University of Jordan
Chemical Engineering Department
905509 Statistical Quality Control

Control Charts

Dr. Ali Kh. Al-Matar
aalmatar@ju.edu.jo

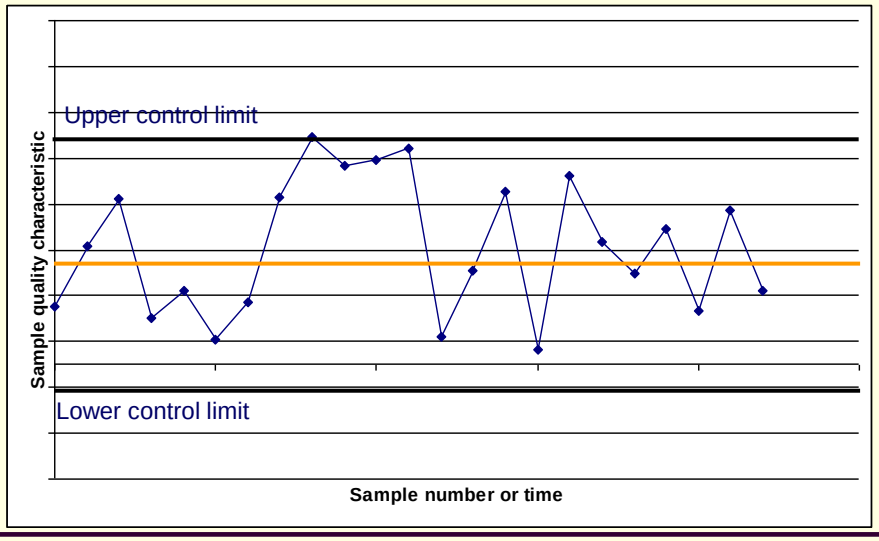
Outline

- What is a control chart.
- Types of control charts.
- Simple interpretation of control charts
- OCAP
- Reasons for using control charts
- Shewhart model of a general control chart
- Action and warning limits
- Sample size and frequency

Control Chart

- A **control chart** is a graphical display of a quality characteristic that has been measured/computed from a sample versus the sample number or time.
- A control chart contains three lines
  - Center line (CL) corresponds to the average of the characteristic corresponding to in-control state
  - Upper control limit (UCL), and lower control limit (LCL). These two lines are chosen such that nearly all of the sample points will fall between them.
- A control chart is specified by its:
  - **Sample size** (how many samples are taken at a time?)
  - **Control limits** (how many standard deviation units from the mean?)
  - **Frequency of sampling** (what is the time interval elapsed before taking another sample?)

Control Chart



Control Chart Types

- Many types, we focus our attention here on the X and R charts.
- Advanced and related topics include
  - Standard Deviation Charts
  - CUSUM approach
  - Exponentially weighted average methods.
- Can deal with
  - Variables
  - Attributes

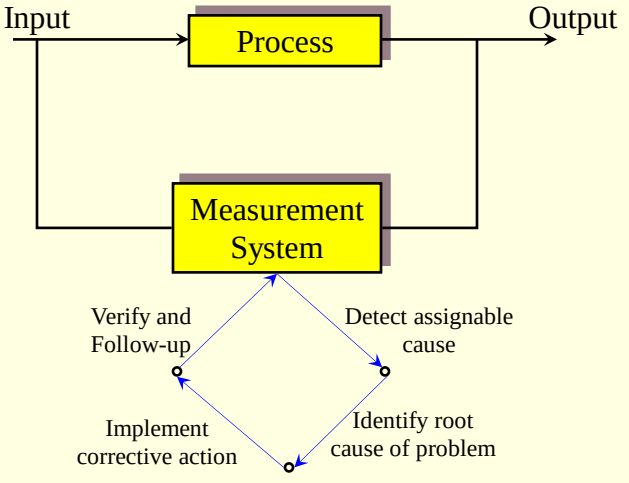
Simple Interpretation of a Control Chart

- Process is in-control
  - As long as the points fall within the control limits, the process is assumed to be in control and no action is necessary.
- Process is out-of-control
  - A point falling outside the limits is interpreted as evidence that the process is out of control, and corrective action is necessary to eliminate the assignable causes that are responsible for such behavior.
  - Even if all the points fall within the control limits, if they behave in a systematic or nonrandom manner, then this is an indication that the process is out of control.

