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

Four dimensions of quality of a good or service

1. Quality of design

- determined before the product is produced
- Uses a cross-functional team to translate the wishes of the customer into specifications
- Concurrent design through the Quality Function Deployment process.

2. Quality of Conformance-

producing a product to meet the specifications independent of the quality of design.

3. Meets the abilities-

-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)

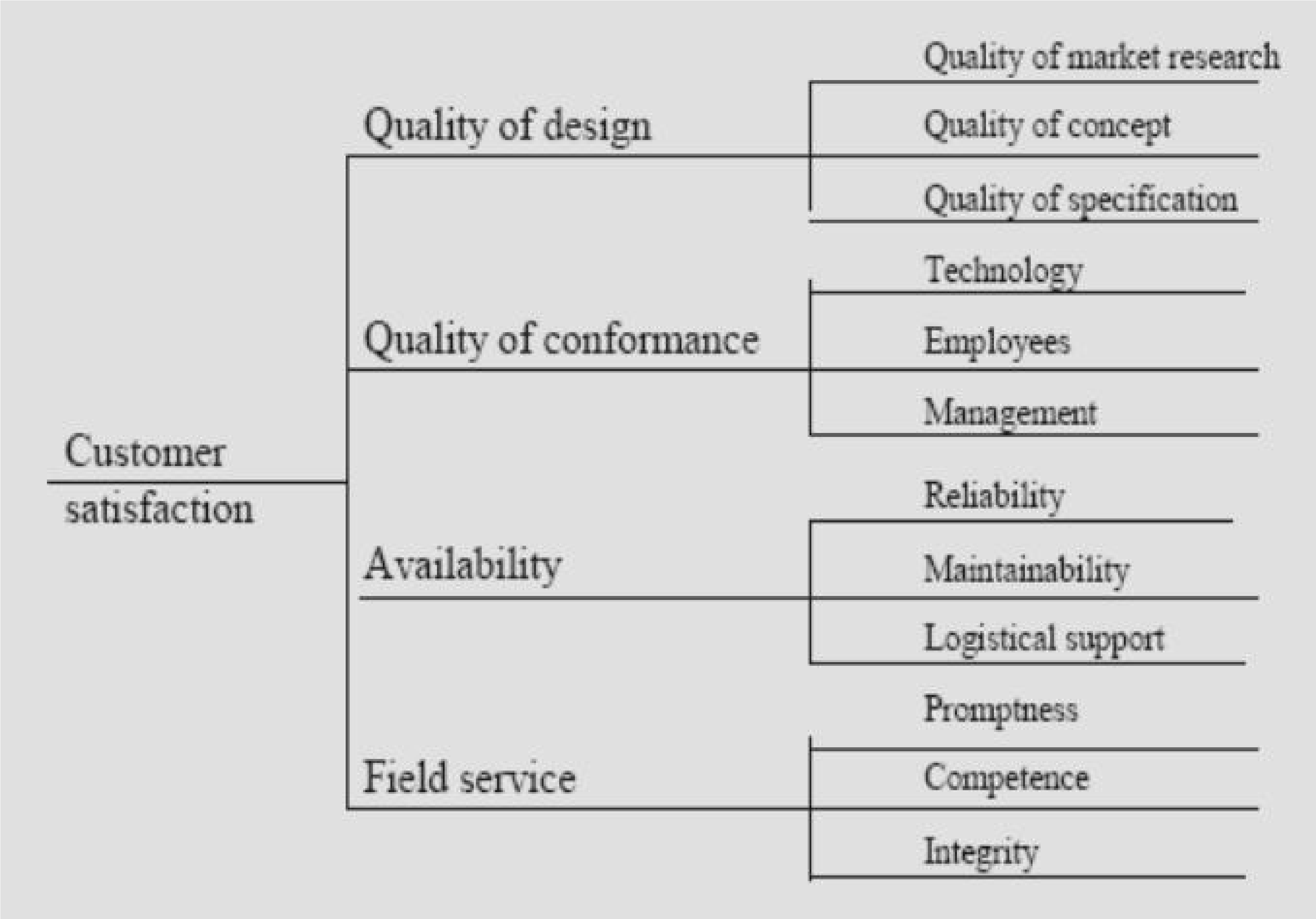
4. Field Service

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

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

– Dimensions

- **Promptness**
- **Competence**
- **Integrity**



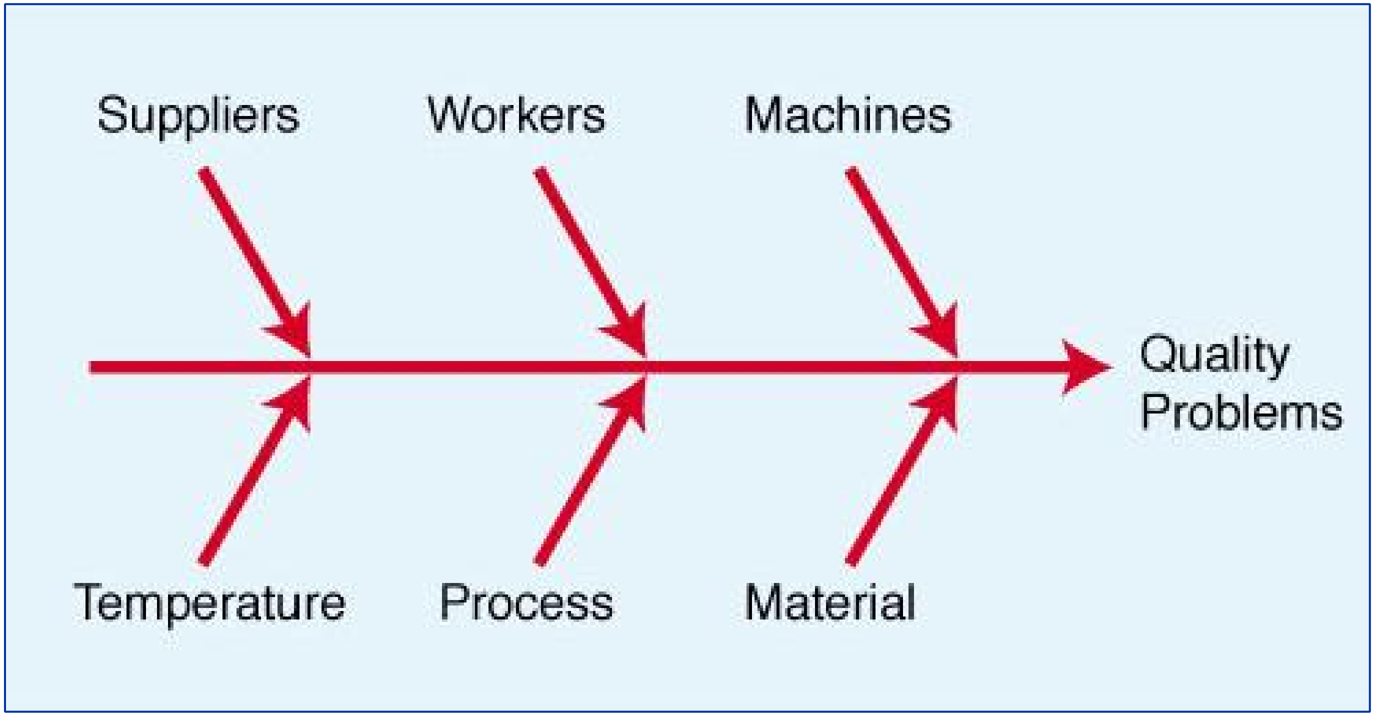
Customer satisfaction
Quality of design
Quality of market research
Quality of concept
Quality of specification
Quality of conformance
Technology
Employees
Management
Availability
Reliability
Maintainability
Logistical support
Field service
Promptness
Competence
Integrity

Seven Problem Solving QC Tools

1. Cause-and-Effect Diagrams
2. Flowcharts
3. Checklists
4. Control Charts
5. Scatter Diagrams
6. Pareto Analysis
7. Histograms

