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Control Charts

Key Learning Points

1. Describe the importance of Control Charts.
2. Explain how to develop and interpret Control Charts.
3. Utilize Control Charts in improvement projects.

What is a Control Chart?

A control chart displays the measured performance of a process at given times. Its control limits show how much variability is normally found in the process. Thus, a control chart can help determine whether measured performance has drifted from the average to a point where corrective action is required.

Track

Control charts statistically track processes over time.

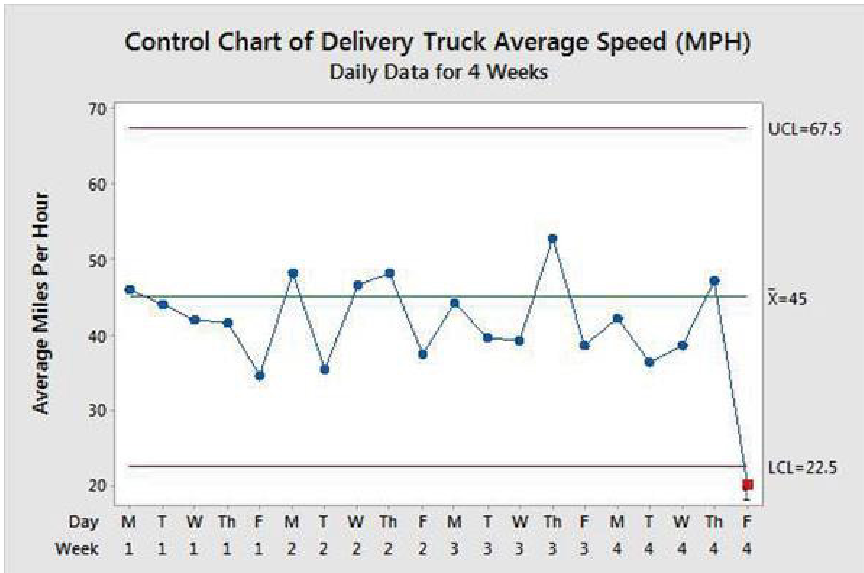
See Patterns

Control charts allow for identification of unnatural (nonrandom) patterns in process variables.

Set Limits

Upper and lower control limits reflect natural limits of (random) variability in the process. Control limits are NOT customer specification limits.

Control Charts



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Control Limits vs. Specification Limits

Do not confuse control limits with specification limits. A process may be in control, but the product or service may still not meet customer needs. Being in control means only that the process is not displaying special cause variation.

Control limits reflect the expected variation in the data and are based on the distribution of the data points. Comparing the data to the control limits will give you information about the consistency of the process over time.

Comparing the process to the specification limits provides information on the adequacy of the process.

Control Limits

- Are derived from process data (± 3 estimated standard deviations of the statistic from the mean of the statistic).
- Are used to determine if your process is "in control" (without special cause variation).
- Are plotted on control charts.
- May be changed when there is a verified, significant change to your process.
- Represent the voice of the process.

Customer Specification Limits

- Are defined based on feedback/needs from the customer(s).
- Are typically used to determine if your process is producing defects.

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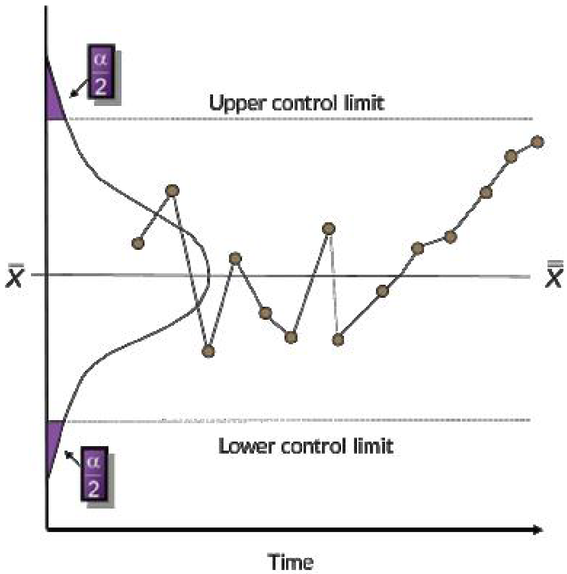
- Are plotted on histograms (not control charts).
- Change when your customers say they do!
- Represent the voice of the customer.