Out of Control Action Plan (OCAP)

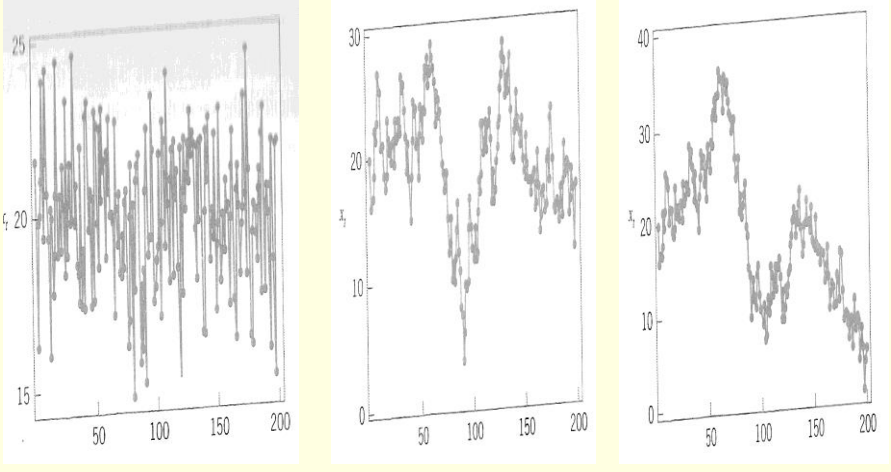
- An **out of control action plan OCAP** is a flowchart or text-based description of the activities that must take place following the occurrence of an activating event.
- Activating events are usually out-of-control signals from the control chart
- OCAP consists of
  - **Checkpoints** are potential assignable causes**.**
  - **Terminators** are actions taken to resolve the out-of-control condition hopefully by eliminating the assignable cause.
- Ultimately, the OCAP grows and evolves to an expert system dealing with the process of interest.

Process Improvement Using Control Charts

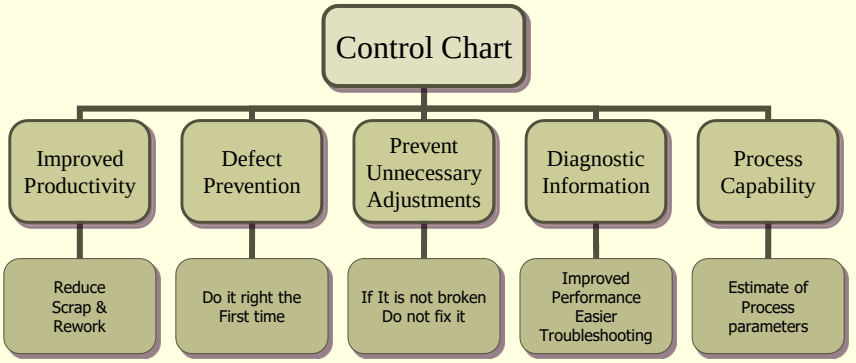


Types of Process Variability

- **Stationary**. Process data vary around a fixed mean in a stable or predictable manner.
  - Uncorrelated (White noise). The past values of the data are of no help in predicting any of the future values.
  - Autocorrelated. Successive observations are dependent.
- **Nonstationary**. The process data drifts (wanders) without any sense of stable or fixed mean.
  - Occurs in chemical and process industries.
  - Use Engineering process control (feedback control) to stabilize the process into somewhat a stationary process.



