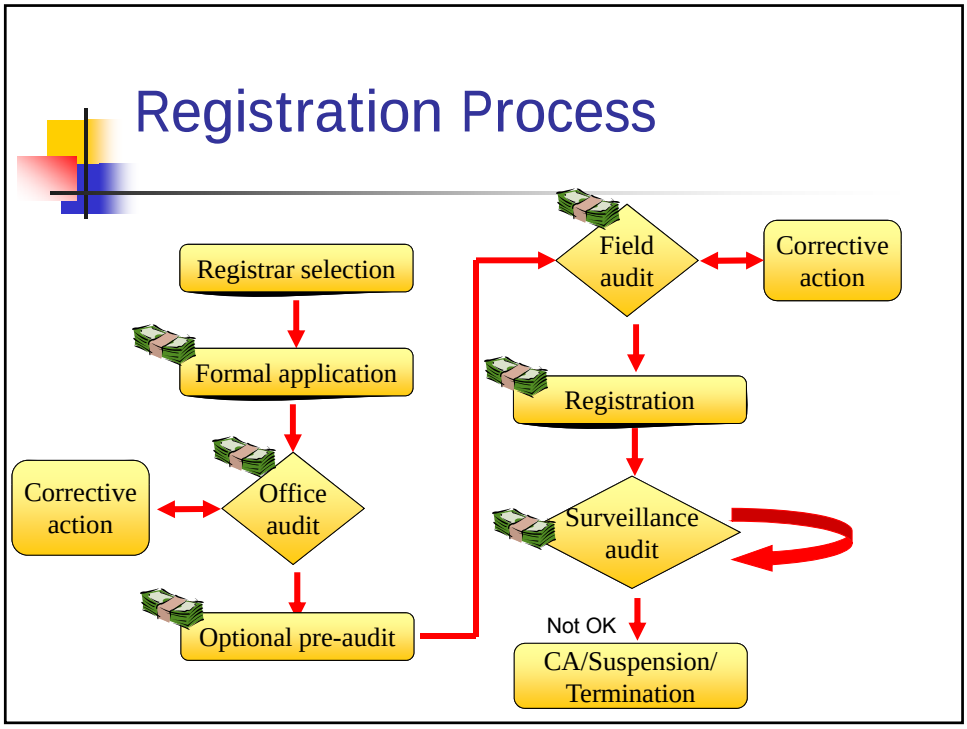
- Preventive Action:
  - Improve.
  - Prevent occurrence.
- Corrective Action:
  - Comply.
  - Stop recurrence.

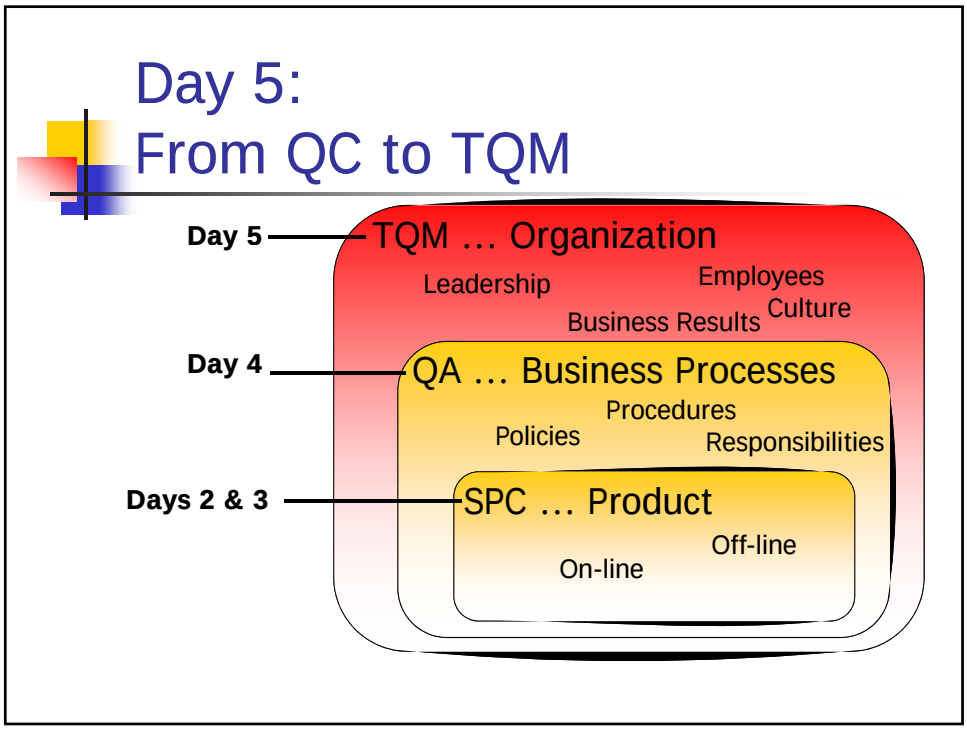
# USA Accreditation/ Registration System