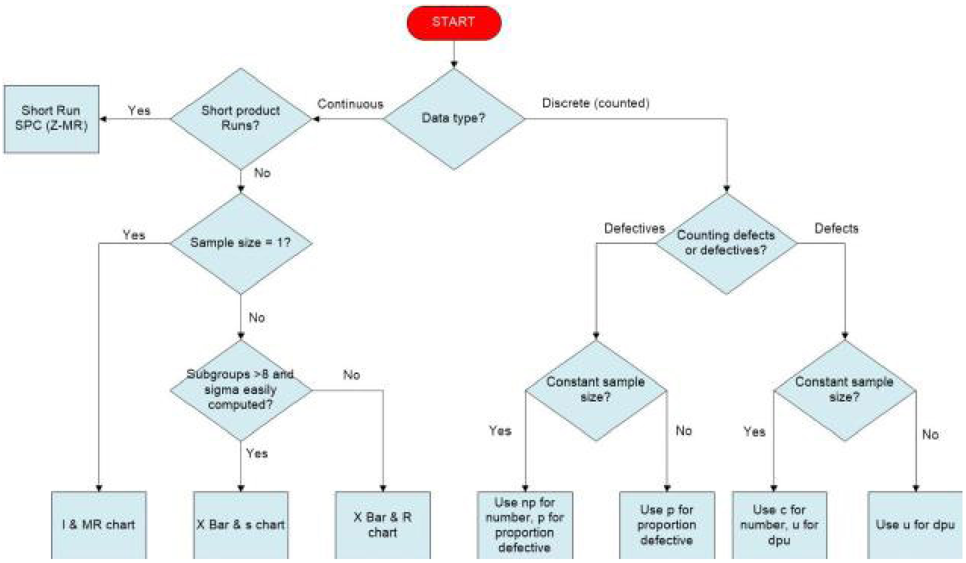
The Shewhart Control Chart Model



Rational Subgroups

- Each point on a control chart (except a chart of individuals) represents a subgroup.
- Subgroups for variables charts should be chosen so as to be most representative of both short-term (within) and long-term (between) variability.
- The rational subgroup for attribute charts should:
  - Encompass a convenient time period or
  - Encompass a convenient material quantity
  - Be representative of the short-term variation in the population

Selecting Appropriate Control Charts



Comparison of Common Control Charts

Statistical Measure Plotted	▪ Average (X-bar) and range (R) ▪ Average (X-bar) and standard deviation (s) ▪ Individual (I) and Moving Range (MR) ▪ Cumulative sum	▪ % defective p Number of ▪ defectives np	▪ Defects per unit u ▪ Number of defects c
Type of Data Required	Continuous data (measured values of a characteristic)	Discrete data (number of defective units of product)	Discrete data (number of defects per unit of product)
General Field of Application	Control of individual characteristics	Control of overall fraction defective of a process	Control of overall number of defects per unit

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Significant Advantages	1. Provides maximum utilization of information available from data 2. Provides detailed information on process average and variation for control of individual dimensions	1. Data required are often already available from inspection records 2. Easily understood by all personnel 3. Provides an overall picture of quality	Same advantages as p chart but also provides a measure of degree of defectiveness
Significant Disadvantages	1. Not understood unless training is provided—Can cause confusion between control limits and tolerance limits 2. Cannot be used with go no-go type of data	1. Does not provide detailed information for control of individual characteristics 2. Does not recognize different degrees of defectiveness in units of product 3. Requires large sample sizes	Does not provide detailed information for control of individual characteristics

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Sample Size	▪ Xbar-R: Minimum 2, usually 4 or 5 ▪ Xbar-S: Minimum 9 ▪ I&MR: 1, otherwise use Xbar-R or Xbar-S ▪ Cumulative Sum: Minimum 2, usually 4 or 5	Depends on rate of defectives, typically samples of 25 to 100	Any convenient unit of product such as 100 ft. of wire or one television set