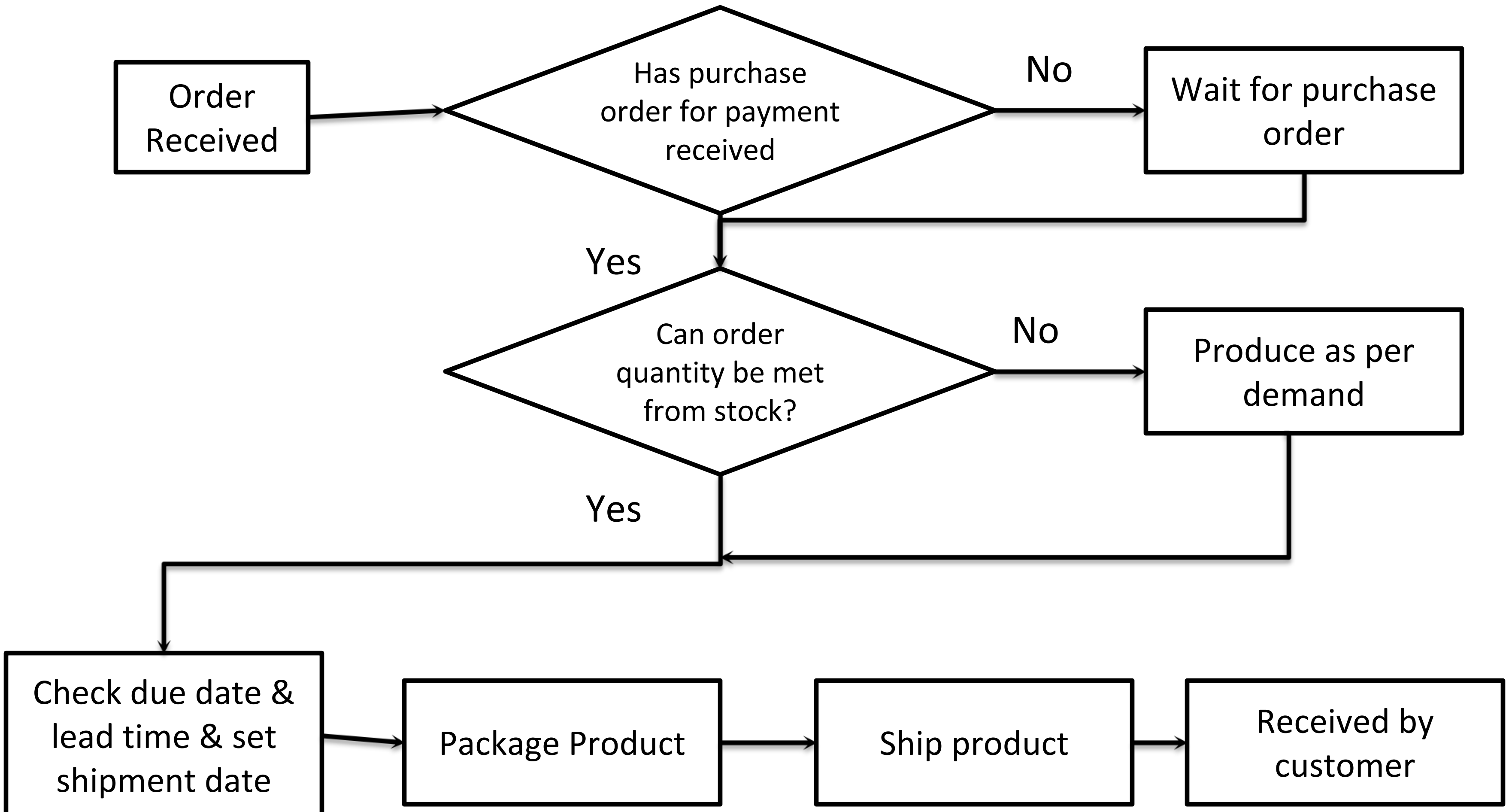
Cause-and-Effect Diagrams

- 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.