# UK Accreditation/ Registration System



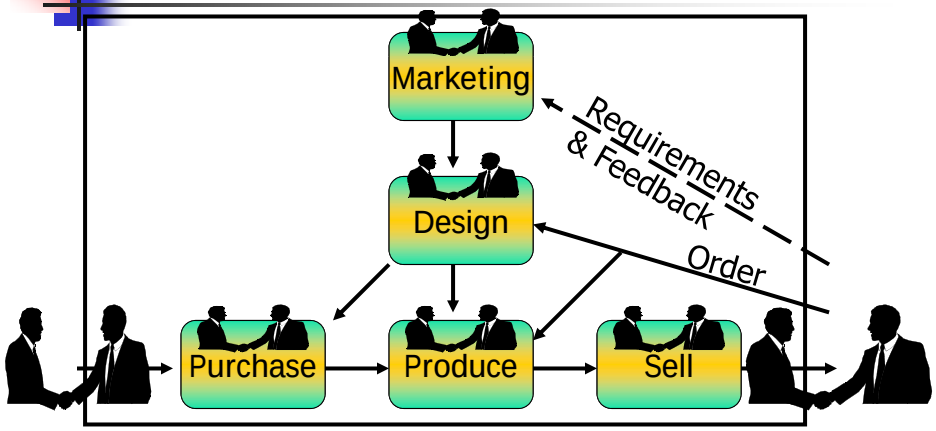

Registration Process
Registrar selection
Formal application
Office audit
Corrective action
Optional pre-audit
Field audit
Corrective action
Registration
Surveillance audit
Not OK
CA/Suspension/ Termination