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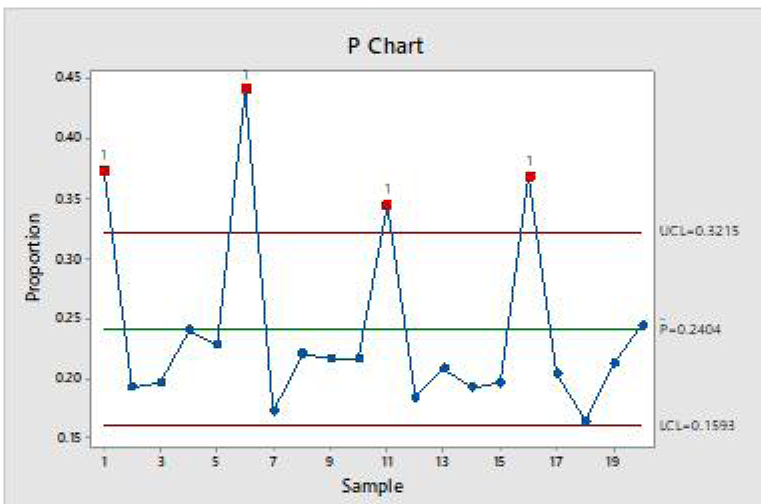
P Chart



The P chart plots the proportion of nonconforming units (also called defectives). While a unit may have many quality characteristics that can be evaluated, it is always considered as either conforming or nonconforming.

The P chart is the most widely used attribute control chart.

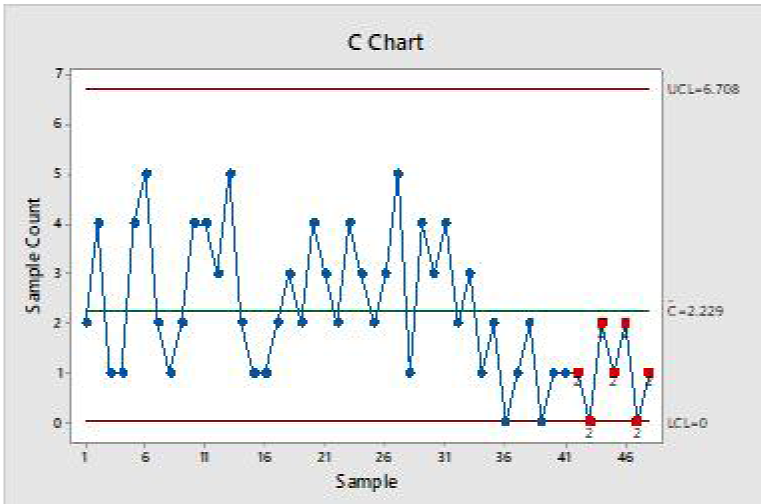
Upper Control Limits (UCL) and Lower Control Limits (LCL) help to determine if process variation is within expected process random variation.

The center line (p-bar) indicates the average proportion of errors of all data points. The red squares indicate out-of-control points. The numbers indicate which test failed.

For example, you can use a P chart to monitor the following:

- The proportion of flights that depart late
- The proportion of bicycle tires that are flat
- The proportion of printed logos that are smudged

C Chart



C charts are used to monitor the number of defects where each item can have multiple defects. You should use a C chart only when your subgroups are the same size. Use this control chart to monitor process stability over time so that you can identify and correct instabilities in a process.

In a C chart, the center line (c-bar) indicates the average number of defects in a set sample of product or process outputs.The red squares indicate out-of-control points and the number indicates what test failed.

For example, you can use a C chart to monitor the following:

- The hour-to-hour variation in the number of defects per 10 foot section of carpet.

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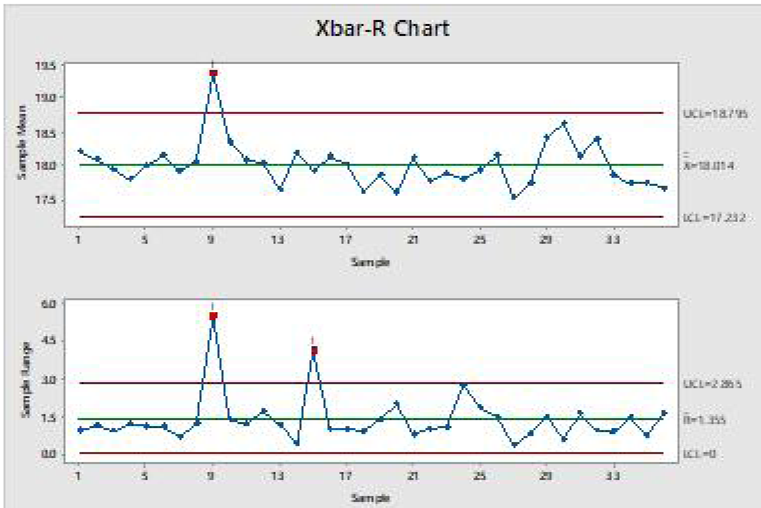
Averages and Ranges Chart (X-bar R)