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

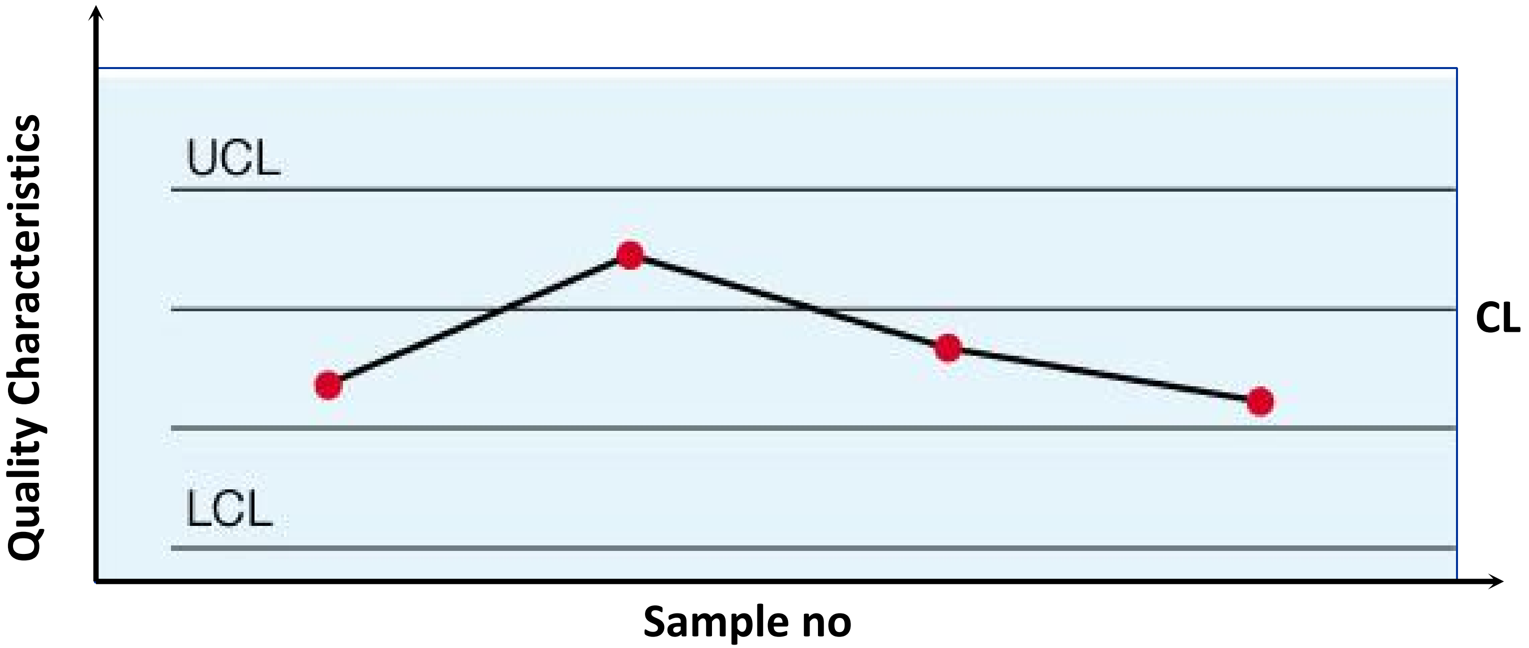
Checklist

- 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

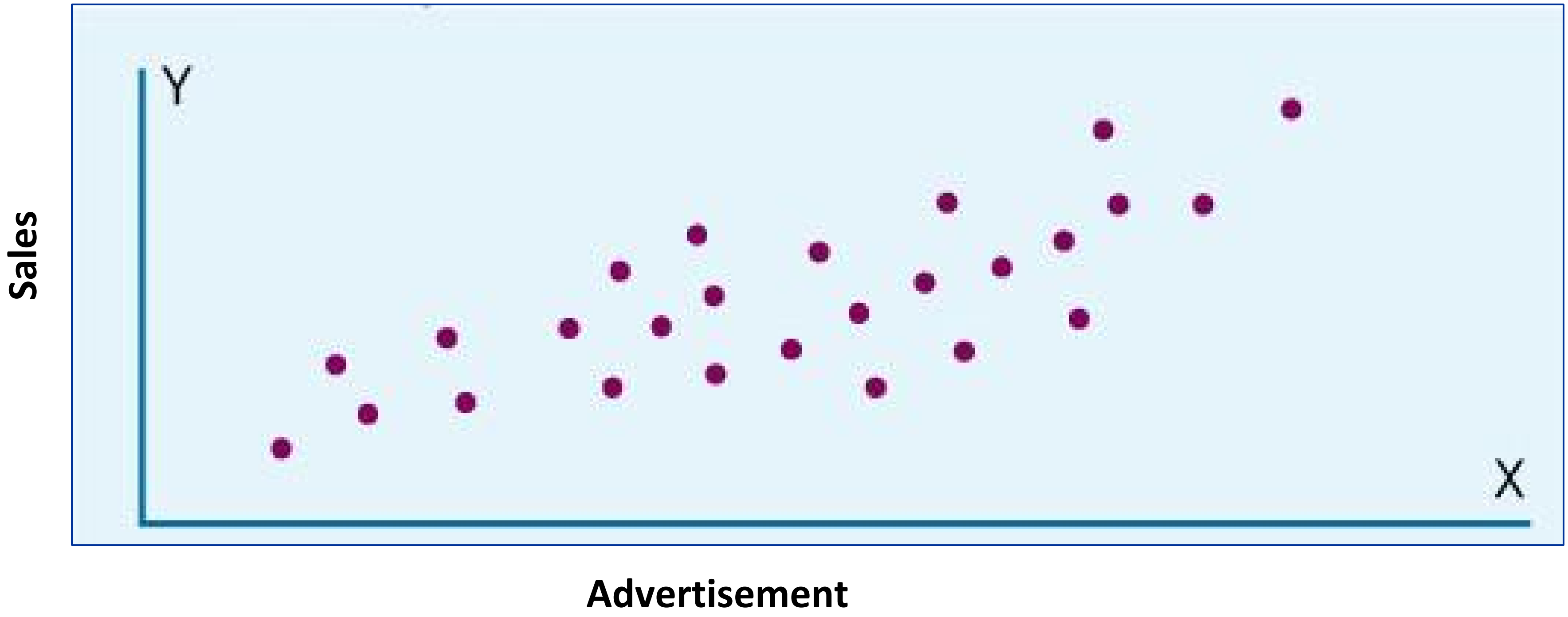
Control Charts

- 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



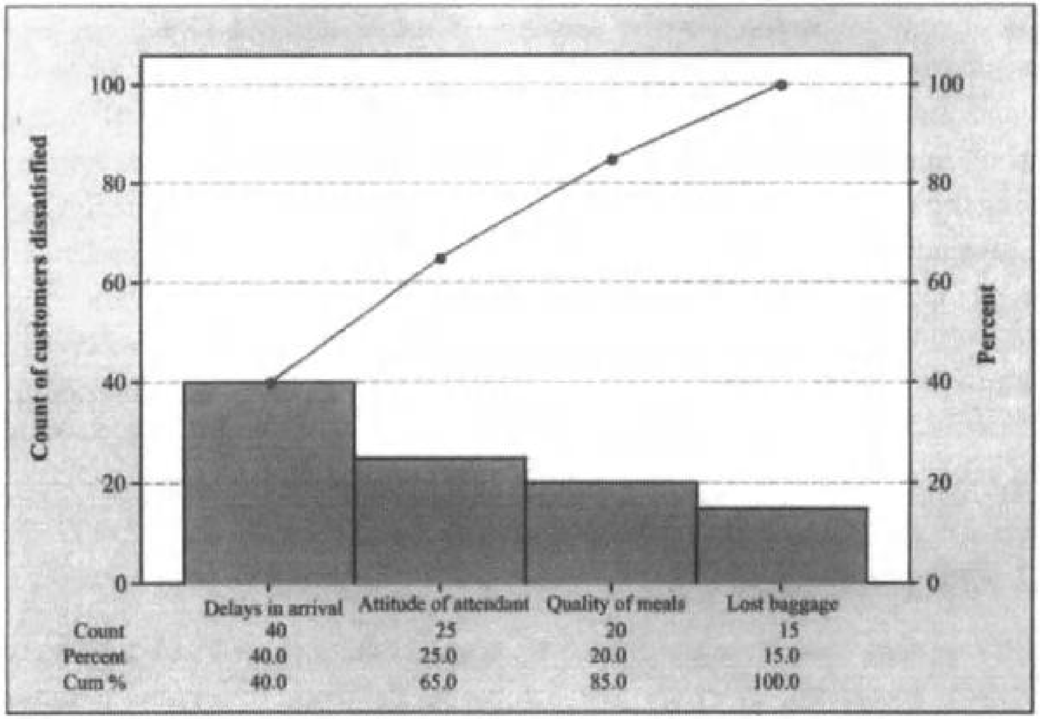
Scatter Diagrams

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



Pareto Analysis

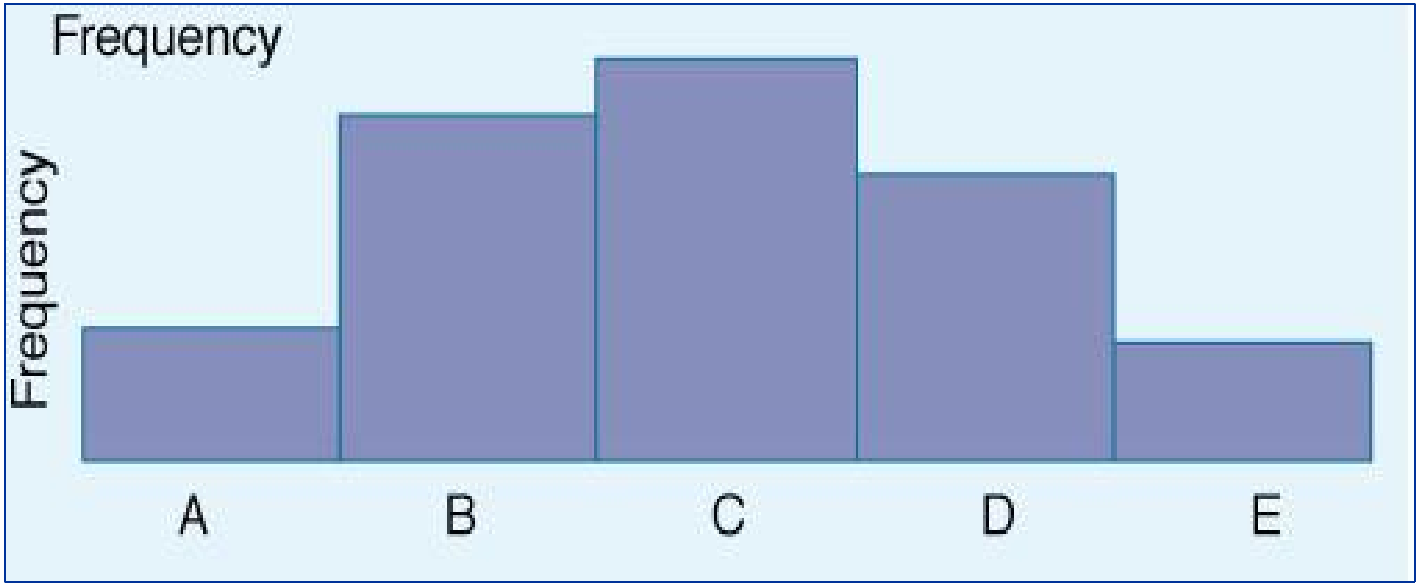
- Identify the critical areas that deserves immediate action.
- Technique that displays the degree of importance for each element
- Named after the 19th century Italian economist Alfredo Pareto.
- Often called the 80-20 Rule (Vital few and trivial many)
- Principle is that quality problems are the result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

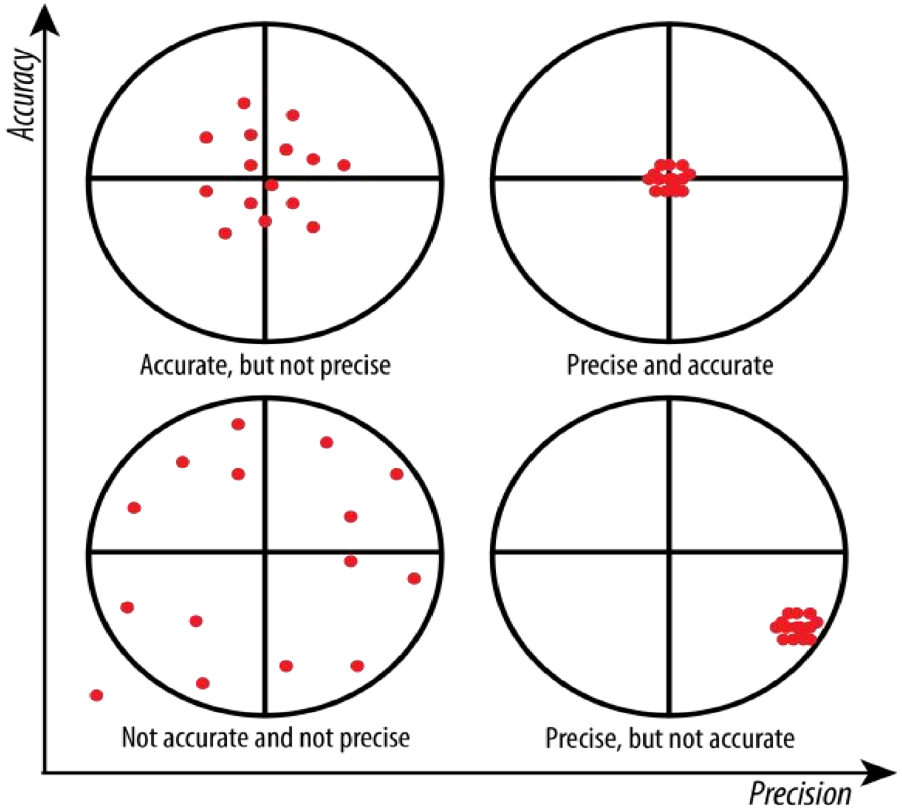
Histograms

- 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.



Accuracy Vs. Precision

Accuracy refers to how close measurements are to the "true" value. It describes the difference between the measurement and the part’s actual value.
precision refers to how close measurements are to each other. It 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;**
  - **Common or chance or Random causes of variation, or**
    - Inherent to the process
    - Unavoidable
    - As per Deming 85% of problems are due to common causes
    - Vibration in machine, fluctuation in working conditions
  - **Assignable causes of variation**
    - Causes can be identified and eliminated
    - wrong tool, improper raw material, incorrect procedure

Quality Characteristics:

- **Variables** : Quality characteristics whose numerical values can be obtained.