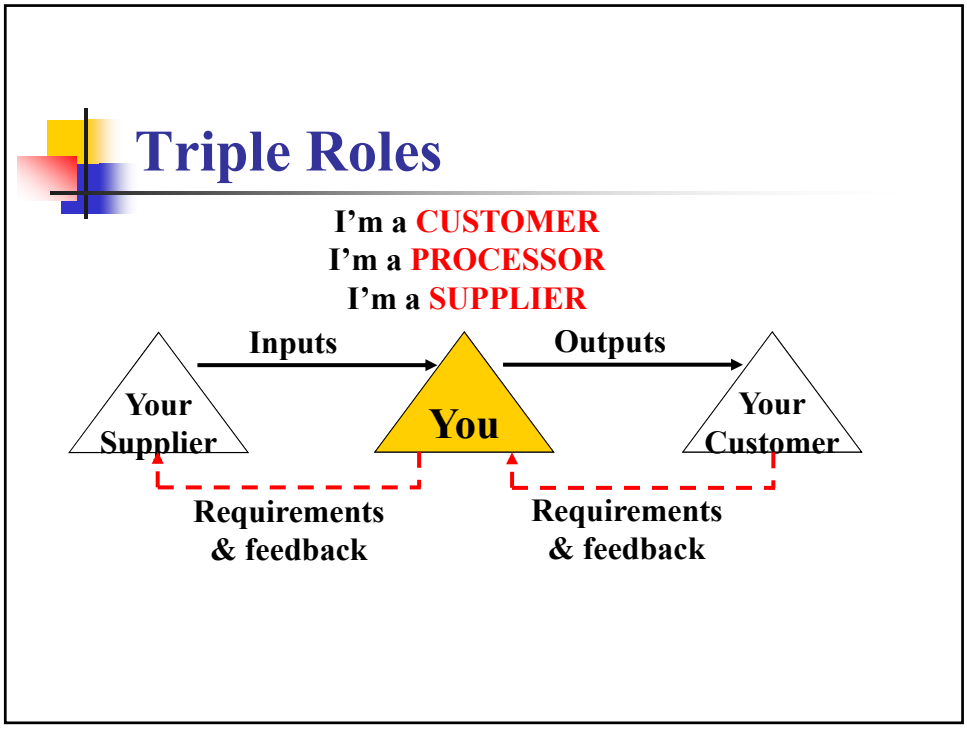

Day 5: From QC to TQM
Day 5
TQM … Organization
Leadership
Employees
Culture
Business Results
Day 4
QA … Business Processes
Procedures
Policies
Responsibilities
Days 2 & 3
SPC … Product
Off-line
On-line

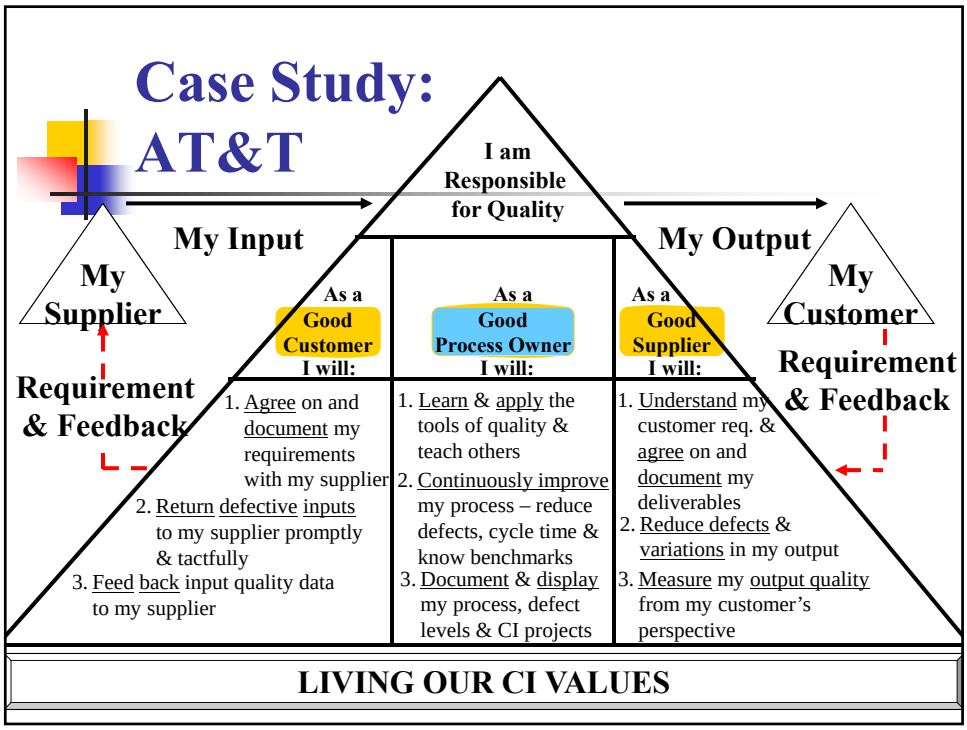
# Fundamentals of TQM

- Customer-focused.
- Process-based QMS.
- Fact-based CI approach.
- People.
- Results-driven.

# Internal & External Customers/Users




Triple Roles
I'm a CUSTOMER
I'm a PROCESSOR
I'm a SUPPLIER
Inputs
Outputs
Your Supplier
You
Your Customer
Requirements & feedback
Requirements & feedback


Case Study: AT&T
I am Responsible for Quality
My Input
My Output
My Supplier
My Customer
Requirement & Feedback
Requirement & Feedback
As a Good Customer I will:
1. Agree on and document my requirements with my supplier
2. Return defective inputs to my supplier promptly & tactfully
3. Feed back input quality data to my supplier
As a Good Process Owner I will:
1. Learn & apply the tools of quality & teach others
2. Continuously improve my process – reduce defects, cycle time & know benchmarks
3. Document & display my process, defect levels & CI projects
As a Good Supplier I will:
1. Understand my customer req. & agree on and document my deliverables
2. Reduce defects & variations in my output
3. Measure my output quality from my customer's perspective
LIVING OUR CI VALUES

# Fundamentals of TQM

- Customer-focused.
- Process-based QMS.
- Fact-based CI approach.
- People.
- Results-driven.

