Control Chart

What is a Control Chart in QC

- It is a statistical tool used to differentiate between process variation resulting from a common cause and special cause.
- The control chart is a type of run chart used to study the process variation over time.
- This is classified as per recorded data is variable or attribute.
- In our business, any process is going to vary, from response to customer, procurement of chemicals & reagents, to customer satisfaction.
- Machines have wear, tear and malfunction and tear after a long run.
- Control charts measure variation and show it to you graphically and we can easily say that it is within an acceptable limit or not.
- Many processes can be tracked by this graph like defects (delay in response to customer), process time, inventory on hand, cost per test, and many other matrics.
- Also we can use this graph to measure other processes like sample booking errors, order lost, delay in reporting, unplanned absence, etc.

Use of Control Chart

- ✓ It is used to predict the performance of the process
- ✓ Find out the special causes within the process
- ✓ Identify the trend of the process

Principles of Variation

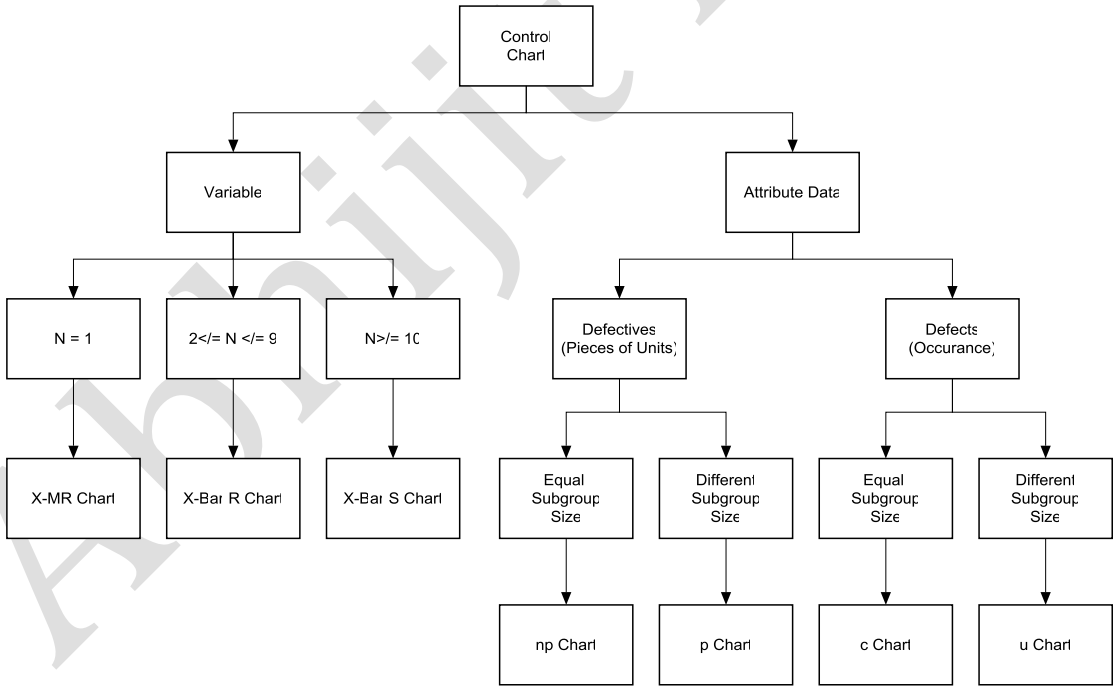
- Every process has variation.
- More the variation, the more loss to the organization.
- Two types of causes are responsible for the variation.
    - Common cause
        - Common cause is fluctuation caused by unknown factors resulting in a steady but random distribution of output around average of the data.
        - Example – Base line noise of analytical instruments.
    - Special cause
        - Special cause is caused by known factors that result in a non-random distribution of output.
        - Example – Machine breakdown.
- Action entirely depends on the types of causes identified.

