# Quality Control:
# Concept ,Quality Gurus, Quality Features

# Quality

- Quality is the degree to which an object or entity (e.g., process, product, or service) satisfies a specified set of attributes or requirements.
- Fitness to use
- Customer satisfaction

# Quality Engineering

- Two major factors of success in any organization are market demand & profitability.
- Factors influencing the competitive edge of a company are the unit cost, product quality and lead time.
- Best approach of product quality is to build quality into the product and process right at the process & product design stage.
- Quality may also be improved at the production stage by using statistical process control technique.

# What is Quality?

" The quality of a product or service is a customer's perception of the degree to which the product or service meets his or her expectations."

According to **Dr**. **W.R.Spriegel** , " The **quality** of a product may be defined as the sum of a number of related characteristics such as shape, dimension, composition, strength, workmanship, adjustment, finish and color."

# What is Quality Control?

- "Quality control may be defined as that industrial management technique or group of techniques by means of which products of uniform acceptable quality are manufactured."

  **Alford and Beatty**

- "Quality control refers to the systematic control of those variables encountered in a manufacturing process which affect the excellence of the end product, Such variables result from the application of materials, men, machines and manufacturing conditions,"

  **Bethel, Atwater and Stackman**

# The Dimensions of quality

- Performance: Primary operating characteristics
- Features : Secondary operating characteristics
- Time : Time of service, time waiting in line
- Reliability : Extent of failure free operation
- Durability : Amount of use until replacement is preferable to repair.
- Uniformity : Low variation among the repeated outcomes of a process.
- Consistency : Match with documentation, advertising, deadlines.
- Serviceability : Resolution of problems
- Aesthetics
- Personal interface
- Harmlessness

# Evolution of Quality

- Operator quality control period (upto 1900)
- Foreman quality control period (1900-1920)

  Mass production, foreman or supervisor control the quality of product.
- Inspection quality control period (1920-1940)

  Inspectors were assigned to check the quality after certain operations.
  1920- Walter Shewhart developed statistical quality chart
  1924- Dodge & Roming developed Acceptance sampling plan
- Statistical quality control period (1940-1960)

  After World war-II, **Edward Deming** visited Japan in 1950 - Statistical quality control
  **J.M.Juran** visited Japan in 1954 - Role of management in quality
- Total quality control period (1960-1970)

  Each department plays an important role in producing quality products.
- Total quality control organization wide (1970)

# The Quality Gurus

- Quality Gurus
  - Individuals who have been identified as making a significant contribution to improving the quality of goods and services.
    - Walter A. Shewhart
    - W. Edwards **Deming**
    - Joseph M. **Juran**
    - Armand Feigenbaum
    - Philip **Crosby**
    - Kaoru Ishikawa

# Quality Gurus

- Walter Shewart
  - In 1920s, developed control charts
  - Introduced the term "*quality assurance*"
- W. Edwards Deming
  - Developed courses during World War II to teach statistical quality-control techniques to engineers and executives of companies that were military suppliers
  - After the war, began teaching statistical quality control to Japanese companies
- Joseph M. Juran
  - Followed Deming to Japan in 1954
  - Focused on strategic quality planning

# Quality Gurus (cont.)

- Armand V. Feigenbaum
  - In 1951, introduced concepts of total quality control and continuous quality improvement
- Philip Crosby
  - In 1979, emphasized that costs of poor quality far outweigh the cost of preventing poor quality
  - In 1984, defined absolutes of quality management—conformance to requirements, prevention, and “zero defects”
- Kaoru Ishikawa
  - Promoted use of quality circles
  - Developed “fishbone” diagram
  - Emphasized importance of internal customer

# Deming’s 14 Points

1. **Create constancy of purpose**
   - Mission statement should be developed and published to all employees, vendors, investors and to customers.

2. **Adopt philosophy of prevention**
   - Acceptable levels of defects should be abandoned & no-defects philosophy should be adopted.
   - Adoption of the new policy must be embraced by everybody.

3. **Cease mass inspection**
   - Quality has to be designed into the product, it can’t be inspected into it.
   - Mass inspection does not prevent defects nor it improves the process.

# Deming's 14 Points (cont.)

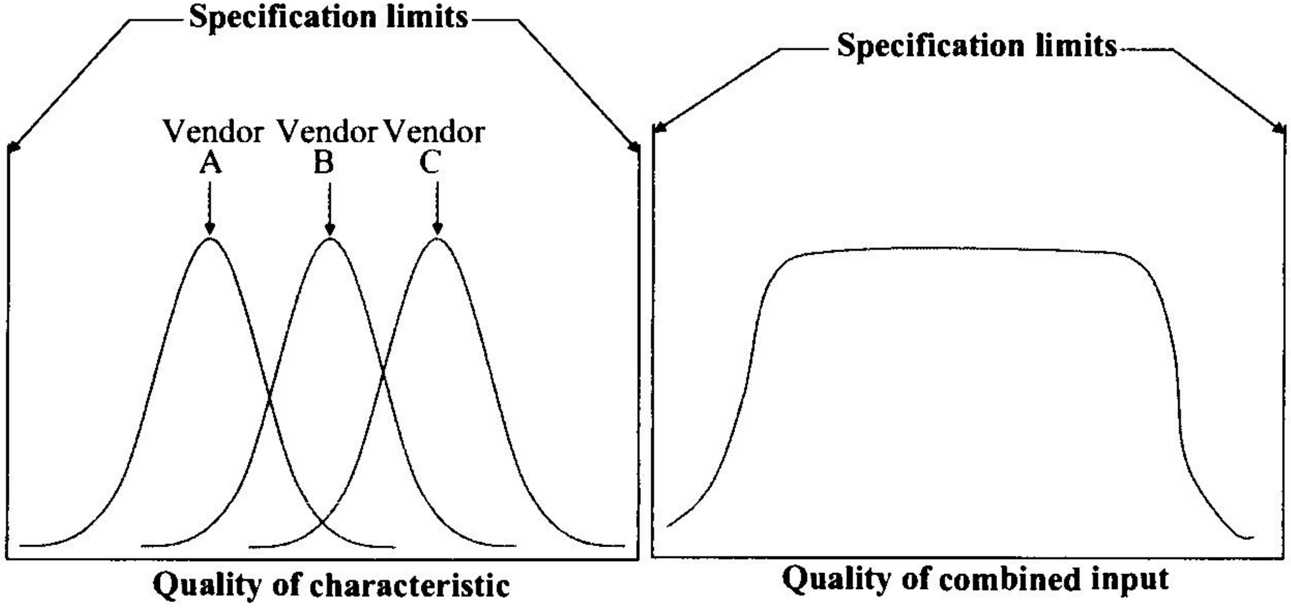
## 4. Select a few suppliers based on quality

- **Goal should be to move towards single suppliers. Multi suppliers policy has many disadvantages –**