# The CI Approach

**NOW TQM**
Focus is on results


**PAST TQM**
Focus was on programs

Plan → Do

## Fundamentals of TQM

- Customer-focused.
- Process-based QMS.
- Fact-based CI approach.
- People.
- Results-driven.

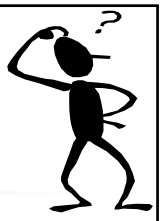
## People

- Leadership.
- Motivation & Recognition.
- Teamworking.
- Training.

## Leadership

- Leaders get people to *want* to do things.
- Leaders do the right things; managers do things right.
- Theory "X" and Theory "Y" Managers.

## Exercise: Leaders vs. Managers



Activity: Creating an agenda

_____ Develop a vision and establish strategies

_____ Establish detailed steps

Activity: Developing a network to achieve agenda

_____ Providing policies and procedures for team

_____ Influencing creation of teams

Activity: Implementing the agenda

_____ Monitoring results against plan

_____ Energizing people to overcome barriers

## Motivation & Recognition

- Leaders are great motivators.
- Motivation theories:
  - Mazlow
  - Hunt
  - Herzberg

## Herzberg Motivation Model

| Hygiene Factors | Motivators |
|---|---|
| Money | Sense of achievement |
| Status | Acknowledgement |
| Work conditions | Authorities |
| Relation with boss | Responsibilities |
| Relation with peers | Growth potential |
| Organization politics | Job pleasure |

# Training

| Identify Needs | Train | Evaluate |
|---|---|---|
| ▪Current knowledge, skills, & attitude<br>▪Desired knowledge, skills, & attitude<br>▪Gap<br>▪Plan | ▪On-the-job vs. off-the-job<br>▪Methods: coaching, lecturing, e-learning | ▪Did you like it?<br>▪Did you learn it?<br>▪Did you apply it?<br>▪Was it effective? |

# Fundamentals of TQM

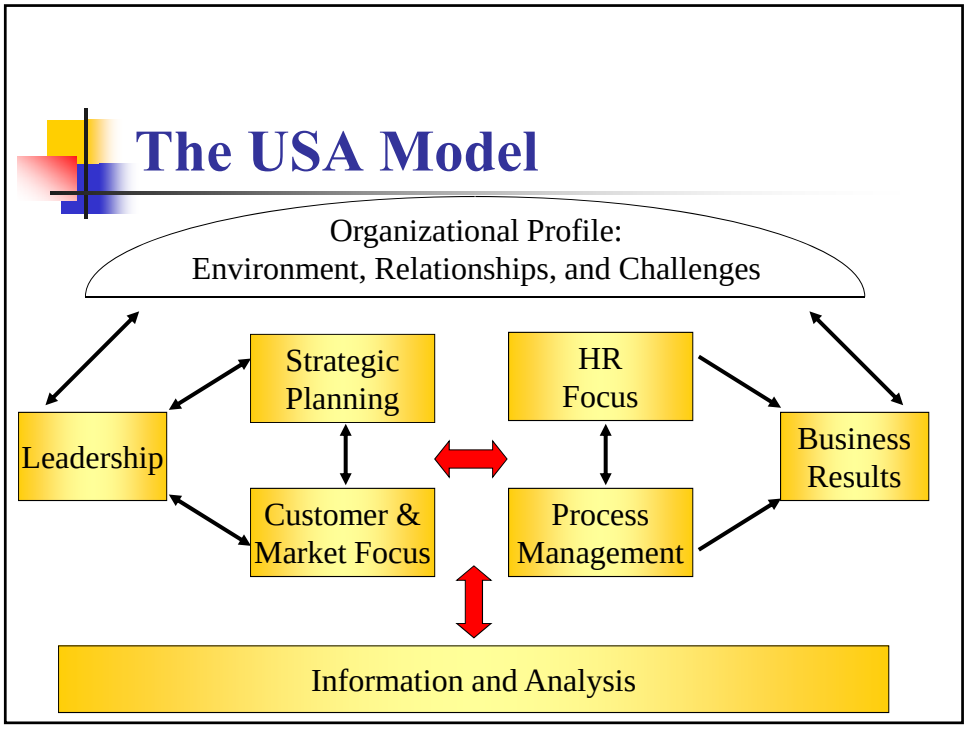
- Customer-focused.
- Process-based QMS.
- Fact-based CI approach.
- People.
- Results-driven.