  Length, width, etc

- **Attributes**: Quality characteristics which can’t be measured on numerical scale. It can be represented as no. of nonconformities in a unit.

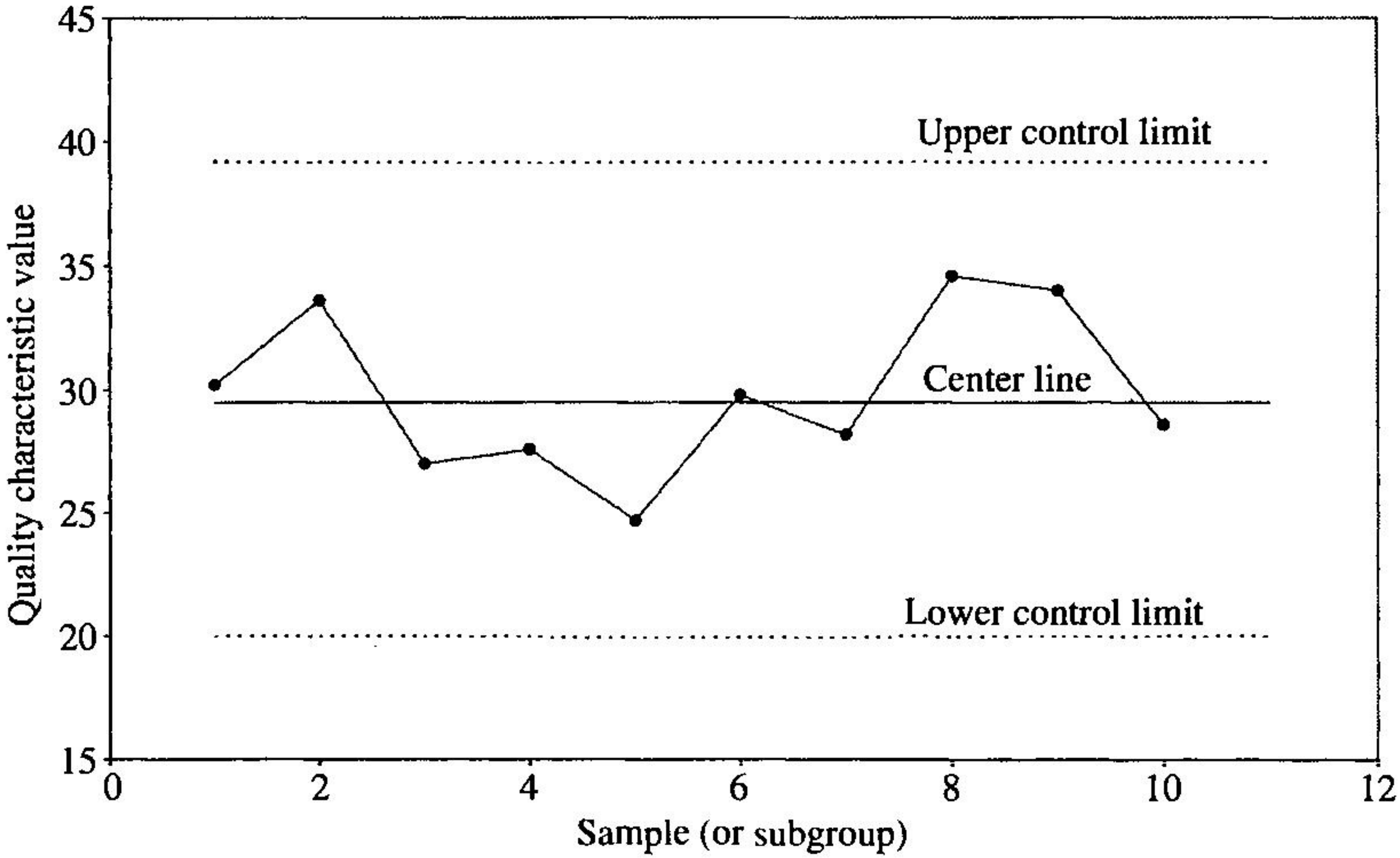
Control Charts:

- Graphical tool used for monitoring the activity of an ongoing process.
- Also known as Shewhart control charts.
- Value of quality characteristics plotted along vertical axis whereas horizontal axis represents the sample.
- Consists of three lines
  - **Centre line (CL)** represents average value of quality characteristics being plotted.
  - **Upper control limit (UCL)** & **Lower control limit (LCL)** are used to make decision regarding the process.

Types of Control Charts :

- **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:

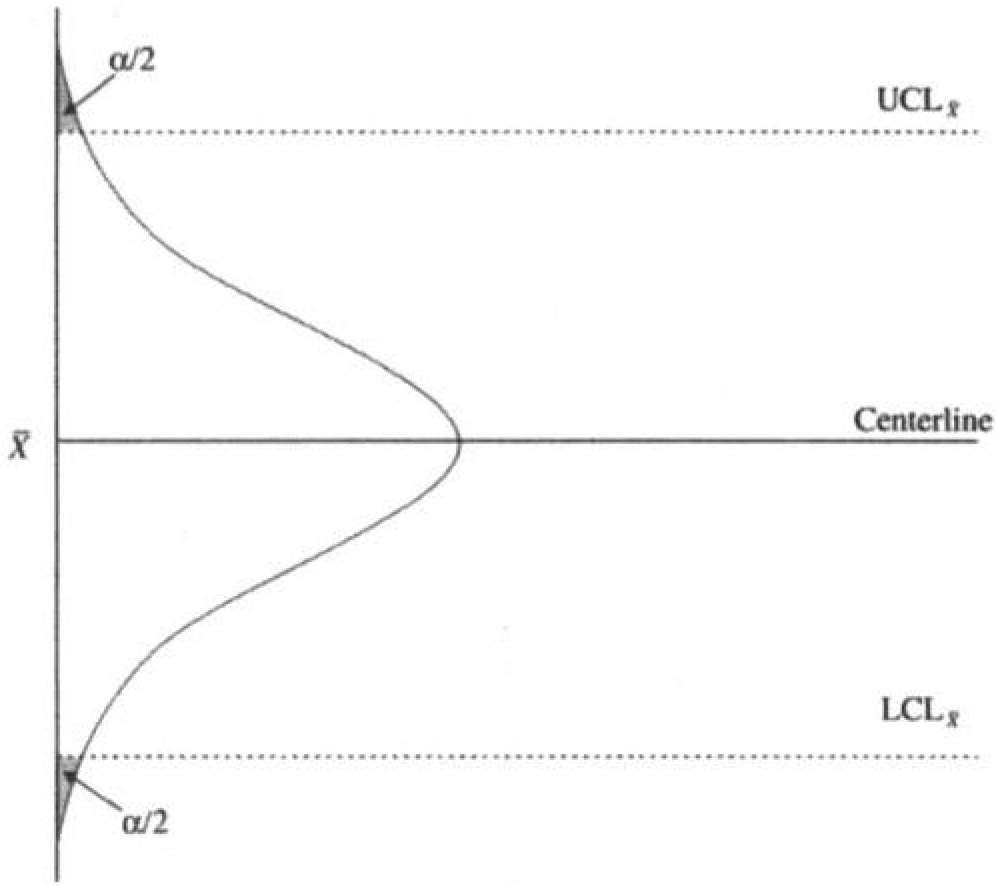


Control Charts (Advantages):

- When to take corrective action
- Type of remedial action necessary
- When to leave a process alone
- Process capability.
- Possible means of quality improvement

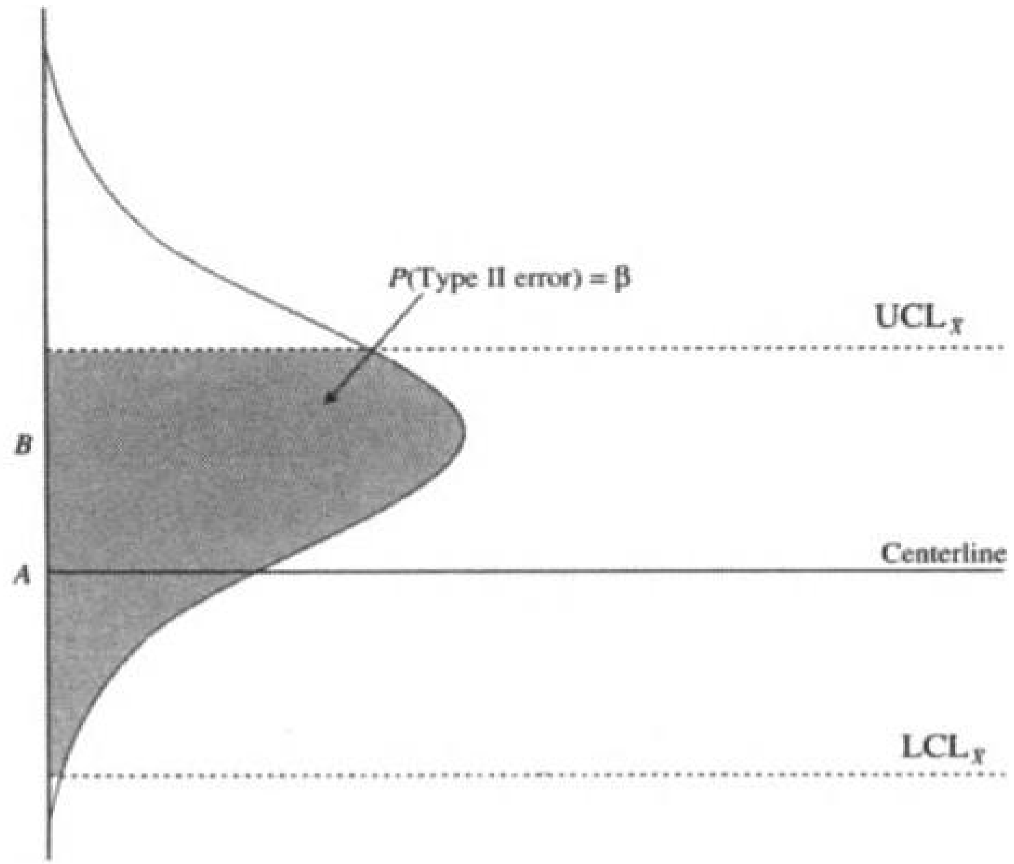
Errors in Control Charts :