  **Mistrust between buyer & vendor**

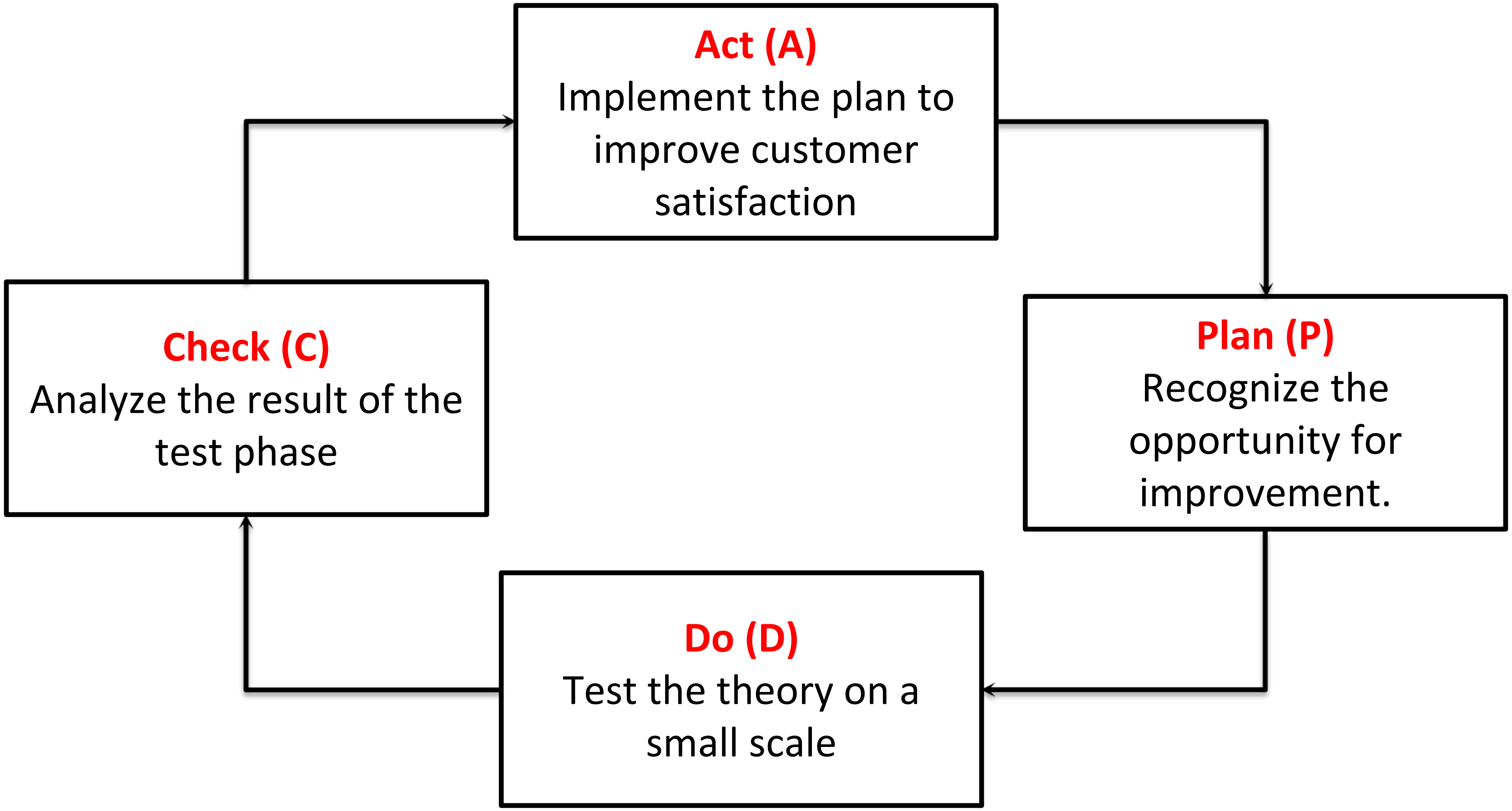
  **Increased cost**

  **Increased variability in incoming quality.**



# Deming's 14 Points (cont.)

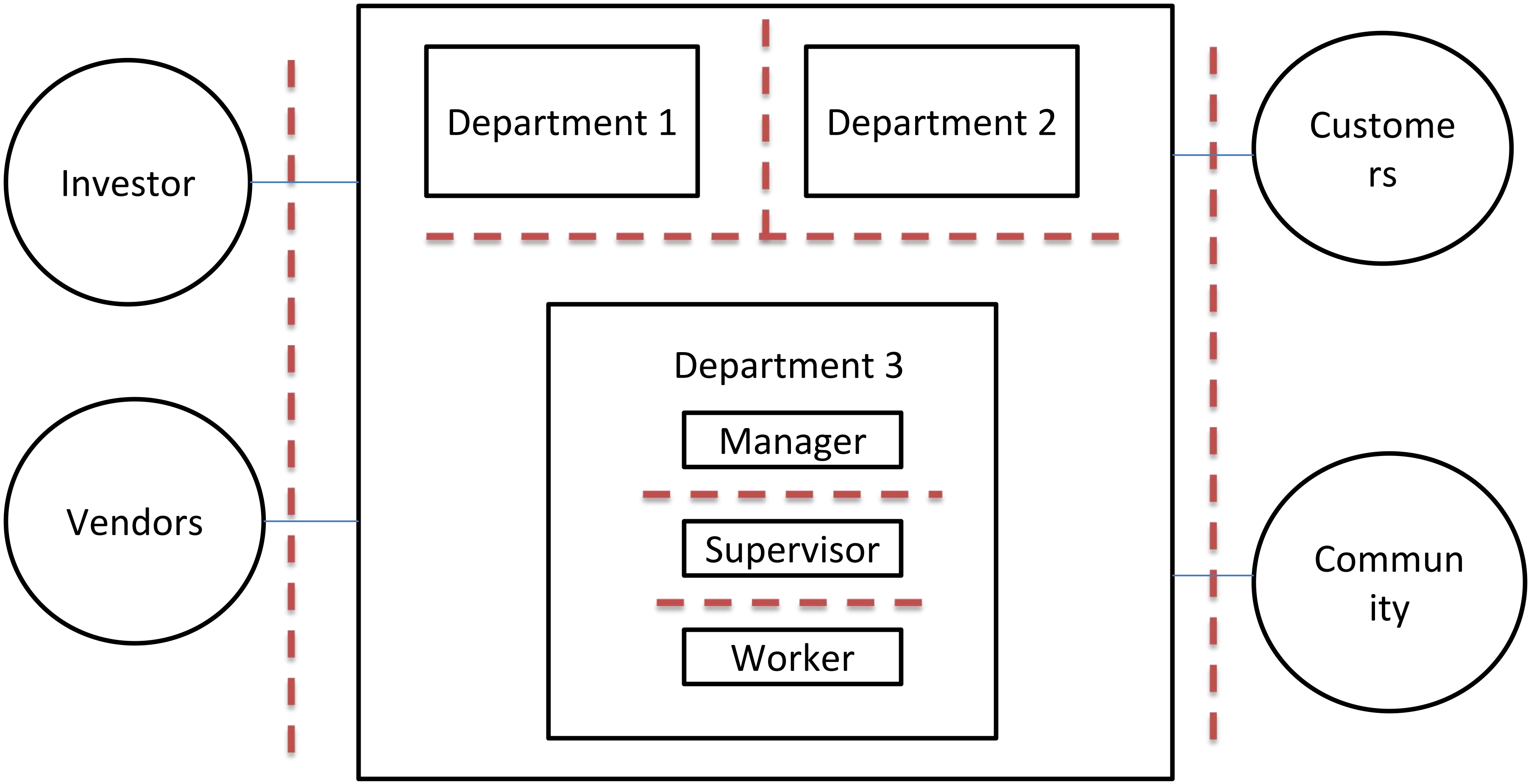
5. **Improve constantly the system of production & services**
   - **Continuous cycle of process improvement is based on a scientific method known as Deming's Cycle which has 4 stages – *Plan, Do, Check, Act ( also known as PDCA cycle)***



# Deming’s 14 Points (cont.)

6. **Institute training**
7. **Teach & institute leadership**
8. **Drive out fear. Create trust. Create climate for innovation**
9. **Optimize towards the aim & purposes of the company the efforts of teams, groups, staff area**
    - **External Barrier : Barrier between vendors & company, the company & the customers , company & community , company & investors**
    - **Internal Barriers : Barriers between different departments of the company**
10. **Eliminate exhortations for the workflow**
    - **Avoid numerical goals or slogans which are set arbitrarily**

# Deming's 14 Points (cont.)



# Deming’s 14 Points (cont.)

11. Remove numerical quotas fr production
    - **Numerical quotas promotes production of nonconforming items.**
    - **The quota system fails to distinguish between special causes and common causes.**
    - **Work standards are based on quantity not quality.**
12. Enhance worker pride
13. Institute vigorous training and education programs
14. Develop a commitment from top management to implement above 13 points

# The Quality Gurus (cont'd)

- Joseph M. Juran
  - Emphasized the importance of producing quality products through an approach focused on quality planning, control, and improvement.
  - Defined product quality as "fitness for use"
  - Categorized the cost of quality as:
    - Cost of prevention
    - Cost of detection/appraisal
    - Cost of failure

# The Juran philosophy

Quality Trilogy –

1. *Quality planning*: Process of preparing to meet quality goals. Involves understanding customer needs and developing product features.
2. *Quality control*: Process of meeting quality goals during operations. Control parameters. Measuring the deviation and taking action.
3. *Quality improvement*: Process for breaking through to unprecedented levels of performance. Identify areas of improvement and get the right people to bring about the change.

# The Juran philosophy

Quality Trilogy –

1. *Quality planning*: Process of preparing to meet quality goals. Involves understanding customer needs and developing product features.

Quality Planning works in 3 levels of organisation

- Upper management-Strategic quality management
- Middle management - Operational Quality management
- Workforce level
    - Establish quality goals
    - Identify the customer
    - Determine customer need
    - Develop product features that responds to customer needs
    - Develop Process fatures
    - Prove Process Capability or establish process control

# The Juran philosophy

Quality Trilogy –

2. *Quality control*: Process of meeting quality goals during operations. Control parameters. Measuring the deviation and taking action.

- Choose control subjects
- Choose units of measurement
- Establish measurement goal
- Create a sensor
- Measure the actual performance
- Interpret the difference
- Take action on the difference

# The Juran philosophy

Quality Trilogy –

3. *Quality improvement(Quality Breakthrough sequence)*:
Process for breaking through to unprecedented levels of performance. Identify areas of improvement and get the right people to bring about the change.
   - Prove the need for improvement
   - Identify specific projects for improvement
   - Organize to guide the projects
   - Organize for diagnosis
   - Find the causes
   - Provide remedies
   - Prove that remedies are effective under operating conditions
   - Provide control mechanisms to hold the gains

# Philip Crosby

- Preached that “quality is free.”
- Believed that an organization can reduce overall costs by improving the overall quality of its processes.

# The Crosby philosophy

4 Absolute’s of Quality Management

- Definition of quaity- *conformance to requirements*
- System for achivement of quality- *Prevention of defects*
- Performance standard - *Zero Defects*
- Performance measurement - *cost of quality*: the cost of non-conformance.

# Three of the Quality Gurus Compared

| | Crosby | Deming | Juran |
|---|---|---|---|
| Definition of quality | Conformance to specifications | A predictable degree of uniformity and dependability at low cost and suited to the market | Fitness for use |
| Degree of senior management responsibility | Responsible for quality | Responsible for 85% of quality problems | Less than 20% of quality problems are due to workers |
| Performance standard/ motivation | Zero defects | Quality has many "scales": use statistics to measure performance in all areas; critical of zero defects | Avoid campaigns to do perfect work |
| General approach | Prevention, not inspection | Reduce variability by continuous improvement; cease mass inspection | General management approach to quality, especially human elements |
| Structure | 14 steps to quality improvement | 14 points for management | 10 steps to quality improvement |

# Three of the Quality Gurus Compared (cont'd)

| | Crosby | Deming | Juran |
|---|---|---|---|
| Statistical process control (SPC) | Rejects statistically acceptable levels of quality | Statistical methods of quality control must be used | Recommends SPC but warns that it can lead to tool-driven approach |
| Improvement basis | A process, not a program; improvement goals | Continuous to reduce variation; eliminate goals without methods | Project-by-project team approach; set goals |
| Teamwork | Quality improvement teams; quality councils | Employee participation in decision making; break down barriers between departments | Team and quality circle approach |
| Costs of quality | Cost of nonconformance; quality is free | No optimum; continuous improvement | Quality is not free; there is an optimum |

# Three of the Quality Gurus Compared (cont'd)

| | Crosby | Deming | Juran |
|---|---|---|---|
| Purchasing and goods received | State requirements; supplier is extension of business; most faults due to purchasers themselves | Inspection too late; allows defects to enter system through AQLs; statistical evidence and control charts required | Problems are complex; carry out formal surveys |
| Vendor rating | Yes and buyers' quality audits useless | No, critical of most systems | Yes, but help supplier improve |
| Single sourcing of supply | | Yes | No, can neglect to sharpen competitive edge |

# Quality Circles

- *Informal group consists of workers , supervisors & managers* that meet regularly to improve ways to make a product or deliver a service.
- Developed by *Kaoru Ishikawa* at University of Tokyo.
- Became immediately popular in Japan as well as USA.
- Typically *small day-to-day problems* are given to quality circles. Since workers are most familiar with the routine tasks, they are asked to identify, analyze and solve quality problems in the routine processes.
- The first Quality circle started at the Nippon Wireless & in India it was introduced by BHEL, Hyderabad
- Team should be of 6-8 members
- Team should participate voluntarily.

# Benefits of Quality Circles

To Organisation:

- Quality improvement of product or service
- Increase the productivity
- Reduce work related errors & cost

To the Employee

- Improve communication skill
- Provides job interest
- Improve problem solving capabilities

# Cost of Quality

1. Prevention Cost
2. Appraisal Cost
3. Internal Failure Cost
4. External Failure Cost

# Cost of Quality

## 1. Prevention Cost

- Cost Incurred in planning, implementing and maintaining quality system to prevent poor quality in product or services.
- Includes salaries & development cost for product design, process & equipment design
- Cost of Education & training

## 2. Appraisal Cost

- Cost of calibrating & maintaining measuring instruments & equipments
- Cost of materials & products used in a destructive test or reliability test.
- Occurs during and after production before the product released to the customer.
- Cost associated with measuring, evaluating or auditing products, purchase material or service to determine their degree of conformance.

# Cost of Quality

## 3. Internal Failure Cost

- Incurred when product, material or service fails to meet quality requirements before dispatching to customer.
- Cost of scrap & rework cost for material, labor
- Cost in determining cause of failure, retesting, re-inspecting reworked products.
- Downgrading cost (sold in lower cost)

## 4. External Failure Cost

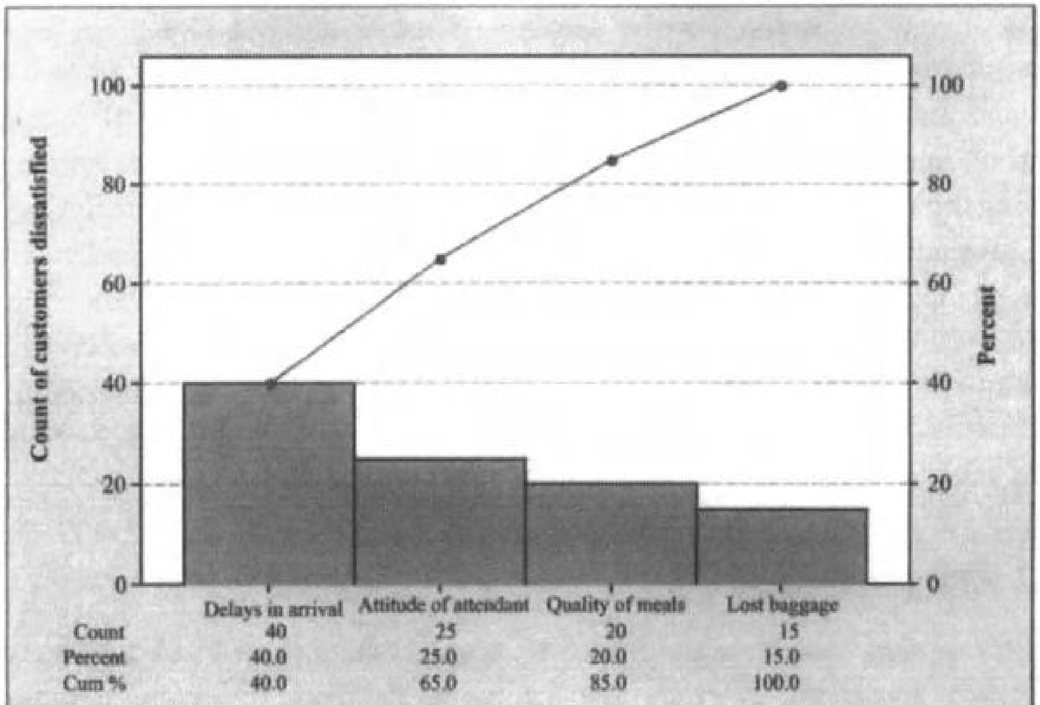
- Incurred when product does not perform satisfactorily after ownership transferred to customer.
- Cost associated to customer complaints which includes handling, repair, replacement of nonconforming products.
- Warranty charges, product liability charges also come under this category.