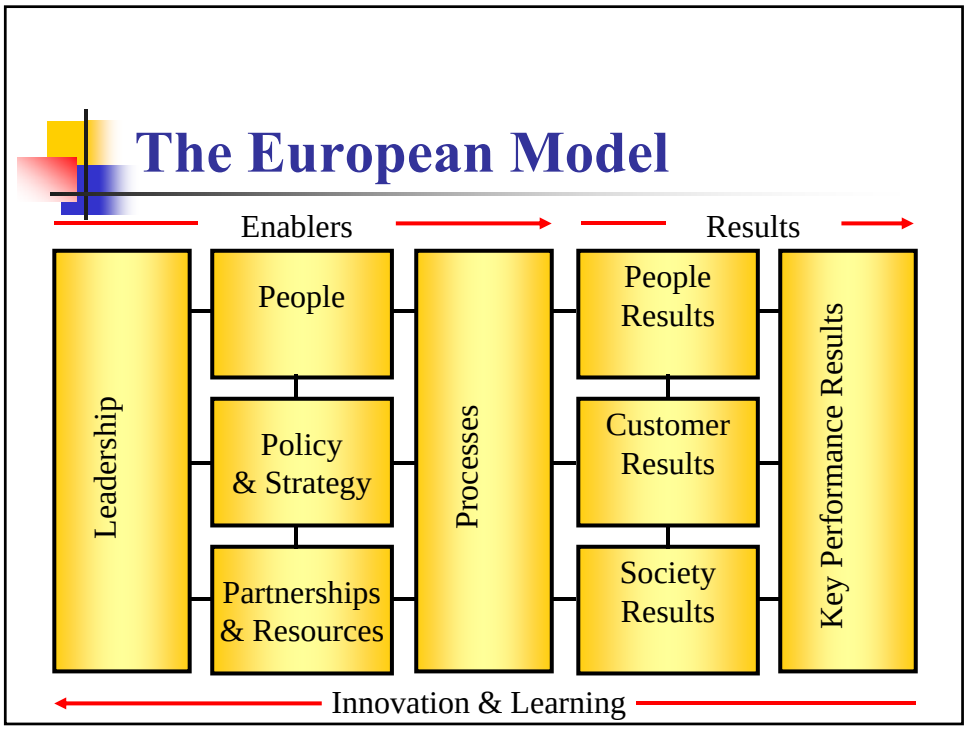
## Global TQM Models

- The USA Quality Award (BNQA), 1987
- European Quality Award (EQA), 1988
- Australian Quality Award (AQA), 1993
- Canadian Quality Award (CQA), 1984
- The Japanese Quality Award
  (The Deming Prize), 1951

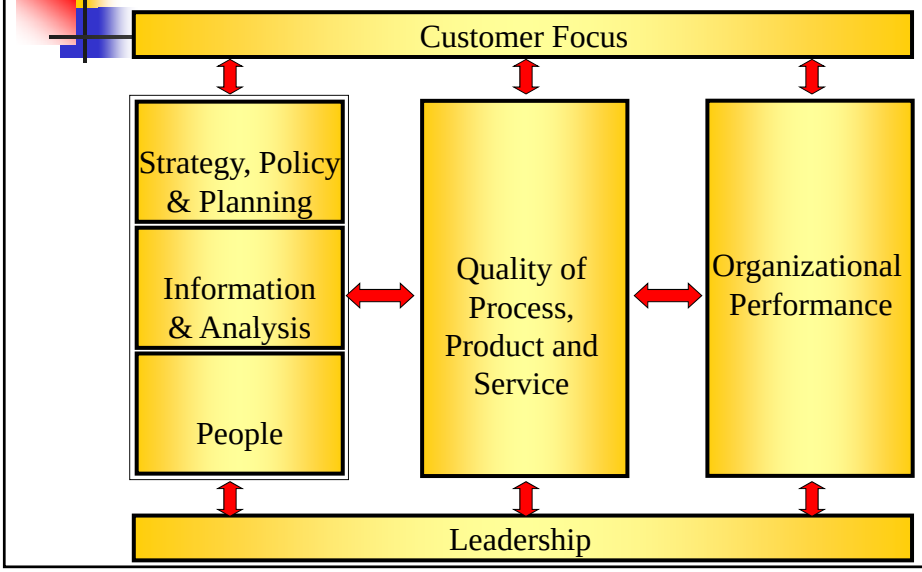
## Why TQM Models?