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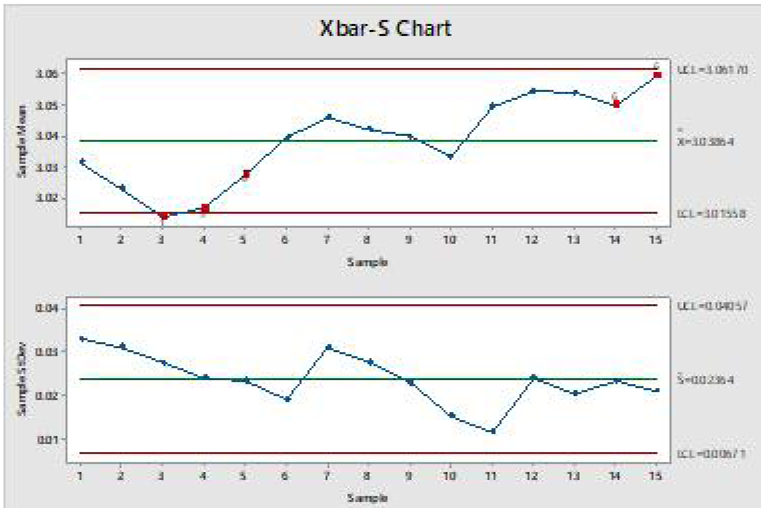
Xbar-R Charts are used to monitor the mean and variation of a process when you have continuous data and subgroup sizes of 8 or less. Use this control chart to monitor process stability over time so that you can identify and correct instabilities in a process.

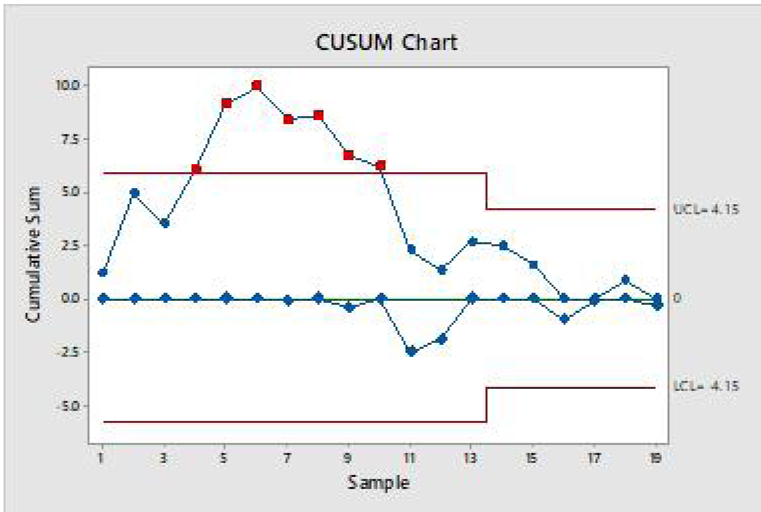
- Xbar charts show where the process is centered.
- If the Xbar chart shows natural variation, the center of the process is not shifting significantly.
- If the Xbar chart shows a trend, the center of the process is moving gradually up or down.
- If the Xbar chart is erratic and OOC, something is changing the center rapidly and inconsistently.
- Xbar charts can be affected by OOC conditions on the R chart.
- If the Xbar chart and R chart are both OOC, look first for the causes affecting the R chart.
- R chart uniformity or consistency:
  - If R chart is narrow, the product is uniform
  - If R chart is OOC, something is operating on the process in a non-uniform manner

Averages and Ranges Chart (X-bar S)



Xbar-S Charts are used to monitor the mean and variation of a process when you have continuous data and subgroup sizes of 9 or more. Use this control chart to monitor process stability over time so that you can identify and correct instabilities in a process.