Types of data

- ✓ There are to types – Attribute and Variable
- ✓ Attribute data that can be counted or can give an answer in Go/No Go, OK/Not OK, or Pass/Fail (example: Microbial test Pass or Fail)
- ✓ Variable data can be measured (example: Chloride in water 32mg/L).

Types of Control Charts

- ➢ There are many types of control charts are available
- ➢ The classification depends on:
  - Nature of recorded data types such as variable or attribute
  - The number of samples is available in each subgroup or we can say subgroup size
  - Focus on defects (occurrence) or defectives (pieces or units)
  - The subgroup size is equal or not
- ➢ For better understanding refer below classification



How to create X-Bar, R Chart

1. Collect data
2. Calculate the subgroup average
3. Determine the overall average

4. Calculate the range
5. Compute the average of the range
6. Calculate the control limit
7. Plot the data in the graph
8. Interpret the graph

Step 1: Collect the data

		Sample								
		X1	X2	X3	X4	X5	X6	X7	X8	X9
	Date	1	2	3	4	5	6	7	8	9
Subgroup	1	15.3	14.4	15.3	15	15.3	14.9	15.6	14	14
	2	14.9	15.5	15.1	14.8	16.4	15.3	16.4	15.8	15.2
	3	15	14.8	15.3	16	17.2	14.9	15.3	16.4	13.6
	4	15.2	15.6	18.5	15.6	15.5	16.5	15.3	16.4	15
	5	16.4	14.9	14.9	15.4	15.5	15.1	15	15.3	15

The above data of chloride estimation in water collected for 9 days. Each day, 5 replicates.

Step 2: Calculate the Subgroup average ($\bar{X}$)

		Sample								
		X1	X2	X3	X4	X5	X6	X7	X8	X9
	Date	1	2	3	4	5	6	7	8	9
Subgroup	1	15.3	14.4	15.3	15	15.3	14.9	15.6	14	14
	2	14.9	15.5	15.1	14.8	16.4	15.3	16.4	15.8	15.2
	3	15	14.8	15.3	16	17.2	14.9	15.3	16.4	13.6
	4	15.2	15.6	18.5	15.6	15.5	16.5	15.3	16.4	15
	5	16.4	14.9	14.9	15.4	15.5	15.1	15	15.3	15
$\bar{X}$	Average	15.36	15.04	15.82	15.36	15.98	15.34	15.52	15.58	14.56

$$\bar{X}1 = \frac{X1,1 + X1,2 + X1,3 + X1,4 + X1,5}{n} = \frac{15.3 + 14.9 + 15 + 15.2 + 16.4}{5} = \frac{76.8}{5} = 15.36$$

Step 3: Determine the overall average, X Double Bar ($\bar{\bar{X}}$)

$$\bar{\bar{X}} = \frac{\bar{X}1 + \bar{X}2 + \bar{X}3 + \bar{X}4 + \bar{X}5 + \bar{X}6 + \bar{X}7 + \bar{X}8 + \bar{X}9}{n} = \frac{15.36 + 15.04 + 15.82 + 15.36 + 15.98 + 15.34 + 15.52 + 15.58 + 14.56}{9}$$
$$= \frac{138.56}{9} = 15.40$$

Step 4: Calculate the Subgroup Range (R)

R = Highest value in subgroup – Lowest value of subgroup

	Sample								
	X1	X2	X3	X4	X5	X6	X7	X8	X9
Date	1	2	3	4	5	6	7	8	9

Subgroup										
	1	15.3	14.4	15.3	15	15.3	14.9	15.6	14	14
	2	14.9	15.5	15.1	14.8	16.4	15.3	16.4	15.8	15.2
	3	15	14.8	15.3	16	17.2	14.9	15.3	16.4	13.6
	4	15.2	15.6	18.5	15.6	15.5	16.5	15.3	16.4	15
	5	16.4	14.9	14.9	15.4	15.5	15.1	15	15.3	15