- They are based on TQM fundamentals
- Their criteria define organization excellence
- They are used to assess current status
- They are used to motivate for results


The USA Model
Organizational Profile:
Environment, Relationships, and Challenges
Leadership
Strategic Planning
HR Focus
Business Results
Customer & Market Focus
Process Management
Information and Analysis


The European Model
Enablers
Results
Leadership
People
Policy & Strategy
Partnerships & Resources
Processes
People Results
Customer Results
Society Results
Key Performance Results
Innovation & Learning

## The Australian Model




## The Canadian Criteria

- Leadership
- Planning
- Supplier focus
- Organizational performance
- Customer focus
- People focus
- Process management

## The Japanese Criteria

- Future Plans
- Human Resources
- Policies
- Organization
- Standardization
- Quality Assurance
- Maintenance
- Information
- Improvement
- Effects

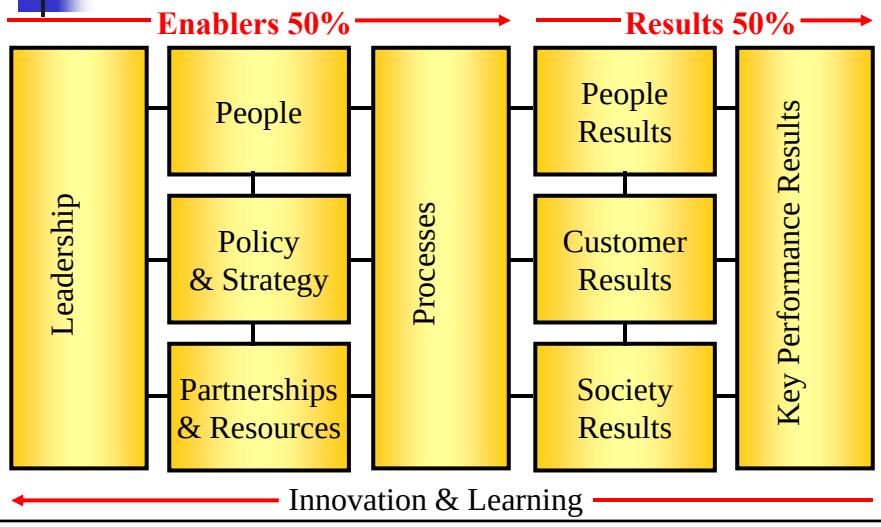
## Analyzing the Models: The USA

- Business Results **450**
- Leadership **120**
- Information and Analysis **90**
- Strategic Planning **85**
- Customer and Market Focus **85**
- Human Resource Focus **85**
- Process Management **85**

# Analyzing the Models: The European

- Customer Results **20%**
- Key Performance Results **15%**
- Processes **14%**
- Leadership **10%**
- People **9%**
- People Results **9%**
- Partnership & Resources **9%**
- Policy & Strategy **8%**
- Society Results **6%**

# The European Model: Enablers & Results



## Analyzing the Models: The Australian

- People **20%**
- Quality of process, product, and service **20%**
- Customer Focus **18%**
- Leadership **14%**
- Organizational Performance **12%**
- Strategy & Policy **8%**
- Information & Analysis **8%**