# Problem Solving QC Tools

1. Pareto Analysis
2. Flowcharts
3. Cause-and-Effect Diagrams
4. Scatter Diagrams
5. Checklists
6. Control Charts
7. Histograms
8. Multivariable Charts
9. Failure mode & effects Criticality analysis (FMECA)

# Pareto Analysis

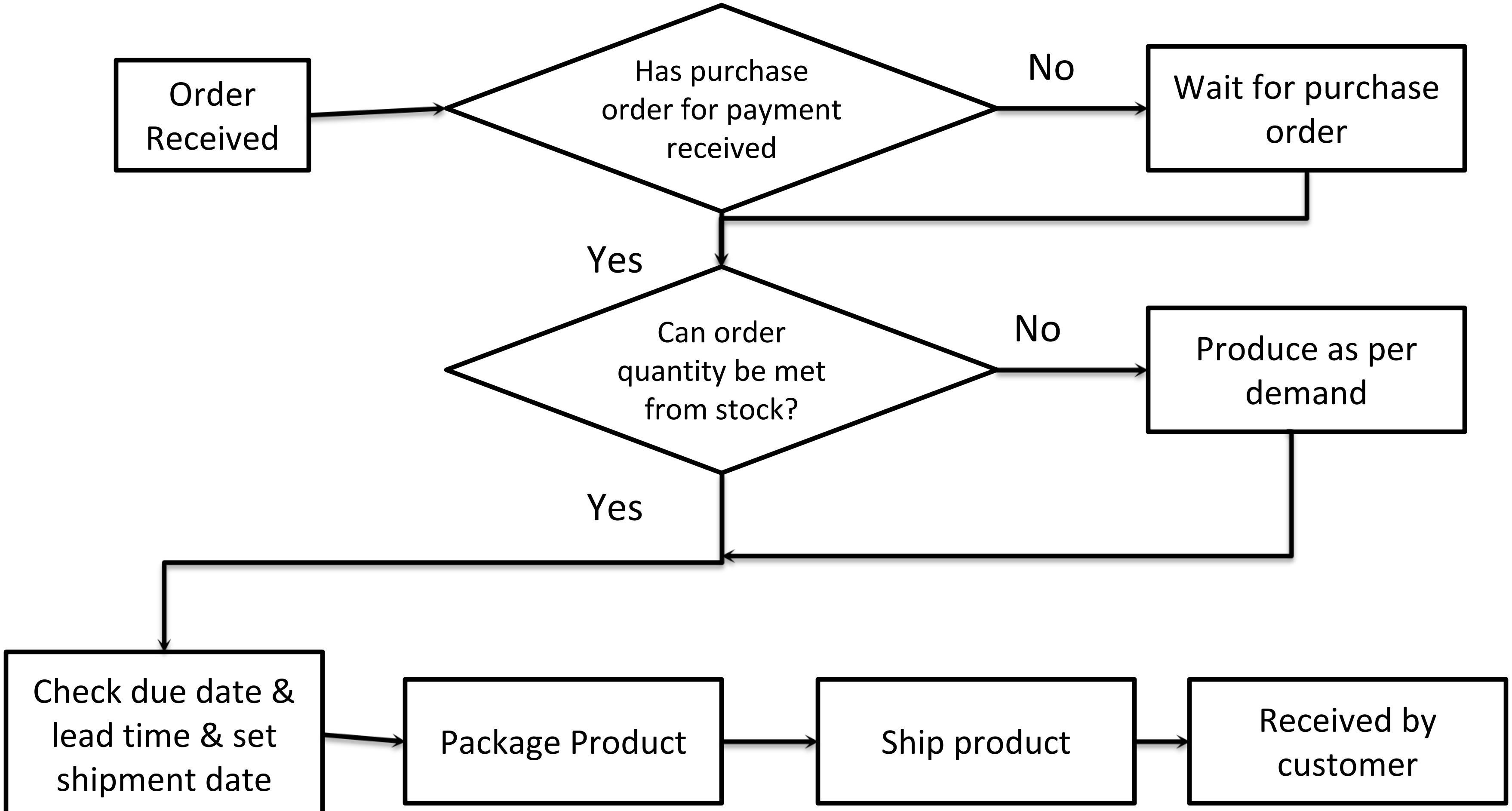
- Identify the critical areas that deserves immediate action.
- Technique that displays the degree of importance for each element
- Named after the 19th century Italian economist Alfredo Pareto.
- Often called the 80-20 Rule (Vital few and trivial many)
- Principle is that quality problems are the result of only a few problems e.g. 80% of the problems caused by 20% of causes




| Reasons | Count |
|---|---|
| Lost baggage | 15 |
| Delay in arrival | 40 |
| Quality of meals | 20 |
| Attitude of attendant | 25 |

# Flowcharts

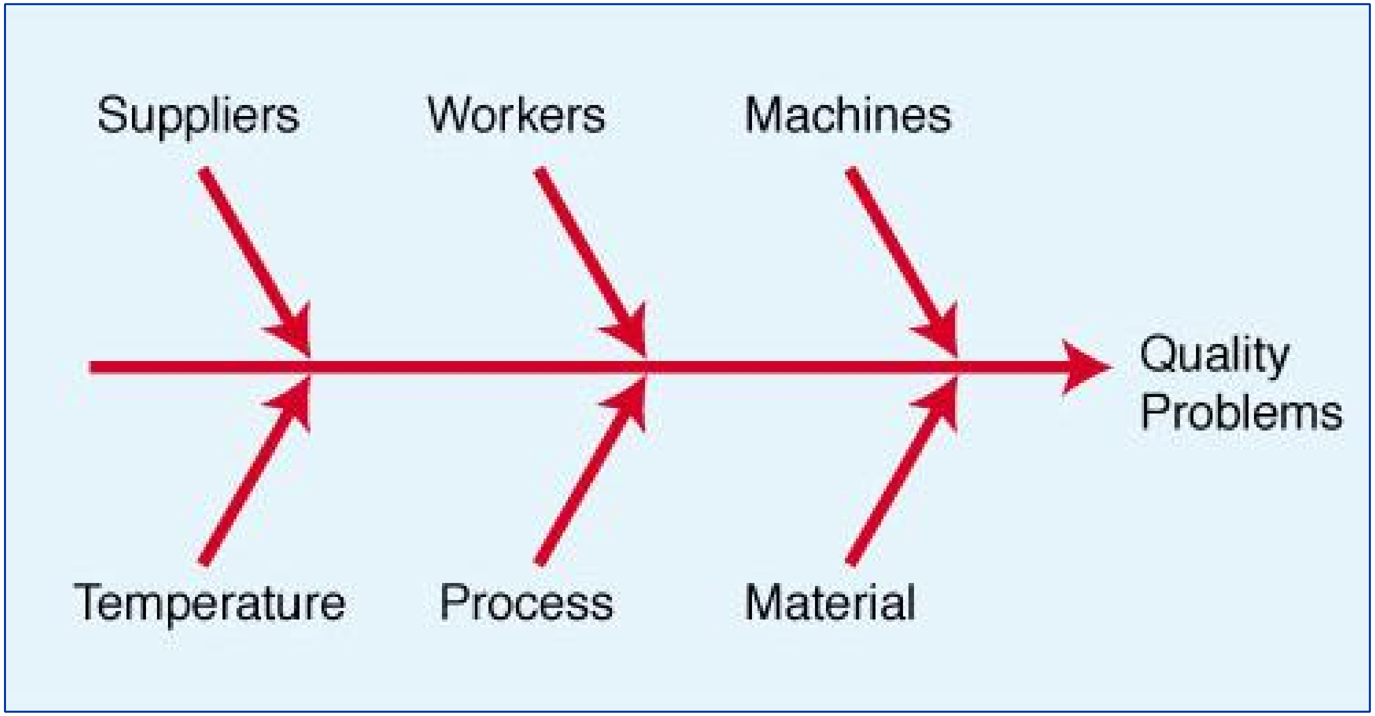
- Used to document the sequence of events in a process.
- A detailed flowchart can identify bottlenecks, redundant steps, non-value added activities.



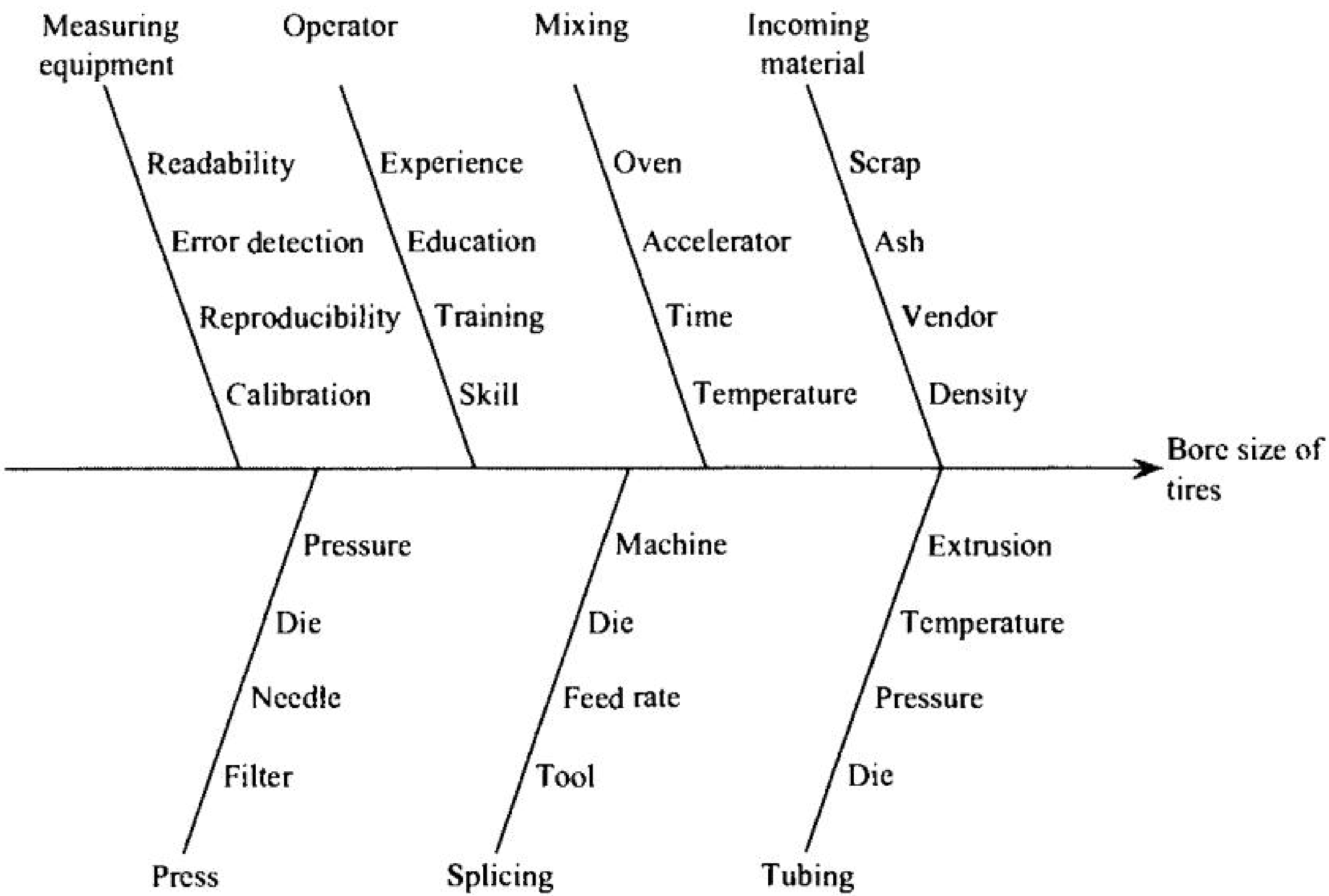

**Flow chart for incoming order processing**

# Cause-and-Effect Diagrams

- Developed by Ishikawa in 1943
- Called Fishbone Diagram or Ishikawa diagram
- Explore possible root causes of a problem
- If process is stable, this diagram helps to decide which causes to investigate for process investigation.