Type I errors result from inferring that a process is out of control when it is actually in control. The probability of a type I error is denoted by α.



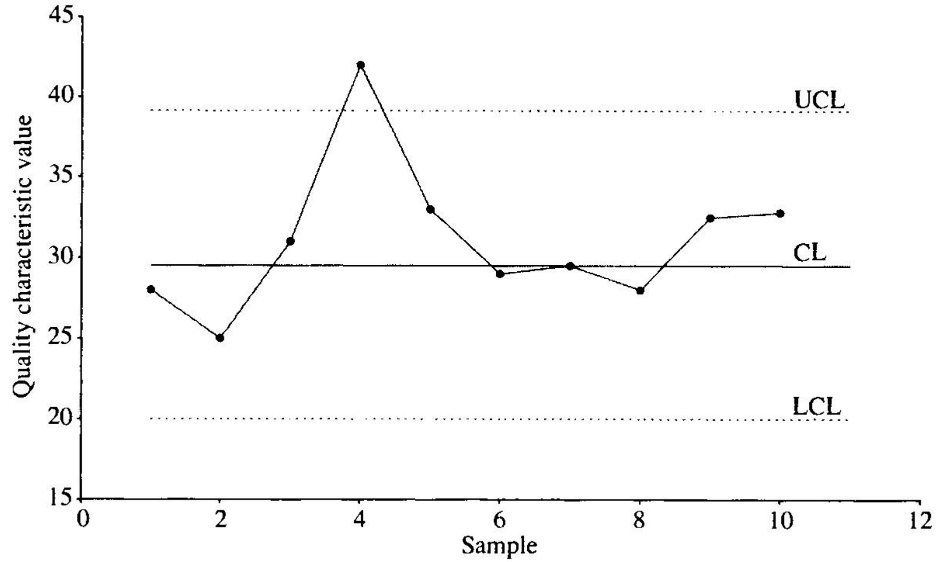
Errors in Control Charts :

Type II errors result from inferring that a process is in control when it is really out of control. If no observations fall outside the control limits, we conclude that the process is in control.

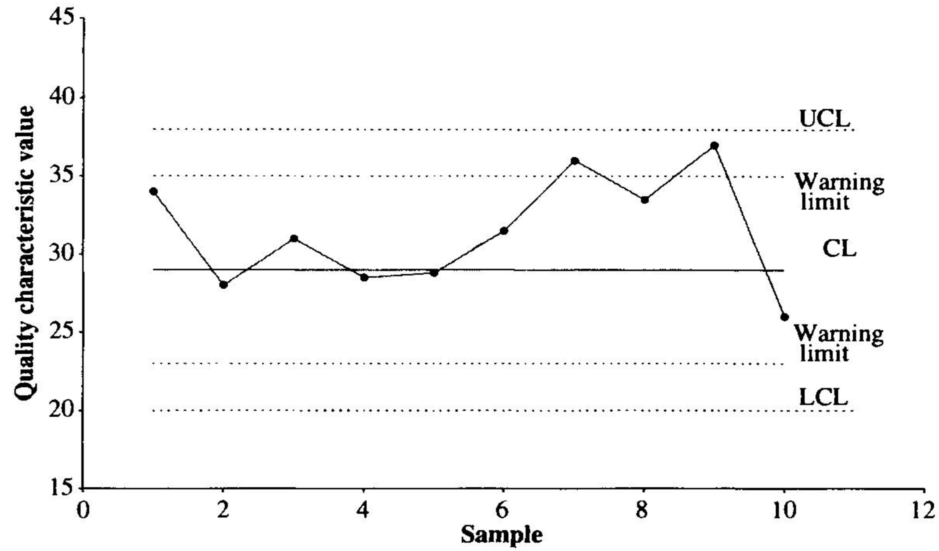


Rules for Identifying an Out-of-Control Process

Rule 1 A process is assumed to be out of control if a single point plots outside the control limits.

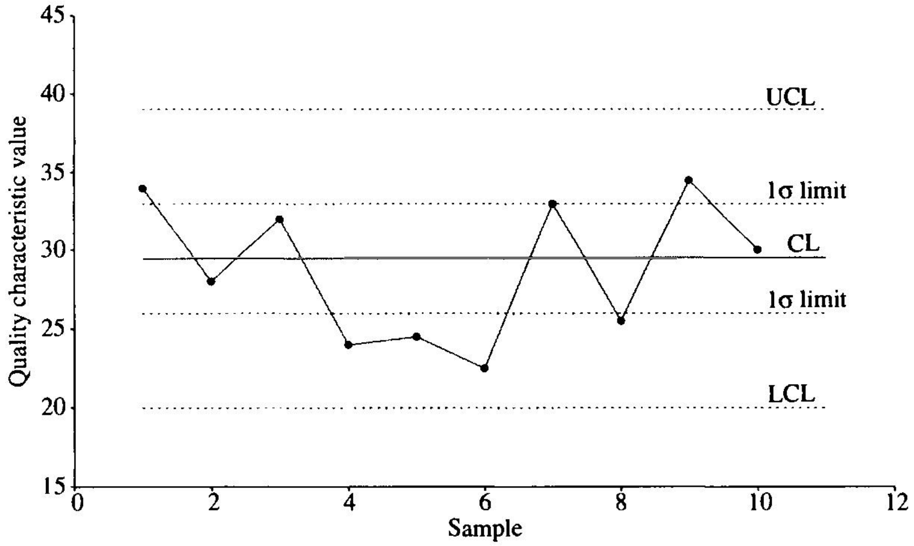


Rule 2 A process is assumed to be out of control if two out of three consecutive points fall outside the 2 σ warning limits on the same side of the centerline.

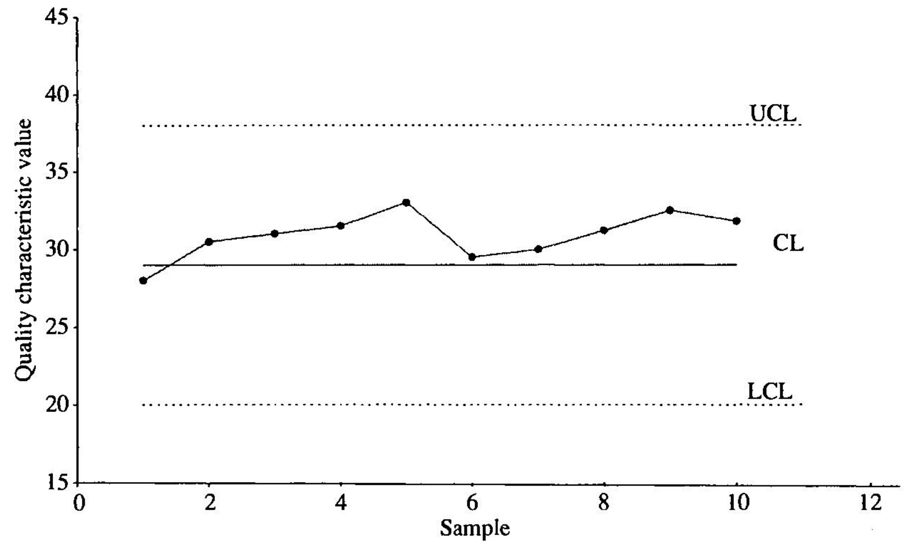


Rules for Identifying an Out-of-Control Process

Rule 3 A process is assumed to be out of control if four out of five consecutive points fall beyond the 1σ limit on the same side of the centerline.