Cumulative Sum Chart (Cusum)



A CUSUM chart is a time-weighted control chart that displays the cumulative sums (CUSUMs) of the deviations of each sample value from the target value. Because it is cumulative, even minor drifting in the process mean will lead to steadily increasing or decreasing cumulative deviation values. Therefore, this chart is especially useful in detecting slow shifts away from the target value due to machine wear, calibration problems, and so on. If a trend develops upward or downward, it indicates that the process mean has shifted, and you should look for

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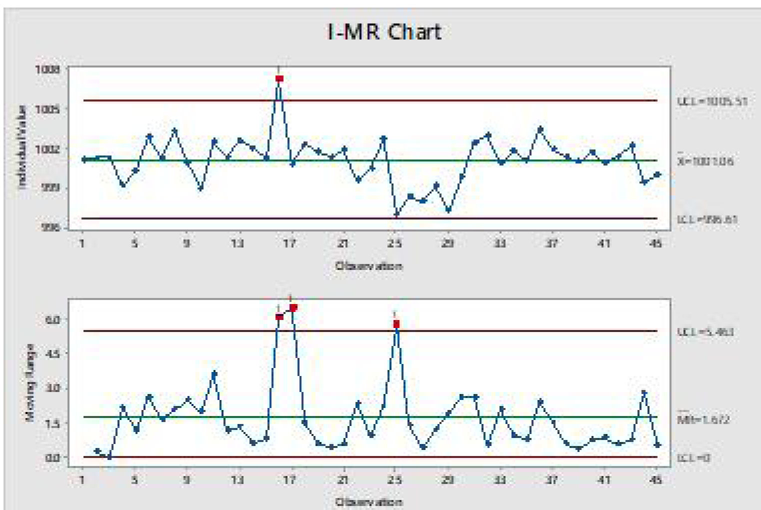
special causes.

The plot points can be based on either subgroups or individual observations. When data are in subgroups, the mean of all the observations in each subgroup is calculated. CUSUM statistics are then calculated from these means. When you have individual observations, CUSUM statistics are calculated from the individual observations.
The points represented by dots are the upper sum which represents the cumulative sum of points above the target. These dots and the connecting lines help identify upward trends in the process level. The points represented by diamonds show the cumulative sum of observations below the target and help identify downward trends. In a stable process, the points should fluctuate randomly about the center line.

For a Cumulative Sum chart, the Control limits are located 4σ from the center line (target).

Upward or downward trends should be noted as they are evidence that the process mean has shifted and you should look for special causes.

Individuals and Moving Range Chart (I&MR)



An Individuals and Moving Range chart plots individual observations (I chart) and moving ranges (MR chart) over time for variables data. Use this combination chart to monitor process center and variation when it is difficult or impossible to group measurements into subgroups. This occurs when measurements are expensive, production volume is low, or products have a long cycle time.
When data are collected as individual observations, you cannot calculate the standard deviation for each subgroup. The moving range is an alternative way to calculate process variation by computing the ranges of two or more consecutive observations.

The individuals' measurements should be tested for normality before using the calculated control limits based on the standard formulas. If the distribution is

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significantly not normal, e.g., pronounced skewness, then the control limits for individuals should be calculated based on transformed data.
Charts for individuals are not as sensitive to process changes as charts for averages. Care must be taken in interpretation of charts for individuals if the process distribution is not normal. Data transformation may be desirable in these cases.
Charts for individuals do not isolate the piece-to-piece repeatability of the process. Therefore, in many applications it may be better to use a conventional Xbar and R chart with small subgroup sample sizes (2 to 4) even if this requires a longer period between subgroups.

Since there is only one individual item per subgroup, values of I and MR can have substantial variability (even if the process is stable) until the number of subgroups is 100 or more.

Box Cox Transformation

The Box-Cox transformation will manipulate non-normal data to suggest the appropriate factor that can be used to change the observed data into data more closely fitting the normal distribution.

Typically, the Box-Cox transformation is used in tandem with a control chart or capability analysis. The Box-Cox transformation command is used to find the optimal value of λ (Lambda), then the transformation factor is automatically applied through MINITAB®.

Steps in Constructing and Analyzing Control Charts

1. Select the appropriate characteristic to chart.
2. Establish a rational subgroup (frequency) and an appropriate sample size.
3. Select the appropriate control chart to use.
4. Implement the data collection system and collect the data.
5. Calculate the center line and control limits.
6. Plot the data.
7. Check for Out-Of-Control (OOC) conditions.
8. Interpret findings, identify special causes of the variation, and remedy the cause(s).