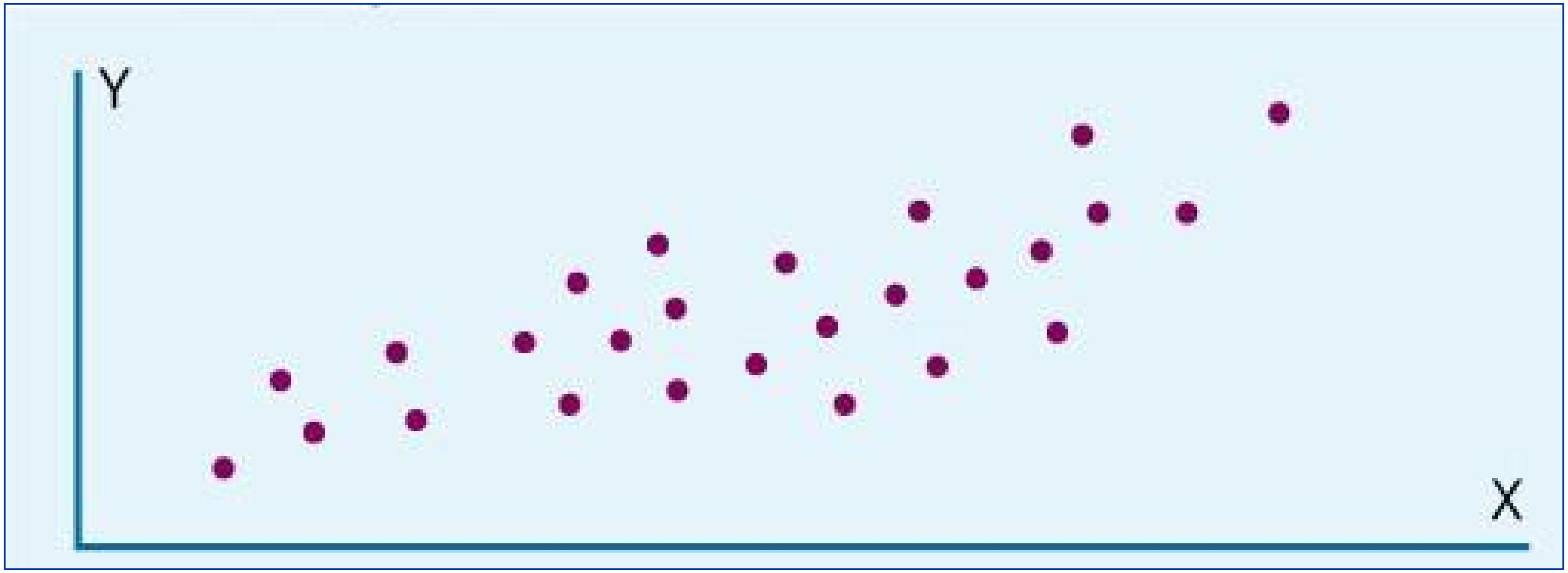


# Cause-and-Effect Diagrams



# Scatter Diagrams

- **A graph that shows how two variables are related to one another**
- **Often used a s follow-ups to a cause & effect analysis**




**Sales**

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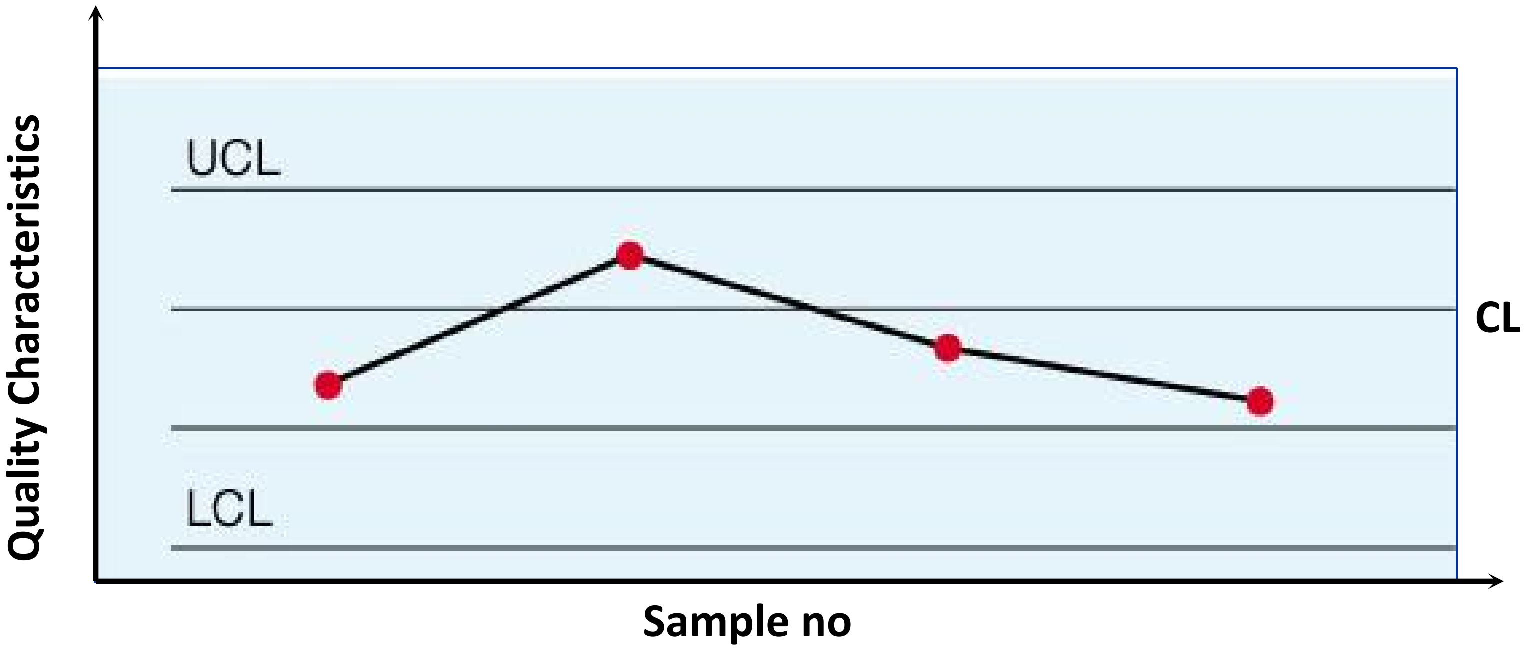
# Checklist

- It facilitates systematic record keeping or data collection
- Observations are recorded as they happen, which reveals pattern or trends.
- Simple data check-off sheet designed to identify type of quality problems at each work station; per shift, per machine, per operator

| Defect Type | No. of Defects | Total |
|---|---|---|
| Broken zipper | ✓✓✓ | 3 |
| Ripped material | ✓✓✓✓✓✓✓ | 7 |
| Missing buttons | ✓✓✓ | 3 |
| Faded color | ✓✓ | 2 |

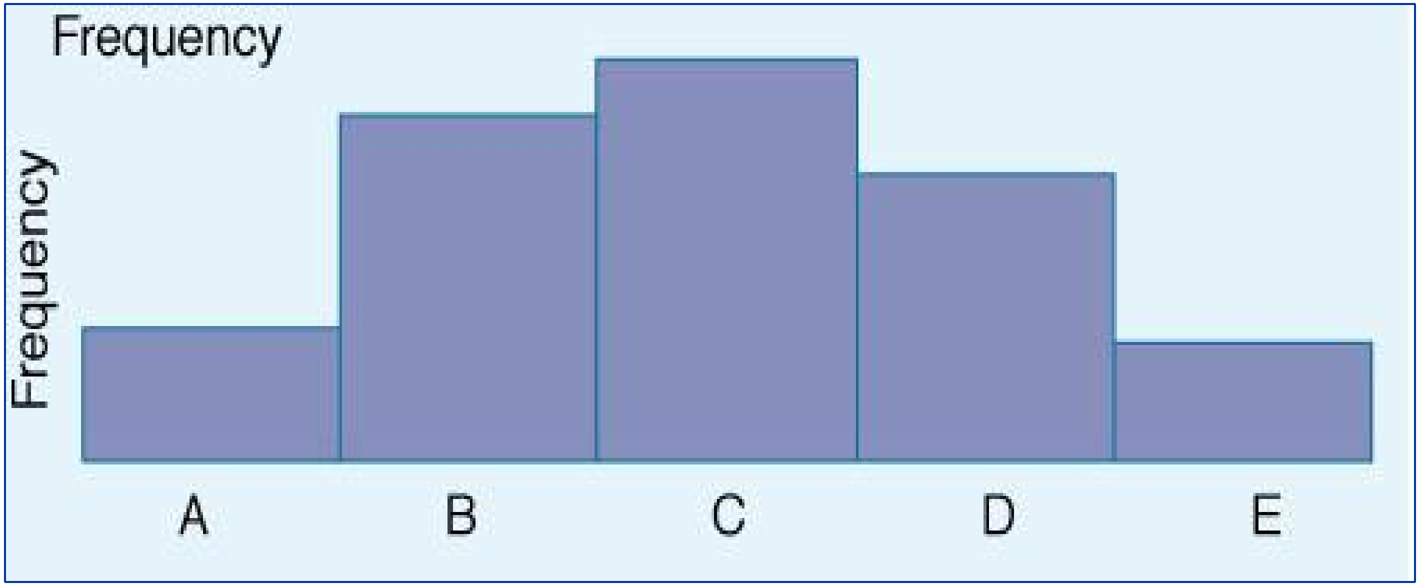
# Control Charts

- Used to monitor & control a process on an ongoing basis.
- Plots a selected quality characteristics as a function of sample number.
- Distinguish special causes of variation from common causes of variation.
- Centre line represents the average value of characteristics being plotted. The UCL and LCL are calculated limits used to show when process is in or out of control

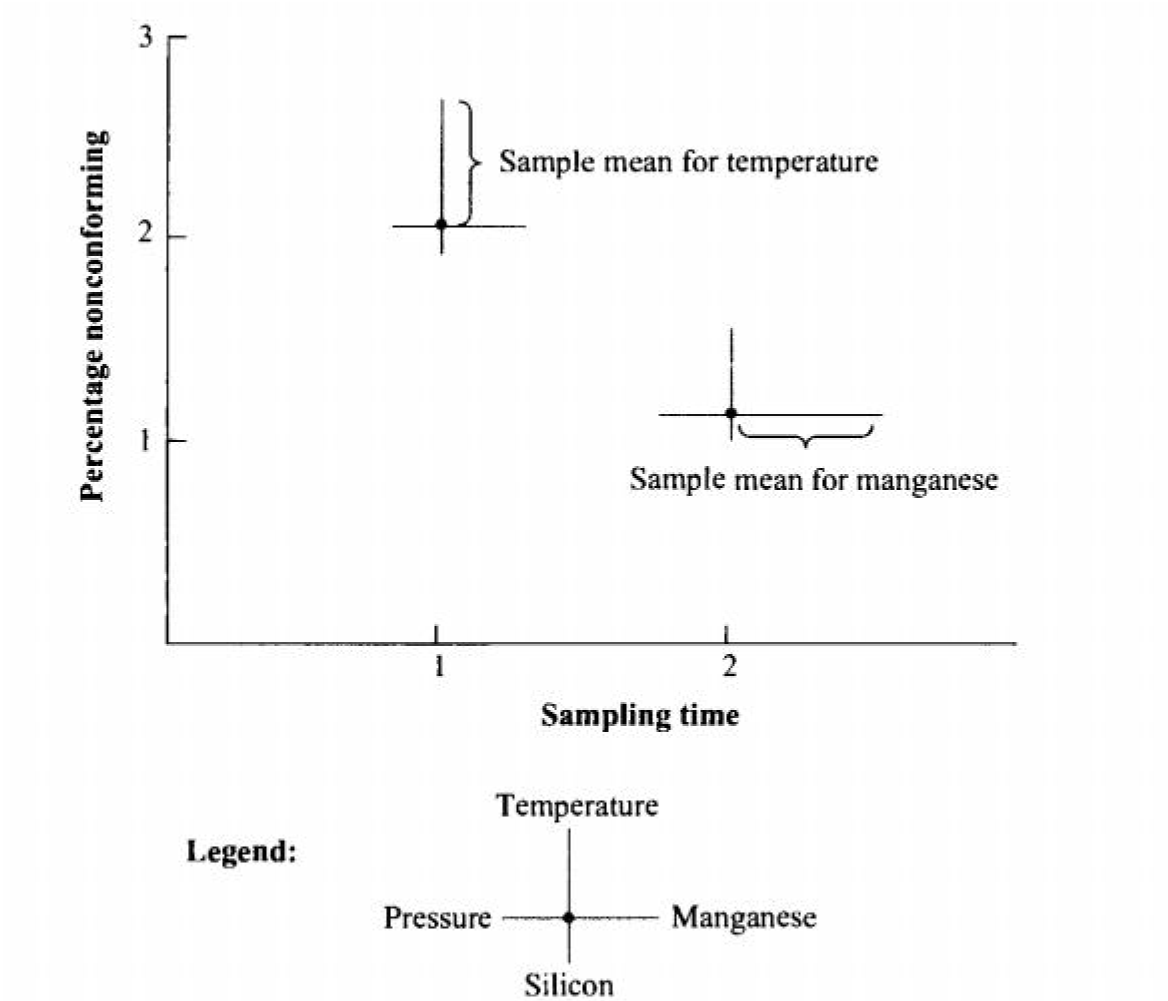


# Histograms

- Displays large amount of data that are difficult to interpret
- Histogram reveals whether the process is centered around a target value, degree of variation in the data and whether data meet specification.
- Help in identifying process capability relative to customer requirements
- A chart that shows the frequency distribution of observed values of a variable like **service time** at a bank drive-up window.