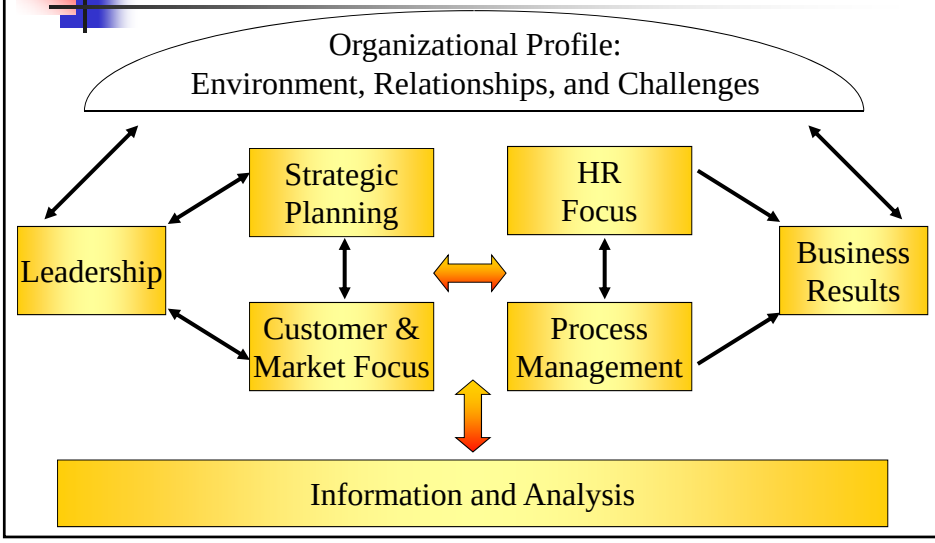
## Analyzing the Models: The Canadian

- Organizational performance **24%**
- Customer focus **17%**
- People focus **17%**
- Process management **17%**
- Leadership **10%**
- Planning **10%**
- Supplier focus **5%**

# Analyzing the Models: The Japanese

All 10 criteria are equally weighted at **10%**

# Closer Look: The BNQA:2001 Model



## BNQA Overview

- Is named after Malcolm Baldridge!
- Is a model for Performance Excellence
- The NIST and ASQ manage the program
- The model is revised annually
- 3 Performance Excellence booklets:
  - 2001 Business Criteria
  - 2001 Education Criteria
  - 2001 Health Care Criteria

## BNQA Overview

- 5 Award categories each year:
  - Manufacturing businesses
  - Service businesses
  - Small businesses (500 or fewer employees)
  - Education organizations
  - Health care organizations
- 3 awards may be given in each award category each year

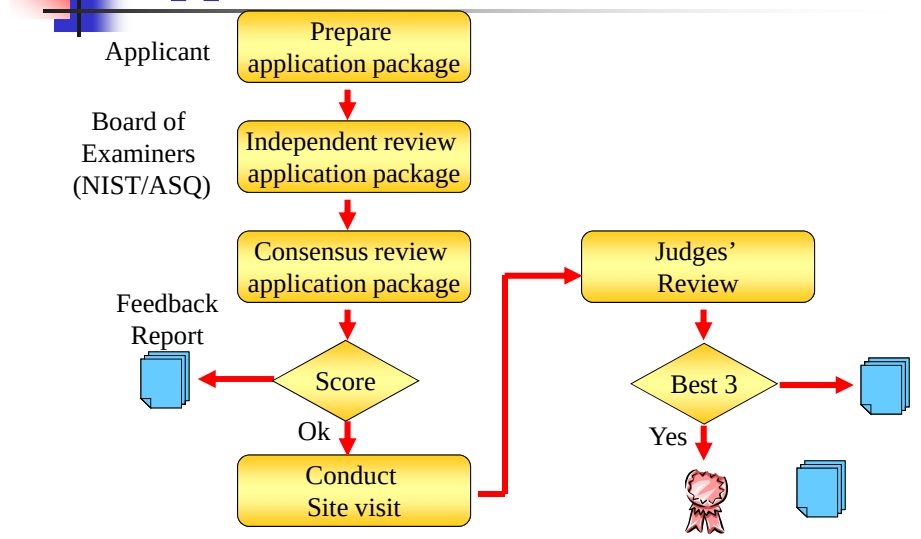
## Company Benefits

- Win award
- Basis for corporate self-assessment
- On average, publicly traded award recipients have outperformed S&P's 500 by four to one
- Cheap consulting!
  - Receive analysis report from 5-6 highly trained experts for only $5,000