Average	15.36	15.04	15.82	15.36	15.98	15.34	15.52	15.58	14.56
Highest	16.4	15.6	18.5	16	17.2	16.5	16.4	16.4	15.2
Lowest	14.9	14.4	14.9	14.8	15.3	14.9	15	14	13.6
Range	1.5	1.2	3.6	1.2	1.9	1.6	1.4	2.4	1.6

Step 5: Calculate the Average Range, R-Bar ($\bar{R}$)

$$\bar{X}1 = \frac{R1 + R2 + R3 + R4 + R5 + R6 + R7 + R8 + R9}{n} = \frac{1.5 + 1.2 + 3.6 + 1.2 + 1.9 + 1.6 + 1.4 + 2.4 + 1.6}{9} = \frac{16.4}{9} = 1.82$$

Step 6: Calculate the Control Limit

Find the limit of X-Bar and R chart using below formula:

Control limit for X-Bar Chart

a) Central Line = X-Double Bar
b) Upper control limit = $UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$
c) Lower control limit = $LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$
   A_2 is the coefficient whose value depends on the subgroup size (n)

Control limit for R-Chart

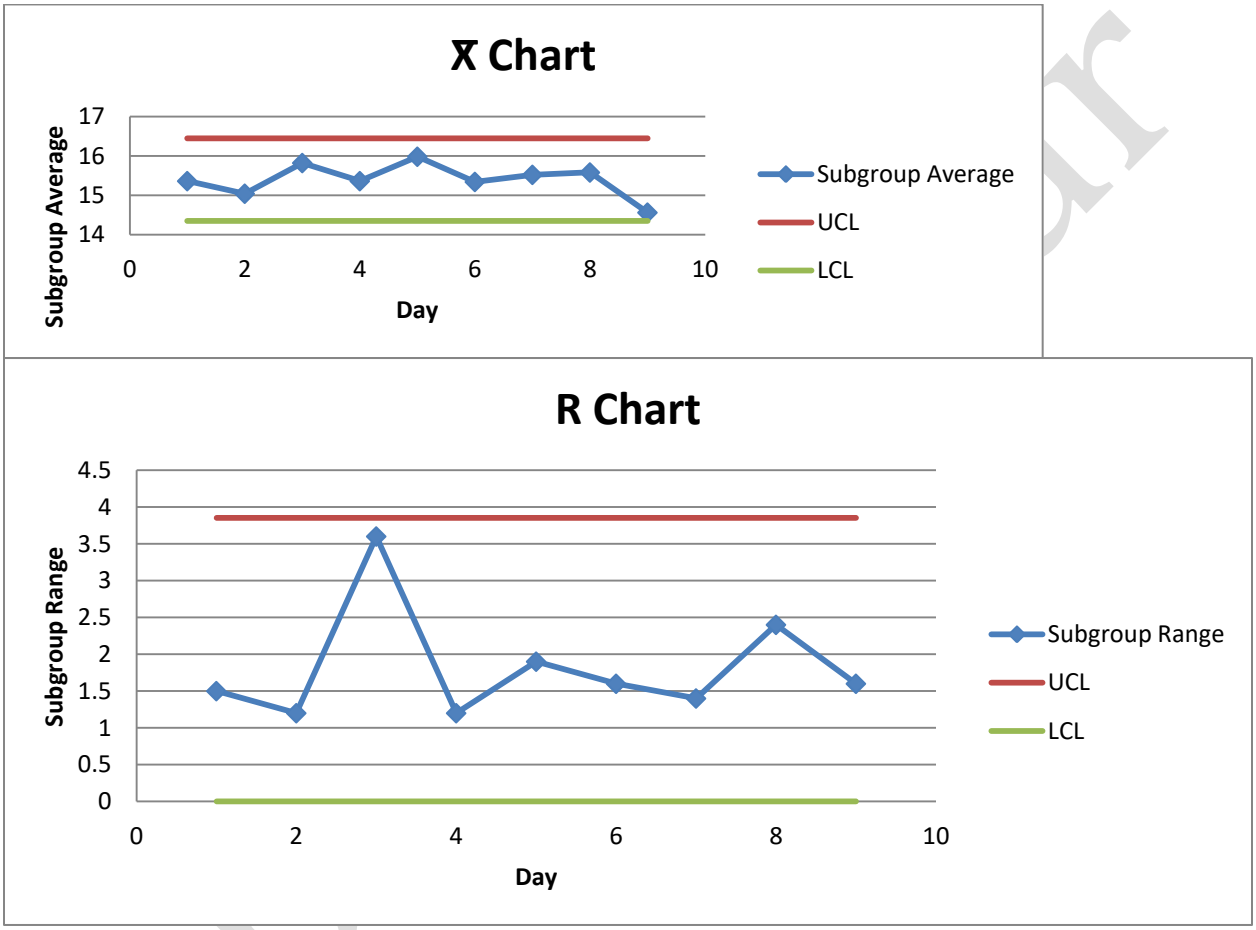
a) Central Line = $\bar{R}$ =
b) Upper control limit = $UCL_{\bar{R}} = D_4 * \bar{R}$
c) Lower control limit = $LCL_{\bar{R}} = D_3 * \bar{R}$
   D3 and D4 are the coefficients whose values are pendends on the subgroup size (n)