# Multivariable chart




**Radial Plot for Multivariable chart**

# FMECA

- Failure mode and effects criticality analysis is a disciplined procedure for systematic evaluation of the impact of potential failures and thereby determining a priority of possible actions that will reduce the occurrence of such failures.

# Four dimensions of quality of a product or service

**<u>1. Quality of design</u>**

- Quality of design deals with the stringent conditions that a product or service must minimally possess to satisfy the requirements of the customer.
- Detrmined before the product is produced
- Uses a cross-functional team to translate the wishes of the customer into specifications

**<u>2. Quality of Conformance</u>-**

- Quality of conformance implies that a manufactured product or service rendered must meet the standards selected in the design phase.

**3. Availability:**

-Availability (Continuity of service to the customers)

- Reliability (Length of time that a product can be used before it fails – MTBF)
- Maintainability (Restoration of the product or service once it has failed-MTTR)

**4. Field Service**

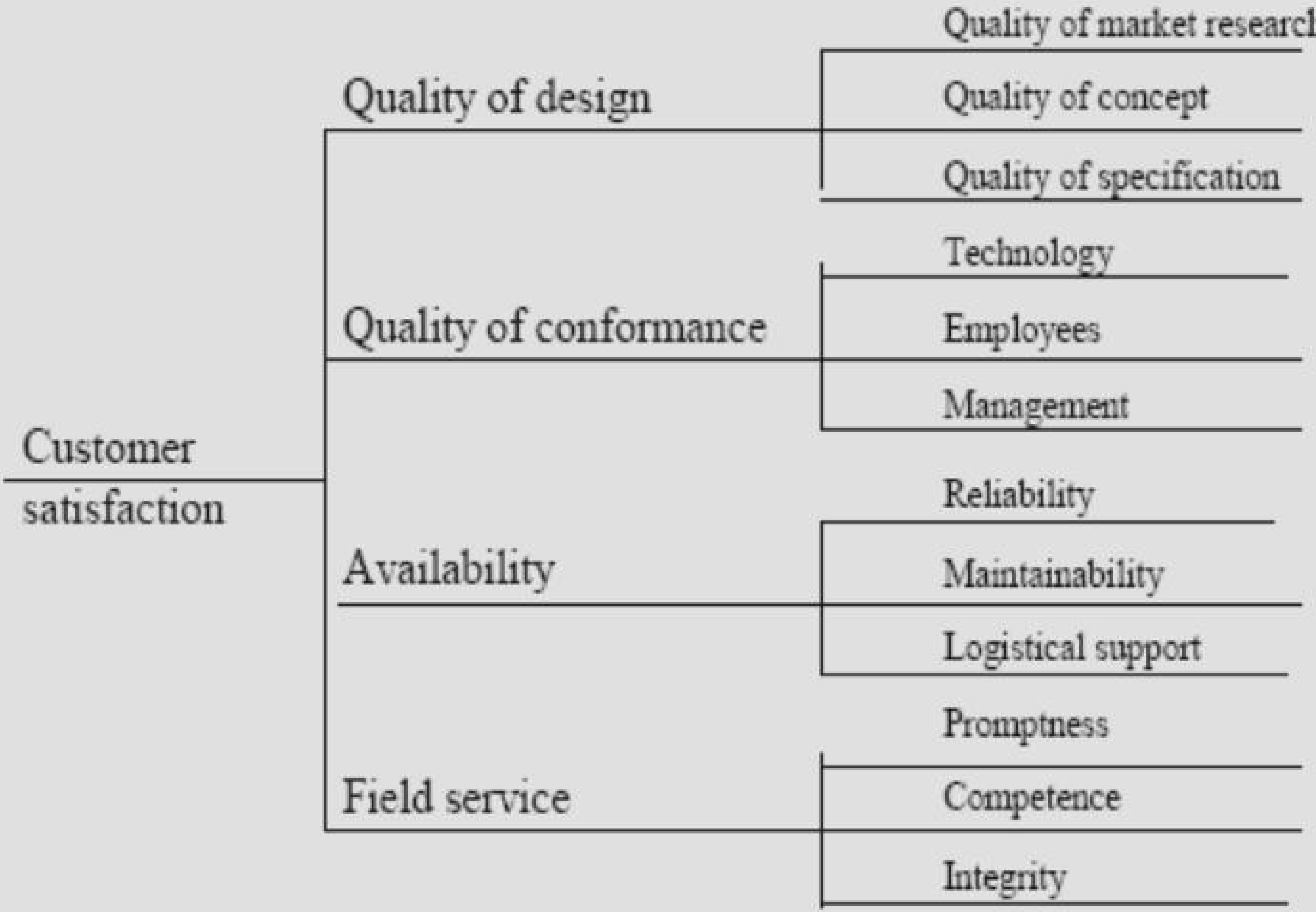
– Warranty and repair or replacement of the product after it has been sold.

– Also called customer service, sales service, or just service

– Promptness

– Competence

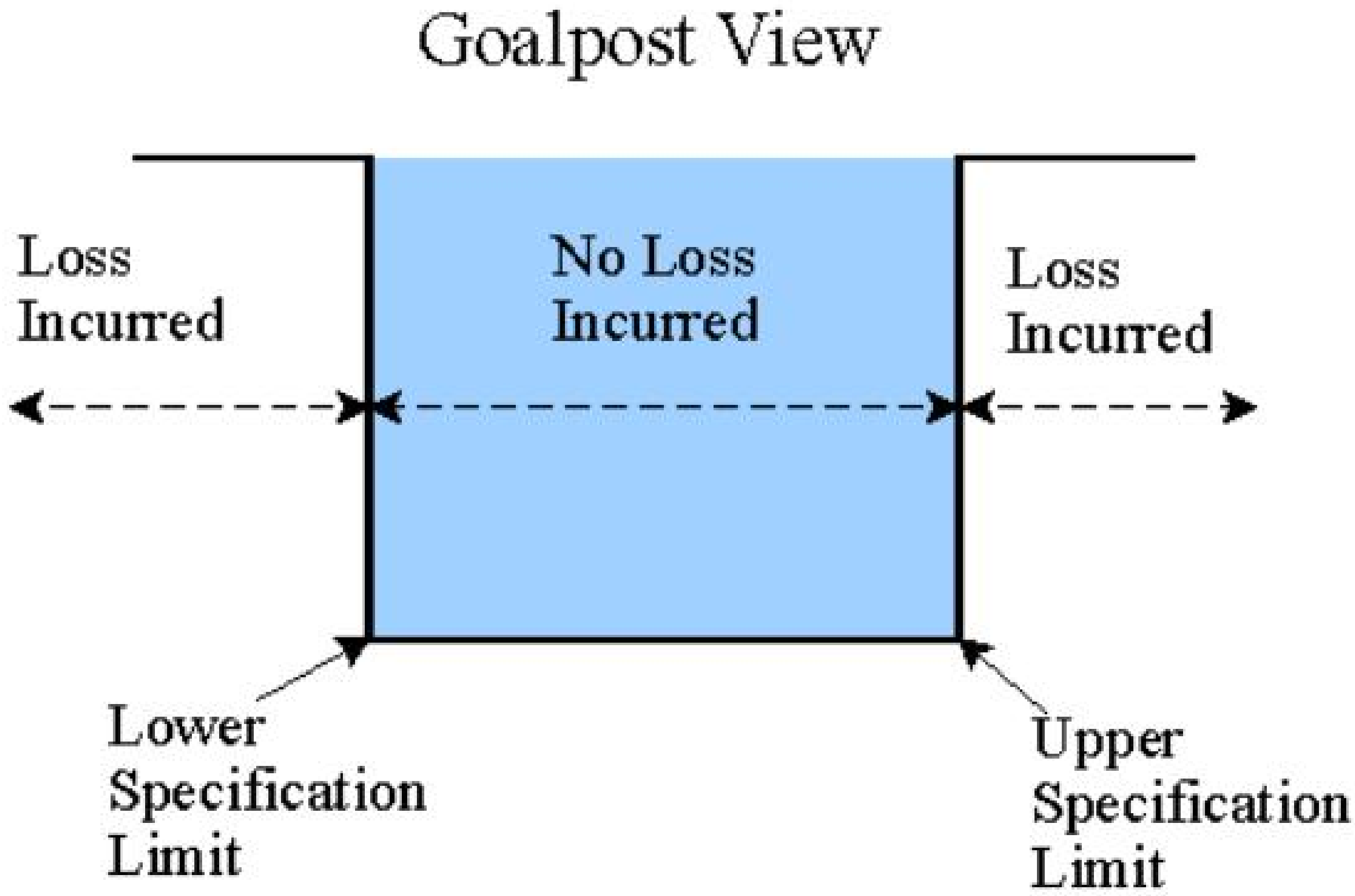
– Integrity


Customer satisfaction
Quality of design
Quality of market research
Quality of concept
Quality of specification
Quality of conformance
Technology
Employees
Management
Availability
Reliability
Maintainability
Logistical support
Field service
Promptness
Competence
Integrity

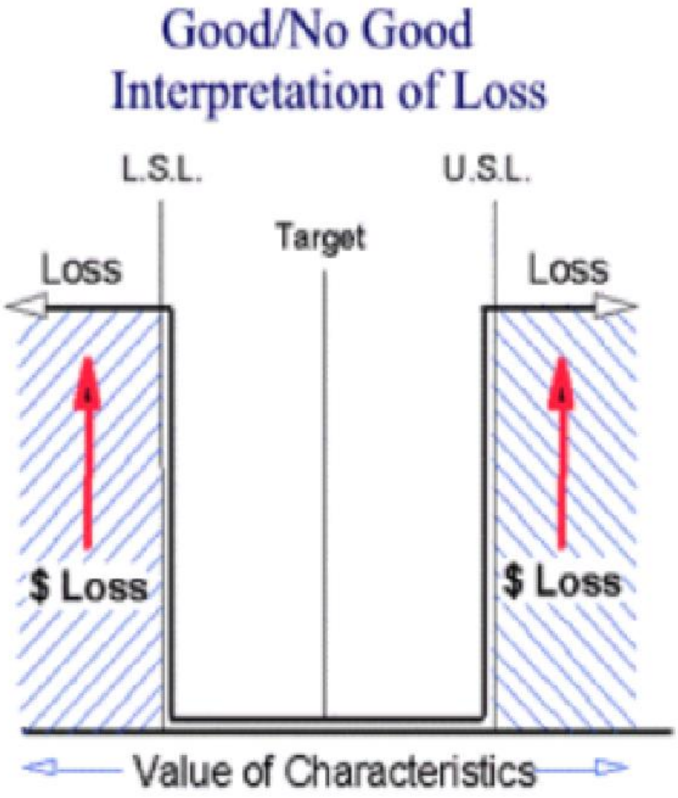
# Quality Losses

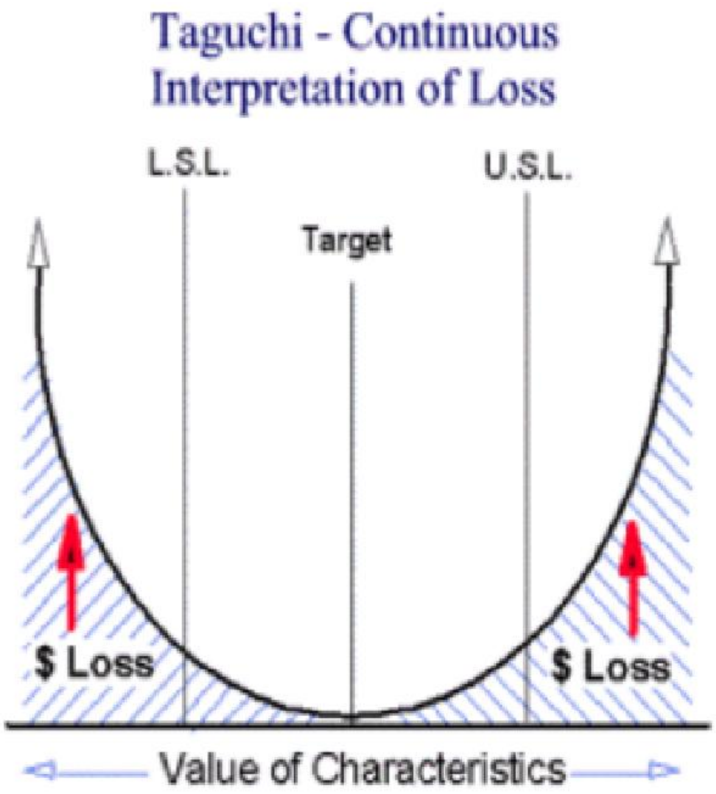
It estimates the loss of quality resulting from the deviation of a product characteristic from its target value. Developed by Dr. Genichi Taguchi of Japan, it is often expressed in terms of money lost, and suggests that such losses increase geometrically as the square of the deviation from the target