Interpretation

- Nonrandom variation lies outside of control limits.
- Nonrandom, out-of-control events can appear as:
  - Sudden shifts in average level
  - Trends in level
  - Wide, alternating swings

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Out of Control Conditions

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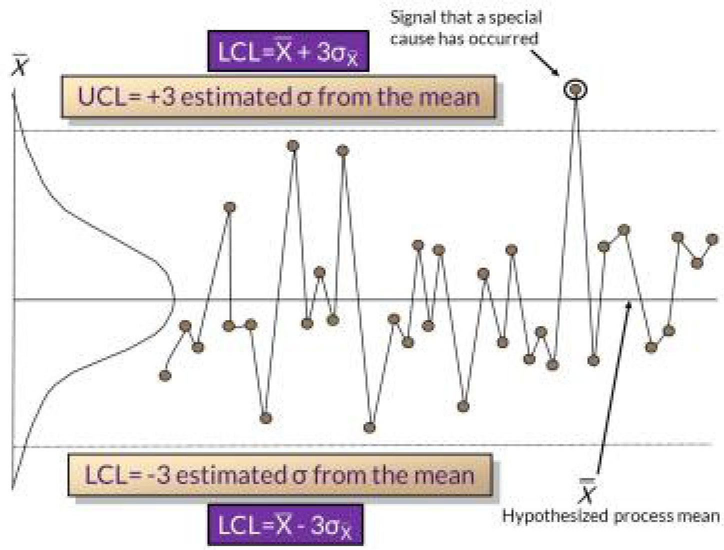
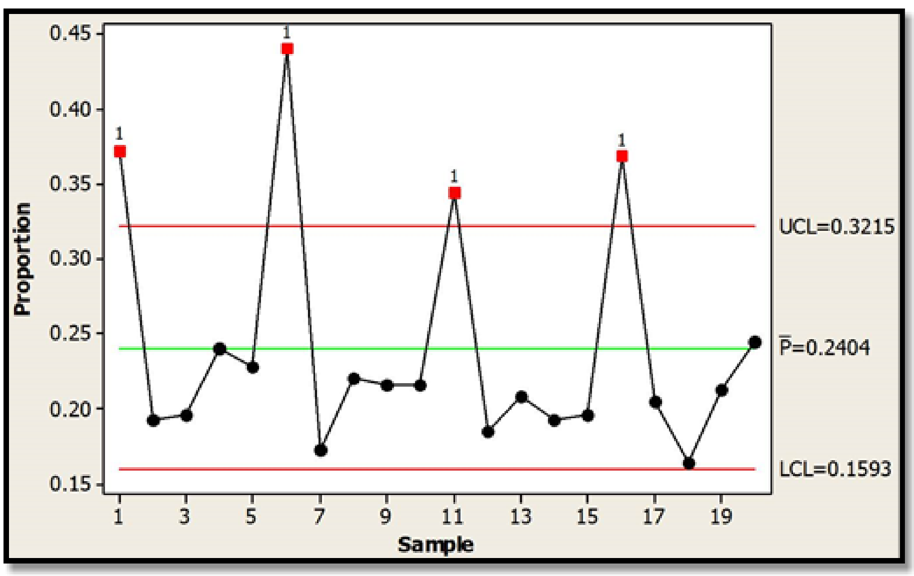


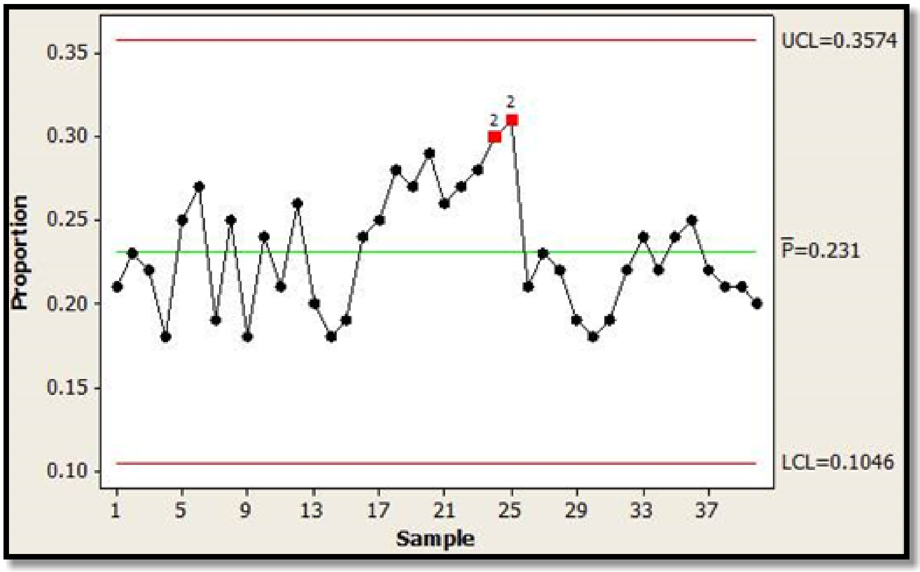
Out of Control Condition # 1

A single point more than three estimated standard deviations from the center line (outside the control limits) signals an out-of-control condition. This test applies to both Attribute and Variables charts.