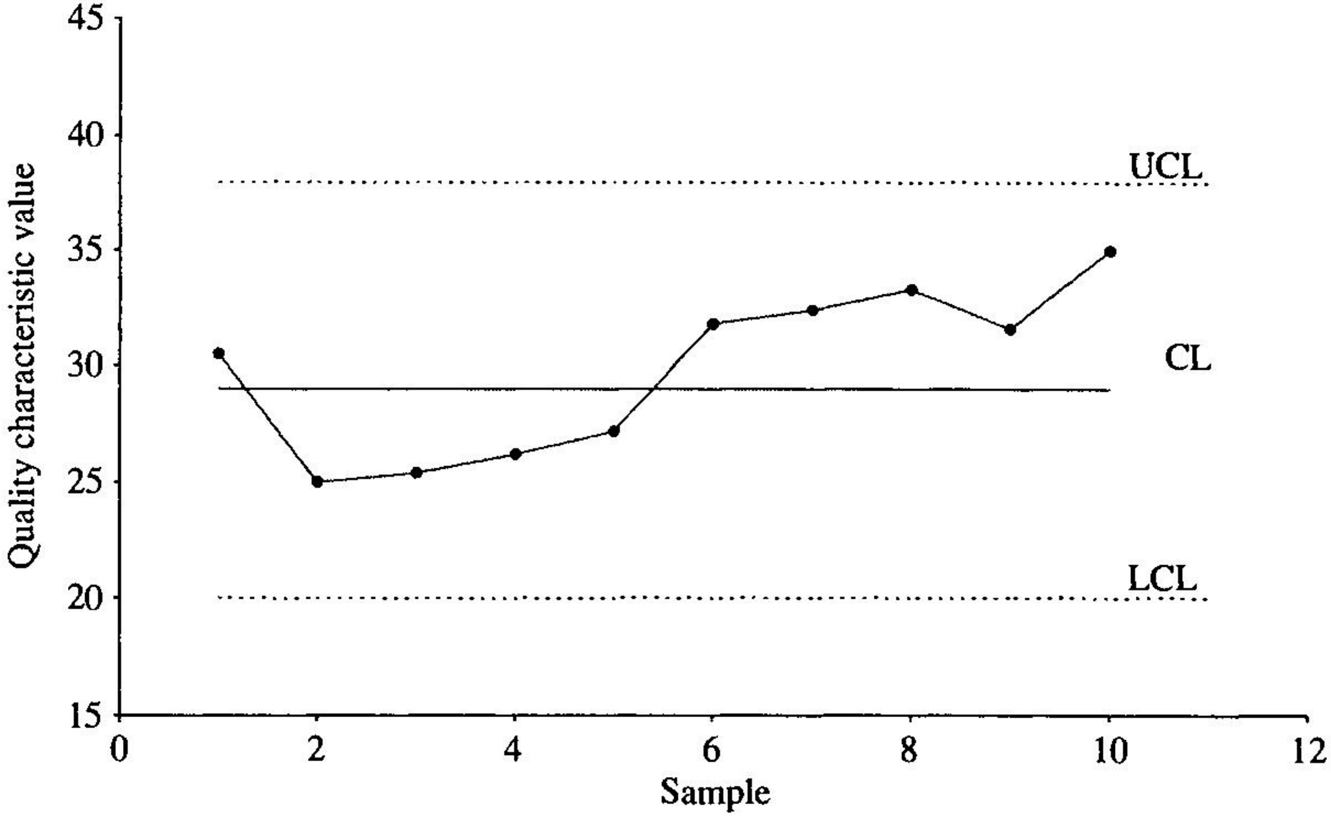


Rule 4 A process is assumed to be out of control if nine or more consecutive points fall to one side of the centerline



Rules for Identifying an Out-of-Control Process

Rule 5 A process is assumed to be out of control if there is a run of six or more consecutive points steadily increasing or decreasing.



Control Charts for Variables

Variables generate data that can be *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

Non conforming- Defective
Non conformities- defects

Steps of development of charts

Step 1: *Using a preselected sampling scheme and sample size, record on the appropriate* forms, measurements of the quality characteristic selected.

Step 2: *For each sample, calculate the sample mean and range using the following* formulas:

$\bar{X}$ is the sample mean =

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

Sample range =

$$R = X_{\max} - X_{\min}$$

where X_i represents the ith observation, *n is the sample size,* X_{max} *is the largest observation,* and X_{min} is the smallest observation.

Step 3: *Obtain and draw the centerline and the trial control limits for each chart. For the* X-chart, the centerline X is given by

$$\overline{\overline{X}} = \frac{\sum_{i=1}^{g} \overline{X}_i}{g}$$

where *g represents the number of samples.*

For the R-chart, the centerline *R is found from*

$$\overline{R} = \frac{\sum_{i=1}^{g} R_i}{g}$$

Steps of development of charts

The control limits for an X-chart are therefore estimated as

$$(UCL_{\overline{X}},\ LCL_{\overline{X}}) = \overline{\overline{X}} \pm A_2\overline{R}$$

The control limits for the **R-chart are estimated as**

$$UCL_R = \overline{R} + 3d_3\frac{\overline{R}}{d_2} = D_4\overline{R}$$

$$LCL_R = \overline{R} - 3d_3\frac{\overline{R}}{d_2} = D_3\overline{R}$$

Step 4: *Plot the values of the range on the control chart for range, with the centerline and the* control limits drawn. *Plot the values of the mean on the control chart for mean, with the centerline and the* control limits drawn.

Step 5: *Delete the out-of-control point(s) for which remedial actions have been taken to* remove **special causes** and use the remaining samples to determine the revised centerline and control limits for the *X- and R-charts.*

These limits are known as the **revised control limits.**

Step 6: *Implement the control charts.*

Sampling by Variable (Table 1)

Number of Observations in Subgroup n	Factor for $\bar{X}$ 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

Sample	Observations (g)				Sample	Observations (g)			
1	352	348	350	351	13	352	350	351	348
2	351	352	351	350	14	356	351	349	352
3	351	346	342	350	15	353	348	351	350
4	349	353	352	352	16	353	354	350	352
5	351	350	351	351	17	351	348	347	348
6	353	351	346	346	18	353	352	346	352
7	348	344	350	347	19	346	348	347	349
8	350	349	351	346	20	351	348	347	346
9	344	345	346	349	21	348	352	351	352
10	349	350	352	352	22	356	351	350	350
11	353	352	354	356	23	352	348	347	349
12	348	353	346	351	24	348	353	351	352

(a) Find the trial control limits for the *X- and R-charts.*

(b) Assuming special causes for out-of-control points, find the revised control limits.

Control Charts for Attributes

- **Nonconformity (defect)** – A quality characteristic that does not meet specification.
- **Nonconforming (defective)** – A product having one or more nonconformities and is unable to function as required.

Types of control chart for attributes:

1. **Proportion of nonconforming items (p-chart)**
2. **No. of nonconforming items (np-chart)**
3. **Chart for total no of nonconformities (c-chart)**
4. **Chart for nonconformities per unit (u-chart)**

Attribute Chart vs variable Chart

- **Attribute charts require larger sample sizes than variable charts.**
- **Attribute information indicates whether a certain quality characteristic is within specification limits. It does not state the degree to which specifications are met or not met.**
- **A variable chart can indicate an upcoming out-of control condition even though items are not yet nonconforming.**
- **Attributes are encountered at all levels of an organization: the company, plant, depart_x0002_ment, work center, and machine (or operator) level whereas Variable charts are typically used at the lowest level, the machine level.**
- **A control chart for attributes can provide overall quality information at a fraction of the cost.**

Advantages and Disadvantages of attribute chart

- A disadvantage of control charts for variables and attributes is that they only use data from the most recent measurement to draw conclusions about the process. This makes it quite insensitive to shifts on the order of 1.5 standard deviations or less.
- Some advantages of using attribute control charts are as follows. (i)Attribute control charts could monitor more than one quality characteristic simultaneously. (ii)Attribute control charts need less cost and time for inspection than variable control charts.