Constant values for Control Chart

n	d2	A_2	D3	D4
2	1.128	1.88	0	3.267
3	1.693	1.023	0	2.574
4	2.059	0.729	0	2.282
5	2.326	0.577	0	2.114
6	2.534	0.483	0	2.004
7	2.704	0.419	0.076	1.924
8	2.847	0.373	0.136	1.864

9	2.97	0.337	0.184	1.816
10	3.078	0.308	0.223	1.777

Step 7: Plot of the data



Step 8: Interpret the graph

A. Process stability
   a. Look at the pattern of variation
   b. It should be random and not a systematic pattern
   c. Look for the presence of special causes
   d. Refer below 8 rules of special cause identification
      Rule 1) One or more points are more than 3σ from the center line
      - It is also called as a point beyond the central line.
      - Sometimes, Rule 1 also known as a large shift from the average.

- If we can get any point beyond the control line then the special cause is available.
- Possible Causes:
    a. The new person doing the job
    b. Wrong setup
    c. Measurement error
    d. Operation step skipped or not completed
    e. Equipment breakdown/power failure

Pattern description: Large shifts from the average

Rule 2) 7 points in a row on the same side of the center

- It is known a small shift from the average
- If we get continuously 7 points on the same side of the centerline then the special cause is available in the process.
- Possible causes:
    a. Raw material change
    b. Change in work instruction
    c. Different measurement device/calibration (e.g. different balance or pipette)
    d. Different work shift
    e. A person gains greater skills in doing the job
    f. Change in the maintenance program
    g. Change in the setup procedure

Pattern description: Small shifts from the average

Rule 3) 6 points in a row increasing or decreasing steadily

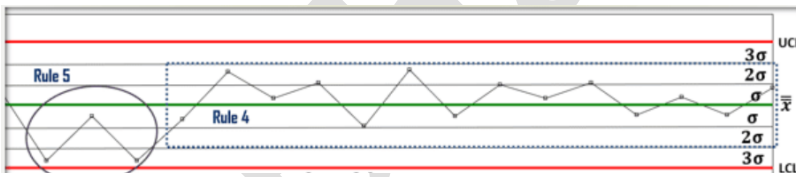
- It is known as a trend pattern
- If we get a pattern of 6 points continuously in increasing order or a decreasing order then the special cause is available in the process
- Possible cause:
    a. Tooling wear (e.g. micro pipette spring)
    b. Temperature effect (cooling, heating) (e.g. variation of room temperature increases the solvent evaporation

rate for HPLC mobile phase; evaporation of matrix of stock solution)