# Quality Losses



# Quality Losses



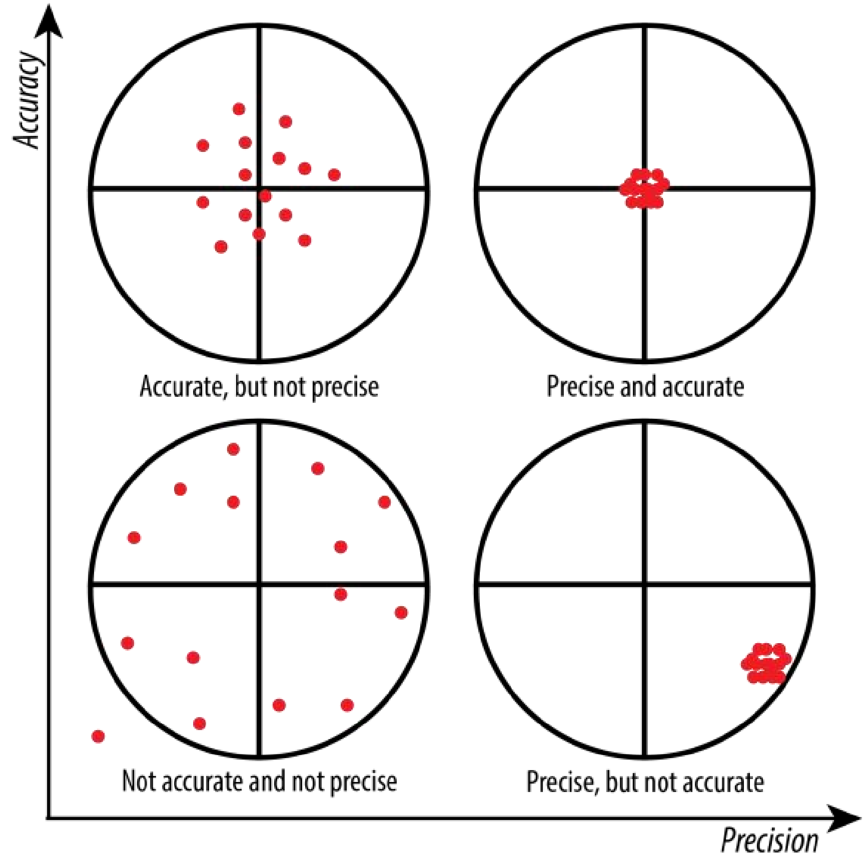



# STASTICAL QUALITY CONTROL

Statistical quality control is the application of statistical techniques to determine how far the product conforms to the standards of quality and precision and to what extent its quality deviates from the standard quality. The purpose of statistical quality control is to discover and correct only those forces which are responsible for variations outside the stable pattern.

# Accuracy Vs. Precision

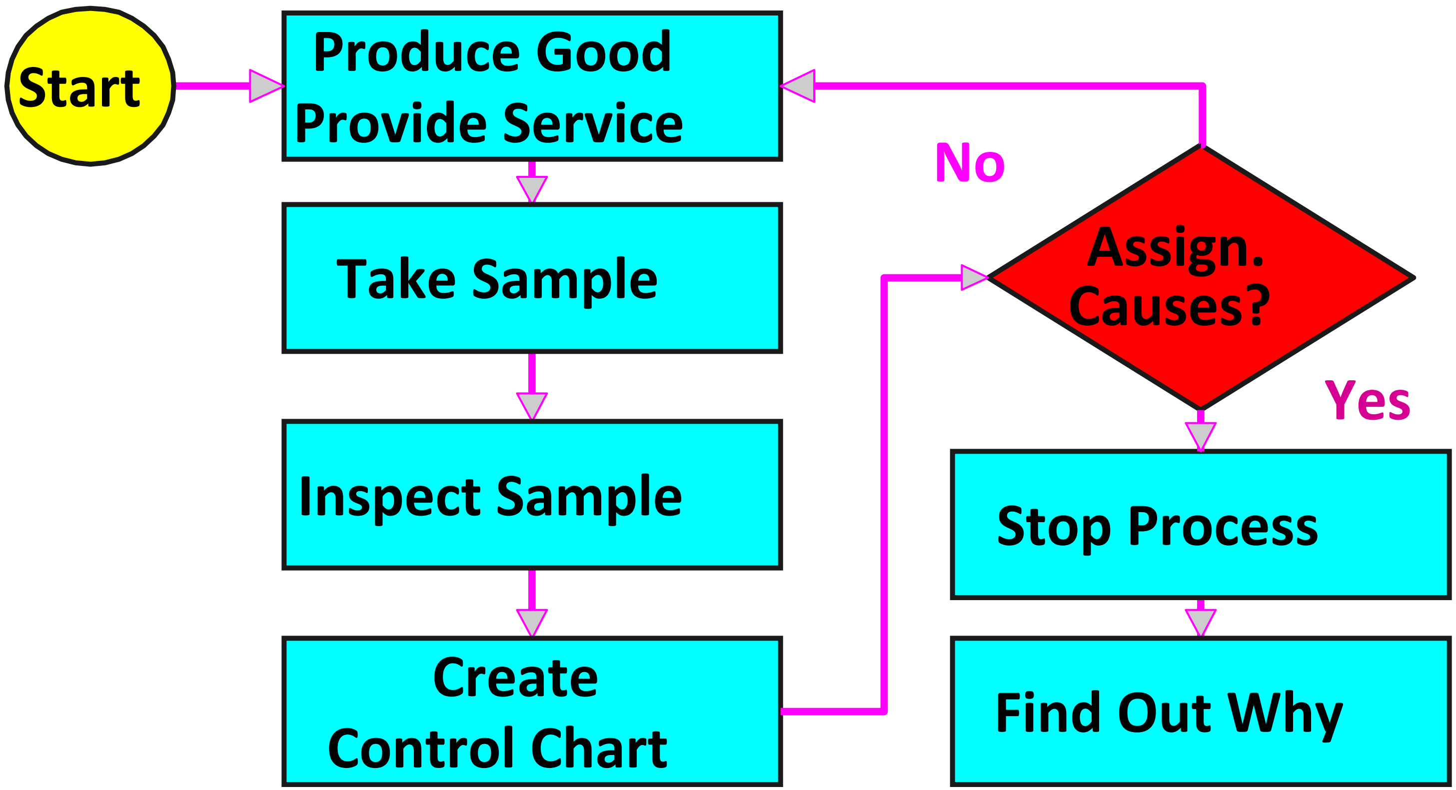
***Accuracy*** refers to how close measurements are to the "true" value, while ***precision*** refers to how close measurements are to each other. In other words, accuracy describes the difference between the measurement and the part's actual value, while precision describes the variation you see when you measure the same part repeatedly with the same device.



# Sources of Variation

- **Variation exists in all processes.**
- **Variation can be categorized as either;**
  - **<u>Common or chance or Random causes</u> of variation, or**
    - Random causes that we cannot identify
    - Unavoidable
    - e.g. slight differences in process variables like diameter, weight, service time, temperature
  - **<u>Assignable causes</u> of variation**
    - Causes can be identified and eliminated
    - e.g. poor employee training, worn tool, machine needing repair

# Statistical Quality Control Steps



# Three SQC Categories

- **Descriptive statistics**
  - e.g. the mean, standard deviation, and range
- **Statistical process control (SPC)**
  - Involves inspecting the output from a process
  - Quality characteristics are measured and charted
  - Helpful in identifying in-process variations
- **Acceptance sampling** used to randomly inspect a batch of goods to determine acceptance/rejection
  - Does not help to catch in-process problems

- Statistical process control is a collection of tools that when used together can result in process stability and variability reduction

# Techniques of statistical quality control

(1) Control Charts

(2) Acceptance Sampling

# Traditional Statistical Tools

- **Descriptive Statistics include**
  - **The Mean-** measure of central tendency

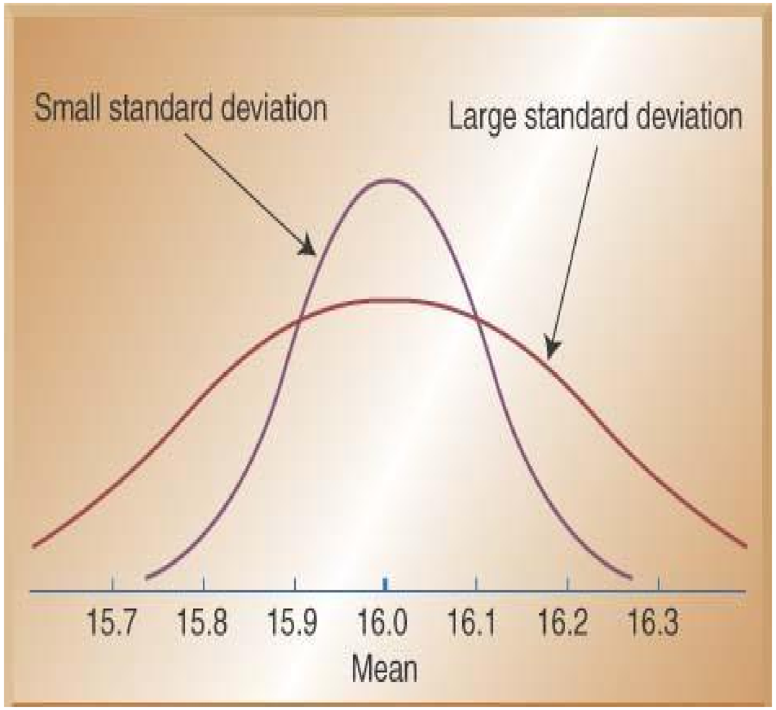
$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