Chart for Proportion of nonconforming (p-chart)

- Based on binomial distribution
- Proportion nonconforming is defined as

$$\hat{p} = \frac{x}{n}$$

where *x is the number of nonconforming items in the sample and n represents the sample size.*

Construction of p-chart:

Step 1: *Determine the sample size and the sampling interval.*

Step 2: *Obtain the data, and record on an appropriate form.*

Step 3: *Calculate the centerline and the trial control limits*

$$\mathrm{CL}_p = \bar{p} = \frac{\sum_{i=1}^{g} \hat{p}_i}{g} = \frac{\sum_{i=1}^{g} x_i}{ng}$$

where *g represents the number of samples*

$$\mathrm{UCL}_p = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$\mathrm{LCL}_p = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

Step 4*: Calculate the revised control limits*

Step 5: *Implement the chart*

Twenty-five samples of size 50 are chosen from a plastic-injection molding machine producing small containers. The number of nonconforming containers for each sample is shown in Table, as is the proportion nonconforming for each sample

Sample	Date	Time	Number of Items Inspected, n	Number of Nonconforming Items, x	Proportion Nonconforming, $\hat{p}$
1	10/6	8:30	50	4	0.08
2	10/6	9:30	50	2	0.04
3	10/6	10:00	50	5	0.10
4	10/6	10:20	50	3	0.06
5	10/7	8:40	50	2	0.04
6	10/7	9:50	50	1	0.02
7	10/7	10:10	50	3	0.06
8	10/7	10:50	50	2	0.04
9	10/8	9:10	50	5	0.10
10	10/8	9:40	50	4	0.08
11	10/8	10:40	50	3	0.06
12	10/8	11:20	50	5	0.10
13	10/9	8:20	50	5	0.10
14	10/9	9:10	50	2	0.04
15	10/9	9:50	50	3	0.06
16	10/9	10:20	50	2	0.04
17	10/10	8:40	50	4	0.08
18	10/10	9:30	50	10	0.20
19	10/10	10:10	50	4	0.08
20	10/10	11:30	50	3	0.06
21	10/11	8:20	50	2	0.04
22	10/11	9:10	50	5	0.10
23	10/11	9:50	50	4	0.08
24	10/11	10:20	50	3	0.06
25	10/11	11:30	50	4	0.08
			1250	90	

$$\bar{p} = \frac{90}{1250} = 0.072$$

$$CL_p = 0.072$$

$$UCL_p = 0.072 + 3\sqrt{\frac{(0.072)(1-0.072)}{50}} = 0.182$$

$$LCL_p = 0.072 - 3\sqrt{\frac{(0.072)(1-0.072)}{50}} = -0.038 \rightarrow 0$$

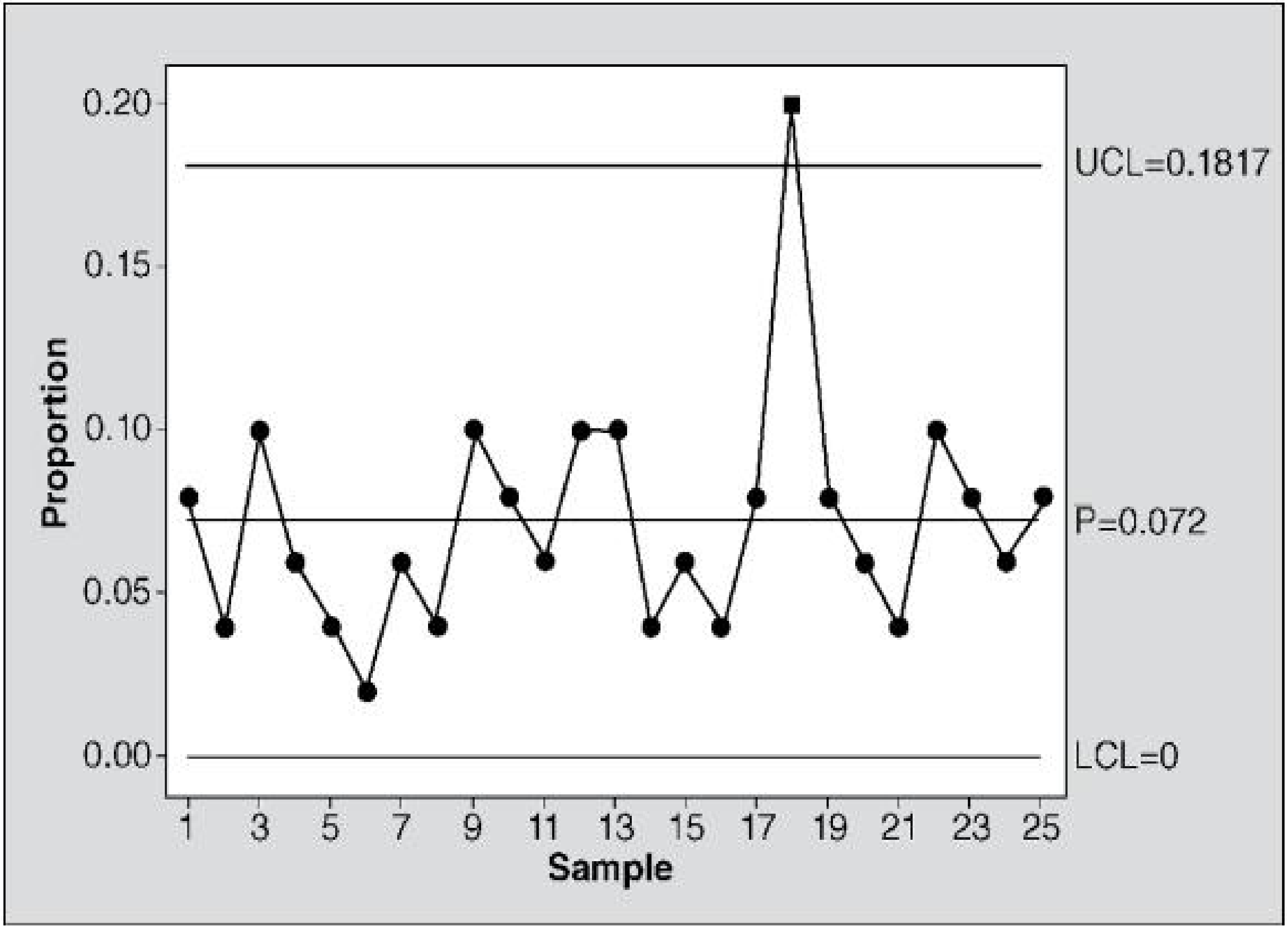


FIGURE 8-2 Proportion-nonconforming chart for containers.

Remedial action is taken to eliminate this special cause, sample 18 is deleted, and the revised centerline and control limits are then found:

$$\mathrm{CL}_p = \frac{90 - 10}{1200} = 0.067$$

$$\mathrm{UCL}_p = 0.067 + 3\sqrt{\frac{(0.067)(1 - 0.067)}{50}} = 0.173$$

$$\mathrm{LCL}_p = 0.067 - 3\sqrt{\frac{(0.067)(1 - 0.067)}{50}} = -0.039 \rightarrow 0$$

The remaining samples are now in control.

Chart for no. of nonconformities (c-chart)

- Based on Poisson distribution

Construction of c-chart:

Step 1: *Determine the sample size and the sampling interval.*

Step 2: *Obtain the data, and record on an appropriate form.*

Step 3: *Calculate the centerline and the trial control limits*

$$\mathrm{CL}_c = \bar{c}$$

$$\mathrm{UCL}_c = \bar{c} + 3\sqrt{\bar{c}}$$

$$\mathrm{LCL}_c = \bar{c} - 3\sqrt{\bar{c}}$$

Step 4*: Calculate the revised control limits*

Step 5: *Implement the chart*

Problem-2

Management has decided to set a standard of 3% for the proportion of nonconforming test tubes produced in a plant. Data collected from 20 samples ofsize 100 are shown in Table 8-3, as is the proportion of nonconforming test tubes for each sample. The centerline and control limits, based on the specified standard, are found to be

TABLE 8-3 Data for Nonconforming Test Tubes

Sample	Date	Time	Number of Items Inspected, n	Number of Nonconforming Items, x	Proportion Nonconforming, $\hat{p}$	Comments
1	9/8	8:20	100	4	0.04	
2	9/8	8:45	100	2	0.02	
3	9/8	9:10	100	5	0.05	
4	9/8	9:30	100	3	0.03	
5	9/9	9:00	100	6	0.06	
6	9/9	9:20	100	4	0.04	
7	9/9	9:50	100	3	0.03	
8	9/9	10:20	100	9	0.09	Die not aligned
9	9/10	9:10	100	5	0.05	
10	9/10	9:40	100	6	0.06	
11	9/10	10:20	100	9	0.09	
12	9/10	10:45	100	3	0.03	
13	9/11	8:30	100	3	0.03	
14	9/11	8:50	100	4	0.04	
15	9/11	9:40	100	2	0.02	
16	9/11	10:30	100	5	0.05	
17	9/12	8:40	100	3	0.03	
18	9/12	9:30	100	1	0.01	
19	9/12	9:50	100	4	0.04	
20	9/12	10:40	100	3	0.03	

$$\bar{p} = \frac{84}{2000} = 0.042$$

This value exceeds the desired standard of 3%. From Figure 8-3 only three points are below the standard of 3%. This confirms our suspicion that the process mean is greater than the desired standard value. If sample 8 is eliminated following removal of its special cause, the revised process average is