Pattern description: Trends

Rule 4) 14 points continuously alternating up and down

- This is also known as an over control pattern
- If we get 14 points in a row up and down then the special cause is available in the process
- Possible causes:
    a. Tampering by the operator
    b. Alternating raw materials



Pattern description: Over-Control

Rule 5) 2 out of 3 consecutive points > 2σ from the center line (same side)

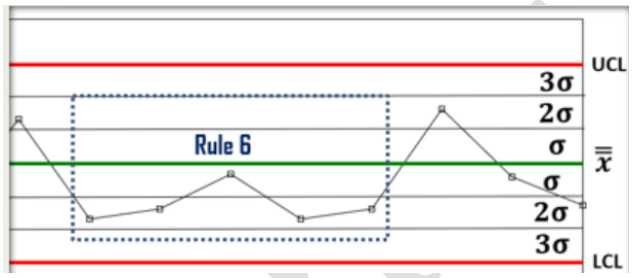
- It is also known as a large shift from the average
- If we get 2 points out of consecutive 3 points present in >2σ distance from the center line on the same side then the special cause is present in the process
- Possible cause:
    a. The new person doing the job
    b. Wrong setup
    c. Measurement error
    d. Operation step skipped or not completed
    e. Equipment breakdown/power failure

Pattern description: Large shifts from the average

Rule 6) 4 out of 5 consecutive points >1 σ limit from the center line (same side)

- It is known as a small shift from the average
- If we get 4 points out of 5 consecutive points present in >1σ distance from the center line on the same side then the special cause is present in the process
- Possible causes:

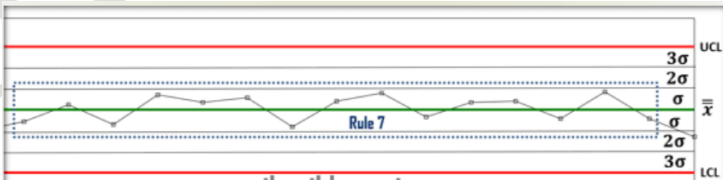
a. Raw material change
b. Change in work instruction
c. Different measurement device/calibration
d. Different work shift
e. A person gains greater skills in doing the job
f. Change in the maintenance program
g. Change in the setup procedure



Pattern description: Small shifts from the average

Rule 7) 15 points in a row within 1σ of the center line (either side)

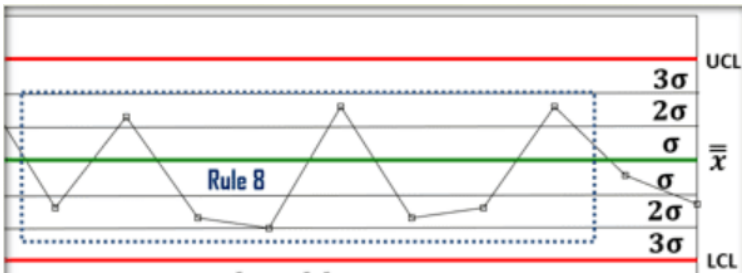
- This is also known as the stratification nature of the pattern
- If we get 15 points in a row within 1σ of the any side of the center line then the special cause is available.
- Possible causes:
  a. Data mixed with more than one process
  b. Mixed data of more than one work shifts, machine s or raw materials



Pattern description: Stratifications

Rule 8) A run of 8 consecutive points >1σ from the center line (either side)

- It is also known as a mixture property of pattern
- If we get 8 consecutive points >1σ from the center line (either side) then special cause is available
- Possible causes:
  a. Data mixed with more than one process
  b. Mixed data of more than one work shifts, machines or raw materials



Pattern description: Mixtures

B. Process capability
    a. Compare with specification and establish Process Capability (e.g. are our processes capable enough to achieve our specifications?). This is not the part of this document. Mail to abhijit.bhar@outlook.com for further reading.