Using Control Charts



Shewhart General Model for Control Charts

- Let w be a sample statistic that measures some quality characteristic, its mean is μ_w, and the standard deviation is σ_w. Then the CL, UCL and LCL become

$$\begin{aligned} \text{UCL} &= \mu_w + L\sigma_w \\ \text{CL} &= \mu_w \\ \text{LCL} &= \mu_w - L\sigma_w \end{aligned}$$

- L is the distance of the control limits from the center line, expressed in standard deviation units.

Action and Warning Limits

- **Three sigma** (three standard deviations from the mean) limits are often referred to as **action limits**.
  - Mainly in Europe a 0.001 probability limit is used for action limits instead of the 3σ limits. This corresponds to 3.09σ.
- **Two sigma** (two standard deviations from the mean) limits are often referred to as **warning limits**.
  - Increases the sensitivity of the control chart.
  - Disadvantage of increased risk of false alarms.

Sample Size & Frequency of Sampling

- There is a need to specify a sample size and the frequency of sampling to construct and/or use a control chart.
- Sample size
  - Large, less frequent
    - Easier to detect small shifts in the process.
    - Longer time to discover process shifts.
  - Small, more frequent
    - Harder to detect small shifts in the process.
    - Shorter time to discover process shifts.

Average Run Length (ARL)

- When a process is in control the Average Run Length (ARL) is used to evaluate the performance of the control chart

$$\text{ARL} = \frac{1}{p}$$

- ARL gives the length of time (or the number of points) that should plot in control before a point plots outside the control limits.
- $p=\alpha$ is the probability that any point exceeds the control limits

$$p = \alpha = \begin{cases} 0.046, & 2\sigma \\ 0.0027, & 3\sigma \end{cases}$$

Average Time to Signal (ATS)

- Desirable to express the performance of the control chart in terms of time. The time corresponding to an ARL is called the average time to signal (ATS)

$$\text{ATS}=\text{ARL} \times h$$

- Where h is the sampling period (how many hours elapse before taking another sample)

Rational Subgroups

- Subgroups or samples should be selected such that
  - if assignable causes are present, the chance for **differences between subgroups will be maximized,**
  - while the chance for differences due to these assignable causes **within a subgroup will be minimized**.

Selection of Rational Subgroups

- Select consecutive units of production.
  - Provides a "snapshot" of the process.
  - Effective at detecting process shifts.
- Select a random sample over the entire sampling interval.
  - Can be effective at detecting if the mean has wandered out-of-control and then back in-control.

Analysis of Patterns on Control Charts

- **Nonrandom patterns can indicate out-of-control conditions**
- Patterns such as cycles, trends, are often of considerable diagnostic value.
- Look for "**runs**" - this is a sequence of observations of the same type (all above the center line, or all below the center line)
- Runs of say 8 observations or more could indicate an out-of-control situation.
  - Run up: a series of observations that are increasing
  - Run down: a series of observations that are decreasing

Western Electric Handbook Rules

- A process is considered out of control if any of the following occur:
  1. One point plots outside the 3-sigma control limits.
  2. Two out of three consecutive points plot beyond the 2-sigma warning limits.
  3. Four out of five consecutive points plot at a distance of 1-sigma or beyond from the center line.
  4. Eight consecutive points plot on one side of the center line.

Sensitizing Rules for Control Charts

Western Electric Rules

1. One or more points outside of control limits.
2. Two of three consecutive points outside the two-sigma warning limits but still inside the control limits.
3. Four of five consecutive points beyond the one-sigma limits.
4. A run of eight consecutive points on one side of the center line.

Remaining Sensitizing Rules

5. Six points in a row steadily increasing or decreasing.
6. Fifteen points in a row in zone C (both above or below the center line).
7. Fourteen points in a row alternating up and down.
8. Eight points in a row on both sides of the center line with none in zone C.
9. An unusual or nonrandom pattern in the data.
10. One or more points near a warning or control limit.

Caution - Sensitizing Rules

- Use sensitizing rules with caution
  - Excessive number of false alarms can be harmful to an effective SPC program.
  - Decision process becomes more complicated contrary to the simplicity principle which led to popularity of the control chart use.