$$\bar{p} = \frac{84 - 9}{1900} = 0.039$$

When the control limits are calculated based on this revised average, we have

$$\mathrm{CL}_p = 0.039$$

$$\mathrm{UCL}_p = 0.039 + 3\sqrt{\frac{(0.039)(1-0.039)}{100}} = 0.097$$

$$\mathrm{LCL}_p = 0.039 - 3\sqrt{\frac{(0.039)(1-0.039)}{100}} = -0.019 \to 0$$

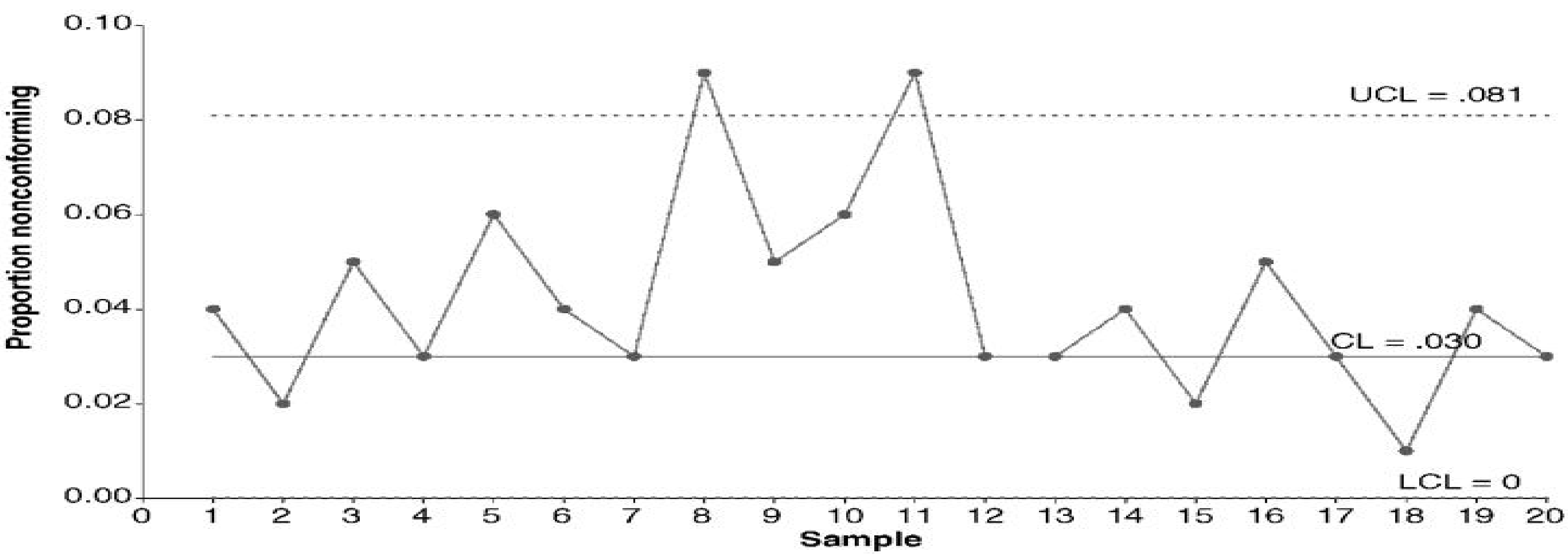


FIGURE 8-3 Proportion-nonconforming chart for test tubes (centerline and control limits based on a

Chart for no. of nonconformities (c-chart)

$$\bar{c} = \frac{189}{25} = 7.560$$

$$UCL_c = 7.560 + 3\sqrt{7.560} = 15.809$$
$$LCL_c = 7.560 - 3\sqrt{7.560} = -0.689 \rightarrow 0$$

Sample	Nonconformities	Sample	Nonconformities
1	5	14	11
2	4	15	9
3	7	16	5
4	6	17	7
5	8	18	6
6	5	19	10
7	6	20	8
8	5	21	9
9	16	22	9
10	10	23	7
11	9	24	5
12	7	25	7
13	8		

Problem -3

Samples of fabric from a textile mill, each 100 m2 are selected, and the number of occurrences of foreign matter is recorded. Data for 25 samples are shown in Table 8-9. Construct a c-chart for the number of nonconformities.

TABLE 8-10 Data on Medical Errors

Sample	Number of Medical Errors	Sample	Number of Medical Errors
1	12	14	13
2	8	15	15
3	15	16	25
4	16	17	18
5	9	18	16
6	10	19	17
7	15	20	14
8	12	21	12
9	13	22	15
10	10	23	16
11	19	24	12
12	16	25	12
13	8		

Solution The average number of nonconformities based on the sample information is found as follows. The centerline is given by

$$\bar{c} = \frac{189}{25} = 7.560$$

The control limits are given by

$$\begin{aligned} UCL_c &= 7.560 + 3\sqrt{7.560} = 15.809 \\ LCL_c &= 7.560 - 3\sqrt{7.560} = -0.689 \to 0. \end{aligned}$$

The c-chart is shown in Figure 8-8. We used Minitab to construct this chart. We selected **Stat > Control Charts > Attribute Charts > c**, indicated the name of the variable (in this case, **Nonconformities**), and clicked **OK**. For sample 9, the number of nonconformities is 16, which exceeds the upper control limit of 15.809. Assuming remedial action has been taken for the special causes, the centerline and control limits are revised as follows (sample 9 is deleted):

$$\bar{c} = \frac{189 - 16}{24} = 7.208$$

$$\begin{aligned} UCL_c &= 7.208 + 3\sqrt{7.208} = 15.262 \\ LCL_c &= 7.208 - 3\sqrt{7.208} = -0.846 \to 0 \end{aligned}$$

After this revision, the remaining sample points are found to be within the limits.

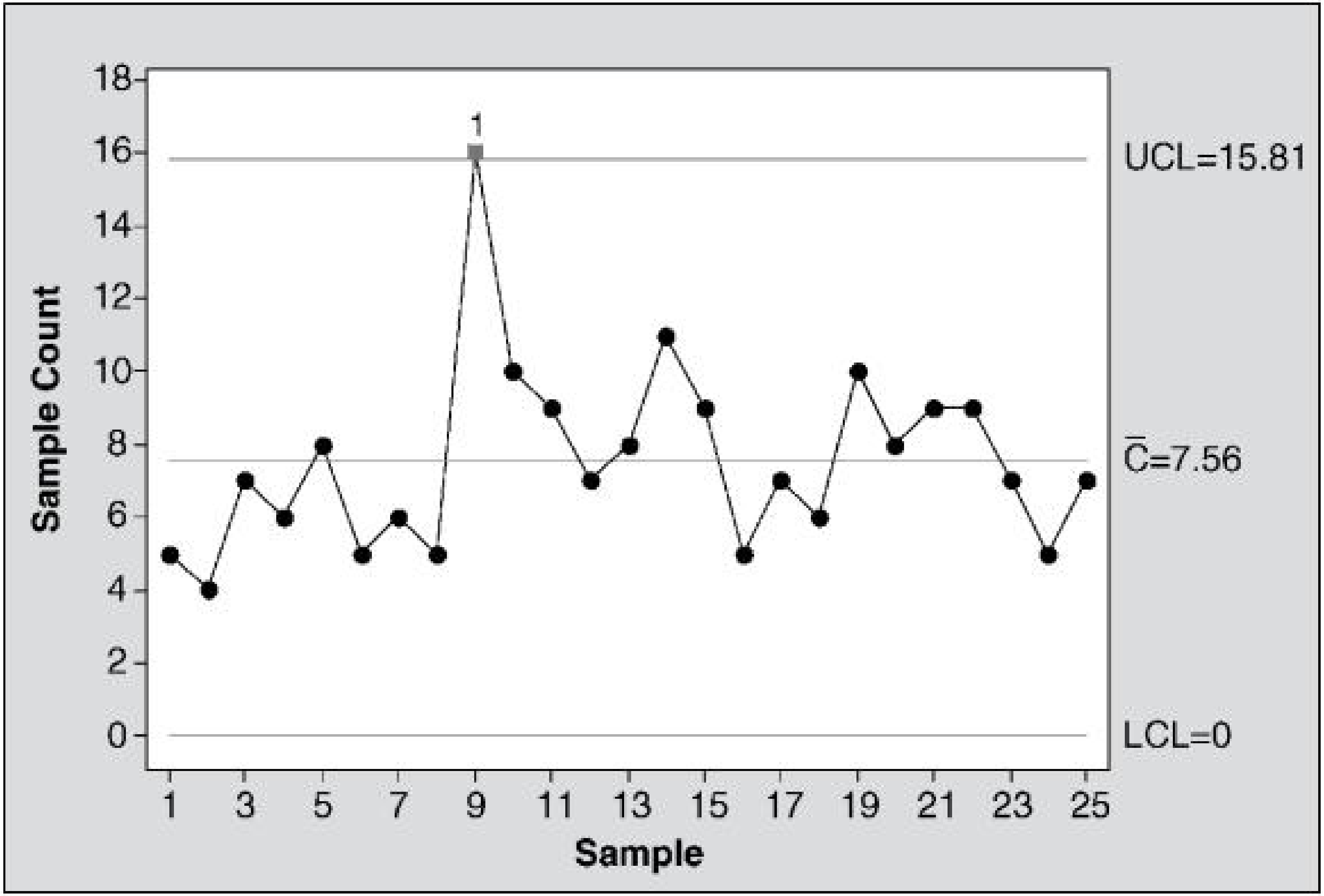


FIGURE 8-8 *c*-Chart for foreign matter data.