## Famous Winners

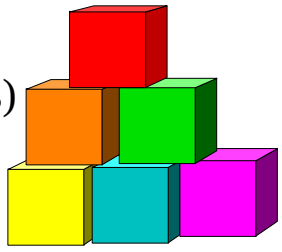
- FedEx
- GE
- Motorola
- 3M
- Eastman Chemical Co.
- Xerox
- American Express
- Ben & Jerry's

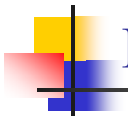
## Application Review Process




## The Model Components

- 7 Criteria
- 18 Items (General Requirements)
- 29 Areas to address (Specific Requirements)





## REMEMBER

In general, Excellence and Quality Models such as BNQA, EQA, and ISO tell you **what** is excellence. They do not tell you **how** to achieve excellence.

## What is Six Sigma? General

- Is a TQM strategy
- Developed by Motorola in 1988
- Focuses on breakthrough process improvement to achieve customer satisfaction, cycle time and defect reductions, and ultimately bottom-line improvement

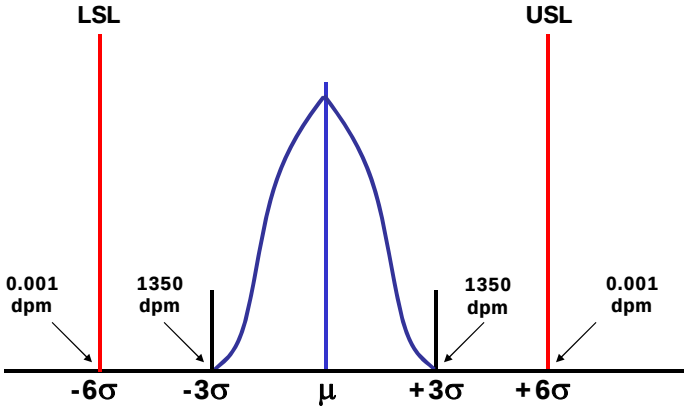
## Six Sigma Success

- Massive bottom-line benefits
- Many BNQA winners (e.g. GE, Motorola)
- Exponential increase in the number of fortune global 500 companies adopting six sigma
  - 1985-1990: **2** (Motorola & IBM)
  - 1991-1995: **6** (GE, Allied Signal, Kodak, etc.)
  - 1996-1999: **31** (Dow Chemicals, DuPont, Sony, American Express, Johnson&Johnson, Raytheon, United Technologies, US Postal Service, etc.)

## The Technical Meaning of Six Sigma

- Sigma is a statistical measure of process variability
- The number of defects per million (dpm) at Motorola's six sigma is 3.4
- True six sigma processes yield 2dpb
- Most processes in good companies operate at three sigma, which yield 2,700 dpm (99.73%)

## Six Sigma Process




## Processes Capabilities

| Spec. Distance from μ | One-sided Spec. | Two-sided Spec. |
|---|---|---|
| Less than 3σ | Incapable Process | Incapable Process |
| 3.0σ | 1,350 | 2,700 |
| 4.5σ | 1.7 | 3.4 |
| 6.0σ | 0.001 | 0.002 |

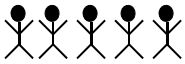
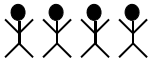
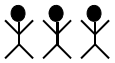
## The Six Sigma CI Approach & PDCA

- Define … Determine project (Plan)
- Measure …. Determine current (Do)
- Analyze …. Find solutions (Do)
- Implement …. Execute (Do)
- Control …. (Check & Act)

## Six Sigma: Common Quality Tools

- Pareto analysis
- Root-cause analysis
- Statistical process control
- Design of experiments

## The Training Pyramid

| Course | | Six Sigma Title |
|---|---|---|
| Basic |  | White Belts |
| Medium |  | Green Belts |
| Comprehensive |  | Black Belts |
| Executive |  | Champions |
| Executive |  | Believer |

## The Training Pyramid

| Rank | | Main Role |
|---|---|---|
|  | Employees | Task improvement |
|  | Supervisors | Lead small IPs |
|  | Managers | Lead major, cross-functional IPs |
|  | In-house Experts | Train, provide expertise |

## Why Six Sigma Succeeds?

- ‘Real’ top management commitment
- Goals with identical improvement rates
- Common quality measurement techniques
- Common language throughout the organization
- Systematic training
- Goal-directed incentives for people