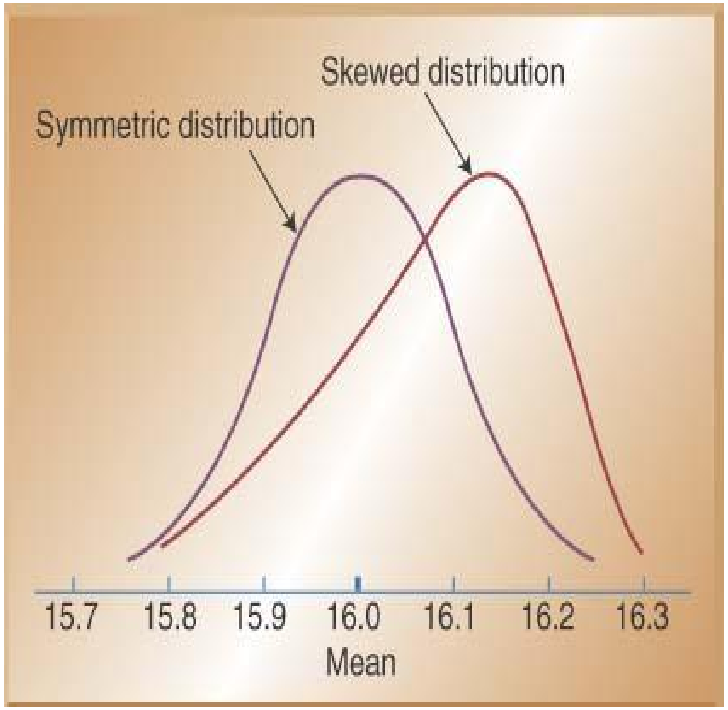
  - **The Range-** difference between largest/smallest observations in a set of data
  - **Standard Deviation** measures the amount of data dispersion around mean
  - **Distribution of Data shape**
    - Normal or bell shaped or
    - Skewed

$$\boldsymbol{\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}}$$

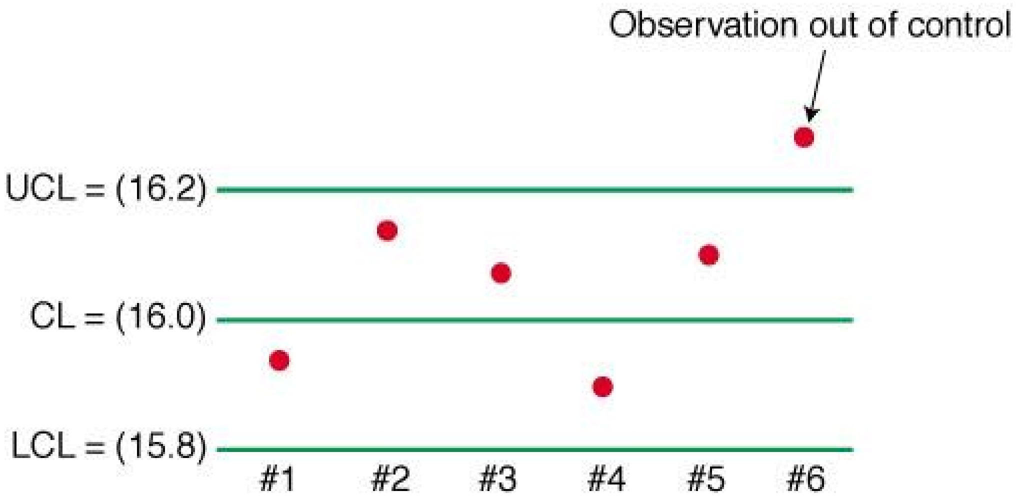
# Distribution of Data

- **Normal distributions**
- **Skewed distribution**



- **Control Charts** show sample data plotted on a graph with CL, UCL, and LCL
- **Control chart for variables** are used to monitor characteristics that can be measured, e.g. length, weight, diameter, time
- **Control charts for attributes** are used to monitor characteristics that have discrete values and can be counted, e.g. % defective, number of flaws in a shirt, number of broken eggs in a box



# Control Charts for Variables

- Use **x-bar** charts to monitor the changes in the mean of a process (central tendencies)
- **Use R-bar** charts to monitor the dispersion or variability of the process
- System can show acceptable central tendencies but unacceptable variability or
- System can show acceptable variability but unacceptable central tendencies

# What is control charts?

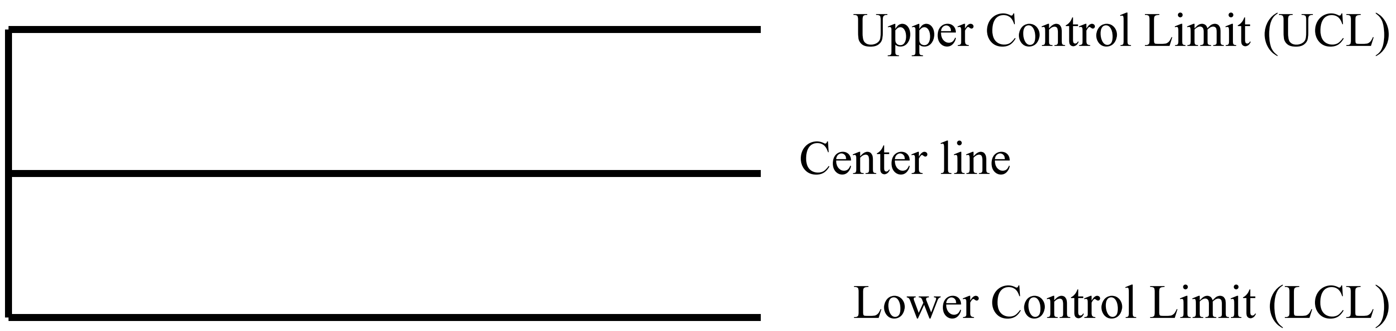
It is a chart and depicts three lines on the chart. One line is the central line showing the average size. The other two lines one below the central line and the other above the central line, indicate the limits of tolerances, within which deviations from standards are permissible. The actual measurements of the whole lot or a sample are plotted on the chart. Those measurement values which fall outside the tolerance limits are considered to be out-of-control points and assignable cause may be said to exist.

# Control Chart

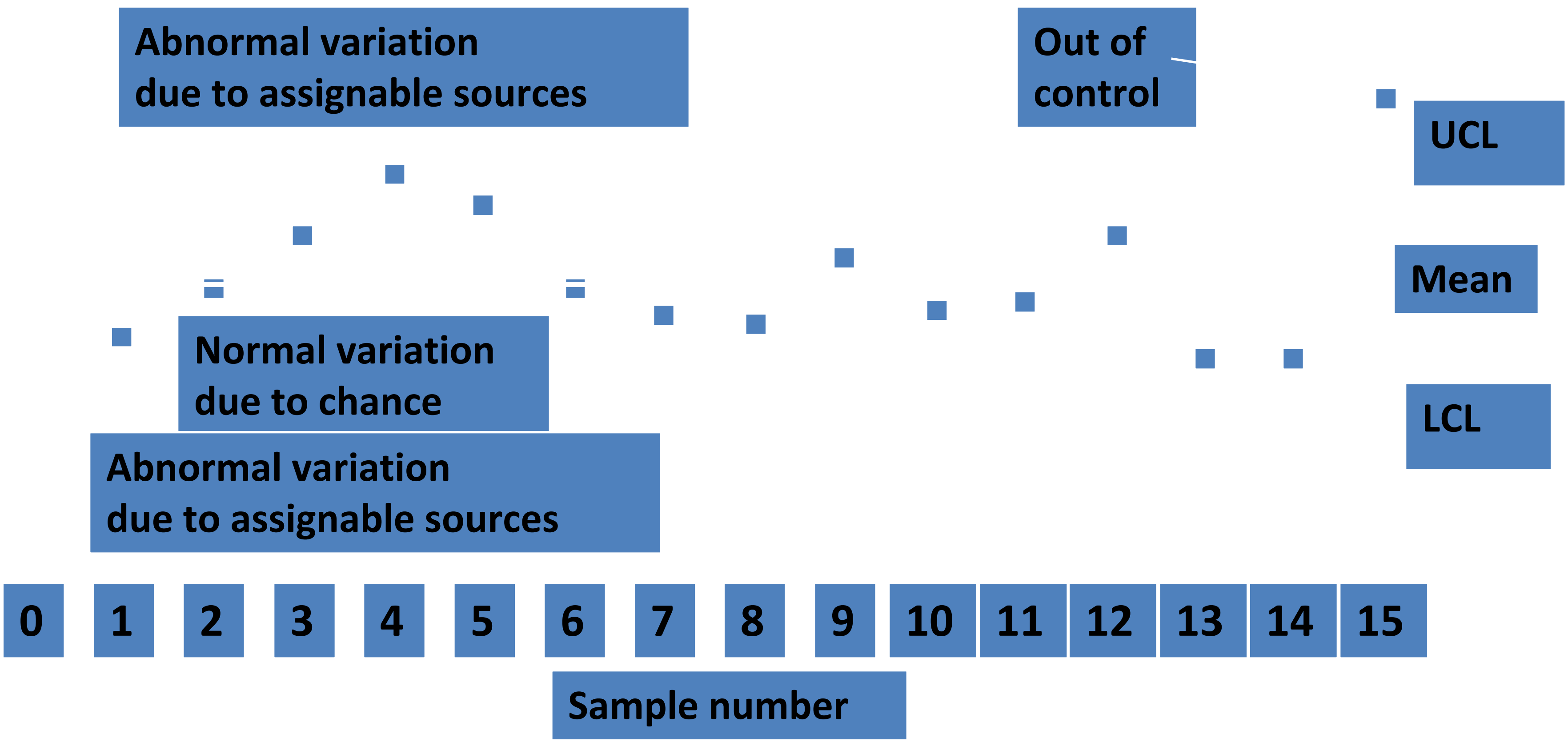
- Control Chart
  - *Purpose:* to monitor process output to see if it is random
  - A time ordered plot representative sample statistics obtained from an on going process (e.g. sample means)
  - Upper and lower control limits define the range of acceptable variation

# Control Charts

- Are named according to the statistics being plotted, i.e., X bar, R, and p
- Have a center line that is the overall average
- Have limits above and below the center line at ± 3 standard deviations (usually)



# Control Chart



# Commonly Used Control Charts

- Variables data
  - x-bar and R-charts
- Attribute data
  - For “defectives” (p-chart)

# Control Charts for Variables

**Variables generate data that are *measured*.**

- Mean control charts
  - Used to monitor the central tendency of a process.
  - X bar charts
- Range control charts
  - Used to monitor the process dispersion
  - R charts

# Variables Data Charts

- Process Centering
  - $\overline{X}$ is a sample mean

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

- Process Dispersion (consistency)
  - R chart
  - R is a sample range

$$R = \max(X_i) - \min(X_i)$$

# X bar charts

- Center line is the grand mean (X double bar)
- Points are X bars

**CL=** $$\overline{\overline{X}} = \frac{\sum_{j=1}^{m} \overline{X_j}}{m}$$

$$UCL = \overline{\overline{X}} + A_2 \overline{R}$$

$$LCL = \overline{\overline{X}} - A_2 \overline{R}$$

# R Charts

- Center line is the grand mean (R bar)
- Points are R
- $D_3$ and $D_4$ values are tabled according to n (sample size)

$$UCL = D_4 \overline{R}$$

$$LCL = D_3 \overline{R}$$

# Sampling by Variable (Table 1)

| Number of Observations in Subgroup $n$ | Factor for $\overline{X}$ Chart $A_2$ | Factors for $R$ Chart: Lower Control Limit $D_3$ | Factors for $R$ Chart: Upper Control Limit $D_4$ |
|---|---|---|---|
| 2 | 1.88 | 0 | 3.27 |
| 3 | 1.02 | 0 | 2.57 |
| 4 | 0.73 | 0 | 2.28 |
| 5 | 0.58 | 0 | 2.11 |
| 6 | 0.48 | 0 | 2.00 |
| 7 | 0.42 | 0.08 | 1.92 |
| 8 | 0.37 | 0.14 | 1.86 |
| 9 | 0.34 | 0.18 | 1.82 |
| 10 | 0.31 | 0.22 | 1.78 |
| 11 | 0.29 | 0.26 | 1.74 |
| 12 | 0.27 | 0.28 | 1.72 |
| 13 | 0.25 | 0.31 | 1.69 |
| 14 | 0.24 | 0.33 | 1.67 |
| 15 | 0.22 | 0.35 | 1.65 |

# Sampling by Variable Example

You collect the following data from a process at your company. Draw the X and R charts for the process.

| Sample Number | Each Unit in Sample | | | | | Average $\overline{X}$ | Range $R$ |
|---|---|---|---|---|---|---|---|
| 1 | 10.60 | 10.40 | 10.30 | 9.90 | 10.20 | 10.28 | .70 |
| 2 | 9.98 | 10.25 | 10.05 | 10.23 | 10.33 | 10.17 | .35 |
| 3 | 9.85 | 9.90 | 10.20 | 10.25 | 10.15 | 10.07 | .40 |
| 4 | 10.20 | 10.10 | 10.30 | 9.90 | 9.95 | 10.09 | .40 |
| 5 | 10.30 | 10.20 | 10.24 | 10.50 | 10.30 | 10.31 | .30 |
| 6 | 10.10 | 10.30 | 10.20 | 10.30 | 9.90 | 10.16 | .40 |
| 7 | 9.98 | 9.90 | 10.20 | 10.40 | 10.10 | 10.12 | .50 |
| 8 | 10.10 | 10.30 | 10.40 | 10.24 | 10.30 | 10.27 | .30 |
| 9 | 10.30 | 10.20 | 10.60 | 10.50 | 10.10 | 10.34 | .50 |
| 10 | 10.30 | 10.40 | 10.50 | 10.10 | 10.20 | 10.30 | .40 |
| 11 | 9.90 | 9.50 | 10.20 | 10.30 | 10.35 | 10.05 | .85 |
| 12 | 10.10 | 10.36 | 10.50 | 9.80 | 9.95 | 10.14 | .70 |
| 13 | 10.20 | 10.50 | 10.70 | 10.10 | 9.90 | 10.28 | .80 |
| 14 | 10.20 | 10.60 | 10.50 | 10.30 | 10.40 | 10.40 | .40 |
| 15 | 10.54 | 10.30 | 10.40 | 10.55 | 10.00 | 10.36 | .55 |
| 16 | 10.20 | 10.60 | 10.15 | 10.00 | 10.50 | 10.29 | .60 |
| 17 | 10.20 | 10.40 | 10.60 | 10.80 | 10.10 | 10.42 | .70 |
| 18 | 9.90 | 9.50 | 9.90 | 10.50 | 10.00 | 9.96 | 1.00 |
| 19 | 10.60 | 10.30 | 10.50 | 9.90 | 9.80 | 10.22 | .80 |
| 20 | 10.60 | 10.40 | 10.30 | 10.40 | 10.20 | 10.38 | .40 |
| 21 | 9.90 | 9.60 | 10.50 | 10.10 | 10.60 | 10.14 | 1.00 |
| 22 | 9.95 | 10.20 | 10.50 | 10.30 | 10.20 | 10.23 | .55 |
| 23 | 10.20 | 9.50 | 9.60 | 9.80 | 10.30 | 9.88 | .80 |
| 24 | 10.30 | 10.60 | 10.30 | 9.90 | 9.80 | 10.18 | .80 |
| 25 | 9.90 | 10.30 | 10.60 | 9.90 | 10.10 | 10.16 | .70 |

# Sampling by Variable Example

- First calculate the average of the sample means and the average of the sample ranges:

$$\bar{\bar{X}} = \frac{\sum_{\forall i} \bar{X}_i}{m} = 10.21 \qquad \bar{R} = \frac{\sum_{\forall i} R_i}{m} = 0.60$$

- Then calculate sample mean control limits:

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \cdot \bar{R} = 10.21 + 0.58 \cdot 0.60 = 10.56$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \cdot \bar{R} = 10.21 - 0.58 \cdot 0.60 = 9.86$$

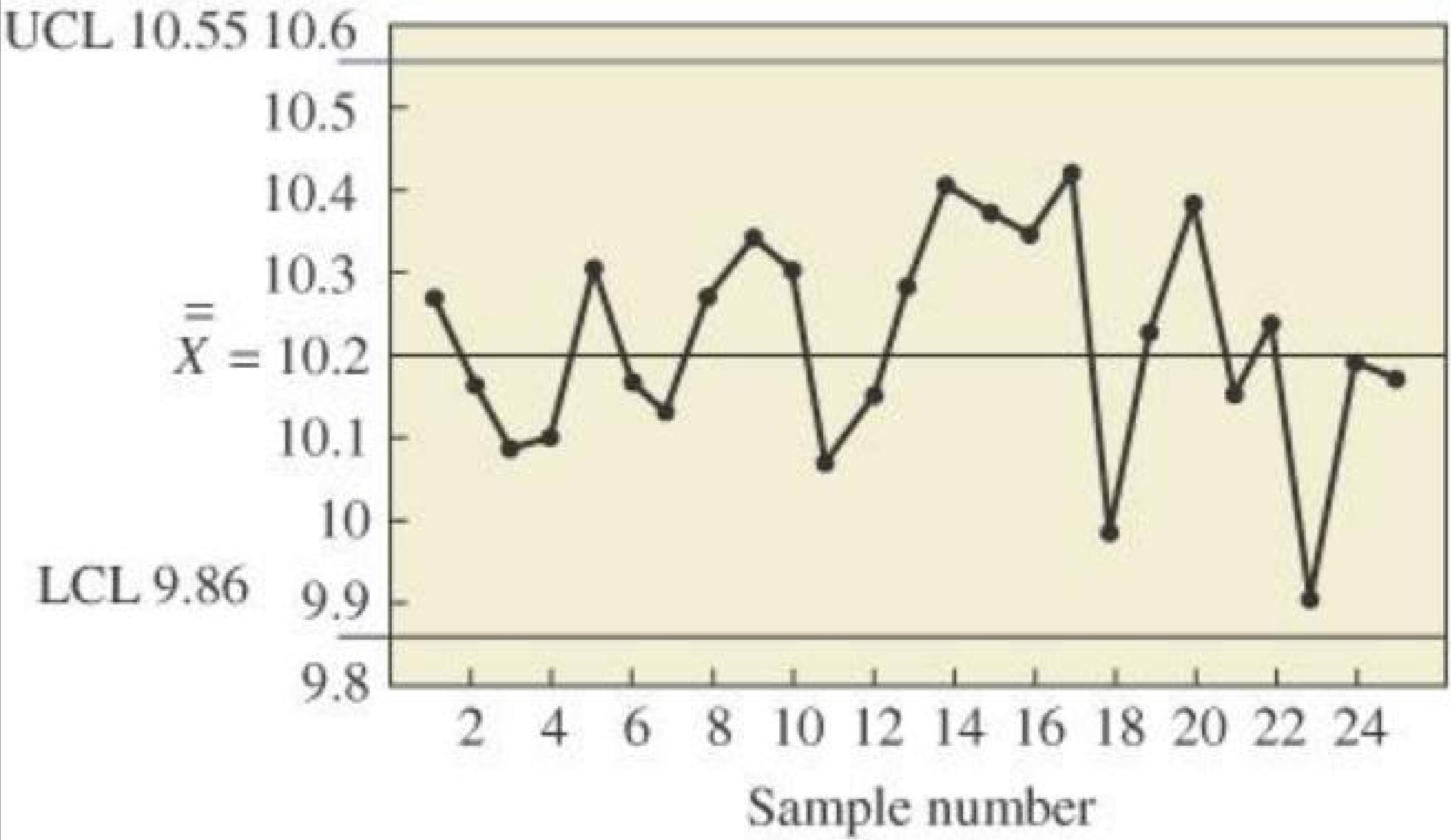
$$UCL_R = D_4 \cdot \bar{R} = 2.11 \cdot 0.60 = 1.27$$

- Finally, calculate sample mean control limits:

$$LCL_R = D_3 \cdot \bar{R} = 0 \cdot 0.60 = 0$$

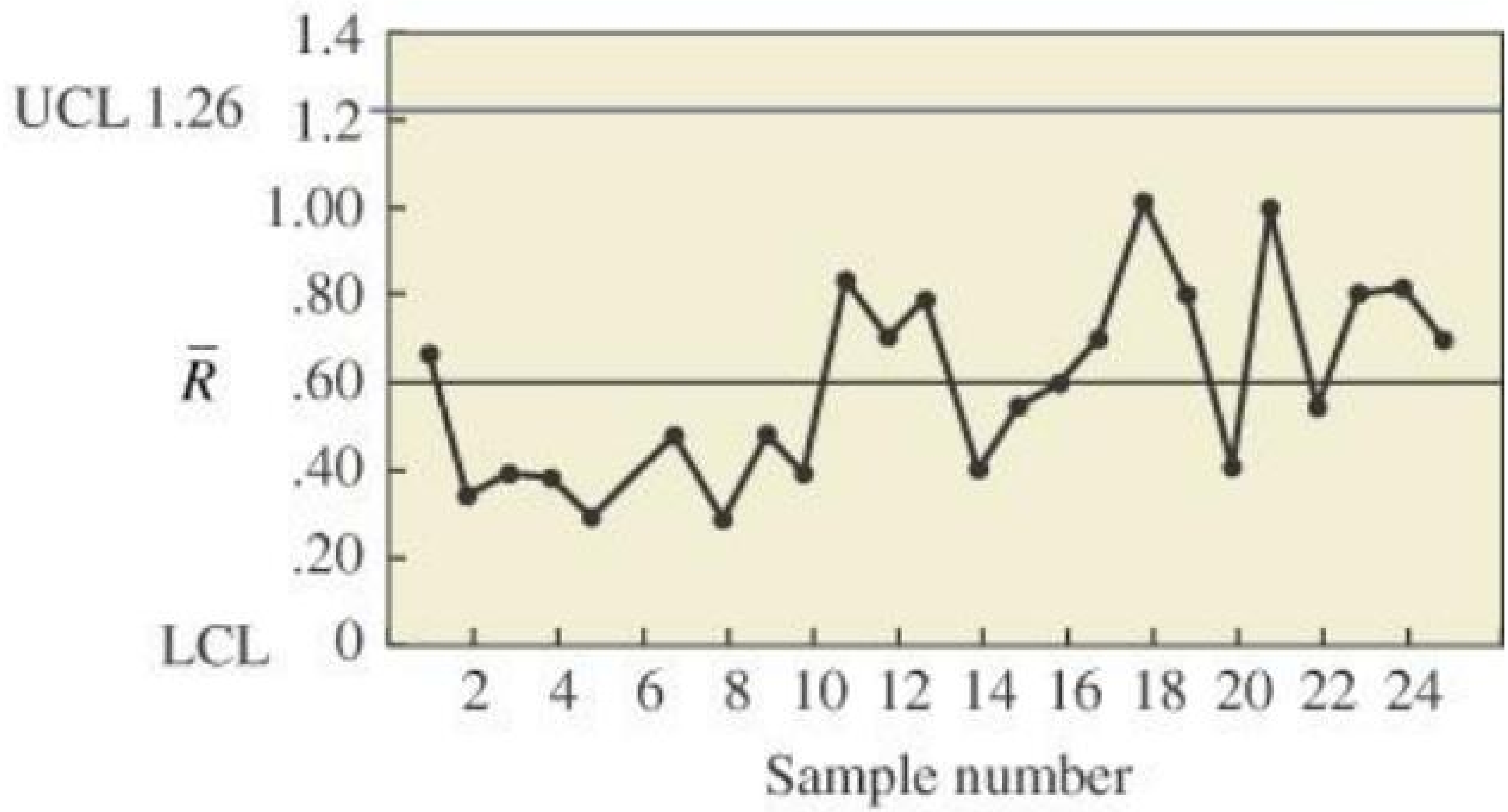
# Sampling by Variable Example

X Chart



# Sampling by Variable Example

**R Chart**



- You collect the following data for one of your company's processes. You can assume the variable's standard deviation is 0.1. Draw process control charts (use z=3).

| Sample | Obs 1 | Obs 2 | Obs 3 | Obs 4 | Obs 5 | Avg | Range |
|---|---|---|---|---|---|---|---|
| 1 | 10.68 | 10.689 | 10.776 | 10.798 | 10.714 | 10.732 | 0.116 |
| 2 | 10.79 | 10.86 | 10.601 | 10.746 | 10.779 | 10.755 | 0.259 |
| 3 | 10.78 | 10.667 | 10.838 | 10.785 | 10.723 | 10.759 | 0.171 |
| 4 | 10.59 | 10.727 | 10.812 | 10.775 | 10.73 | 10.727 | 0.221 |
| 5 | 10.69 | 10.708 | 10.79 | 10.758 | 10.671 | 10.724 | 0.119 |
| 6 | 10.75 | 10.714 | 10.738 | 10.719 | 10.606 | 10.705 | 0.143 |
| 7 | 10.79 | 10.713 | 10.689 | 10.877 | 10.603 | 10.735 | 0.274 |
| 8 | 10.74 | 10.779 | 10.11 | 10.737 | 10.75 | 10.624 | 0.669 |
| 9 | 10.77 | 10.773 | 10.641 | 10.644 | 10.725 | 10.710 | 0.132 |
| 10 | 10.72 | 10.671 | 10.708 | 10.85 | 10.712 | 10.732 | 0.179 |
| 11 | 10.79 | 10.821 | 10.764 | 10.658 | 10.708 | 10.748 | 0.163 |
| 12 | 10.62 | 10.802 | 10.818 | 10.872 | 10.727 | 10.768 | 0.250 |
| 13 | 10.66 | 10.822 | 10.893 | 10.544 | 10.75 | 10.733 | 0.349 |
| 14 | 10.81 | 10.749 | 10.859 | 10.801 | 10.701 | 10.783 | 0.158 |
| 15 | 10.66 | 10.681 | 10.644 | 10.747 | 10.728 | 10.692 | 0.103 |