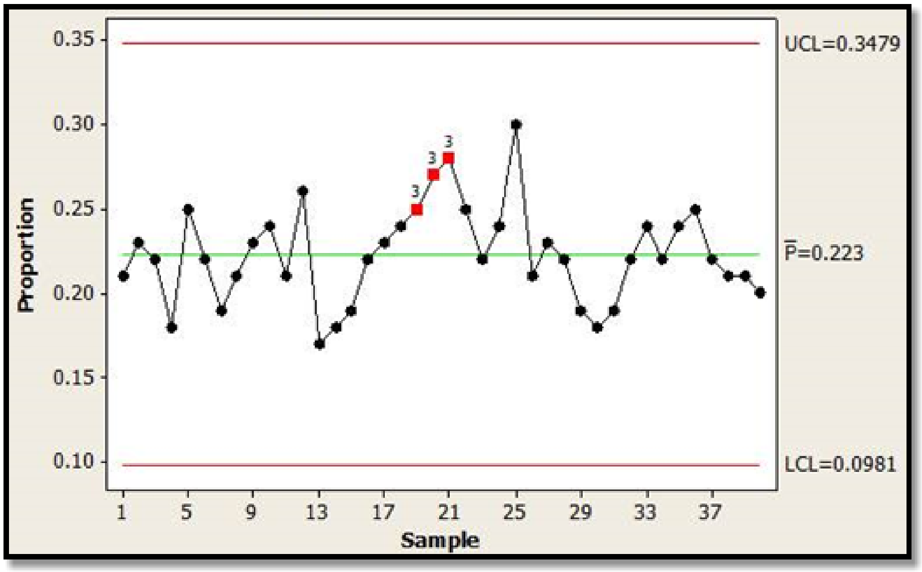
Out of Control Condition # 2

Nine points in a row on the same side of the center line (a mean shift) signals an out-of-control condition. This test applies to both Attribute and Variables charts.



Out of Control Condition # 3

Six points in a row all increasing or decreasing (a trend) signals an out-of-control condition. This test applies to both Attribute and Variables charts.



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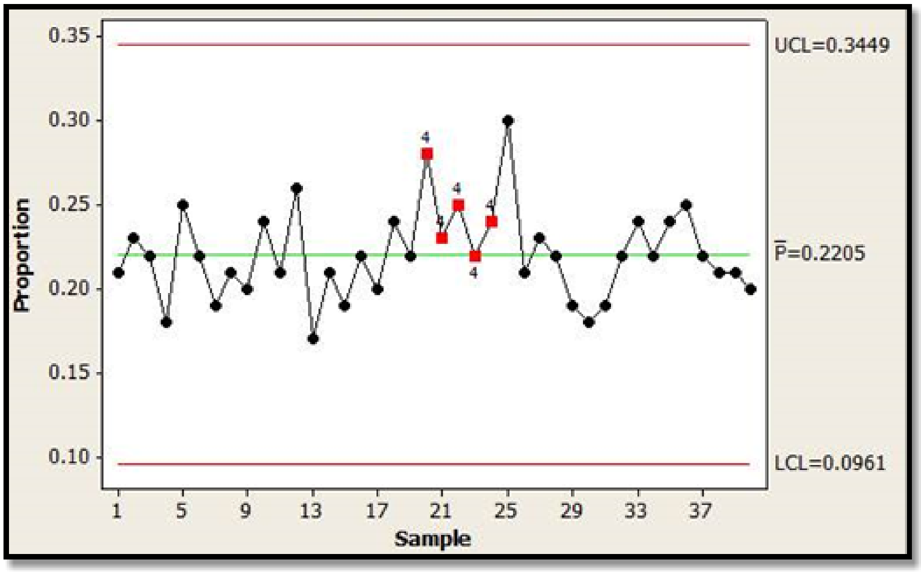
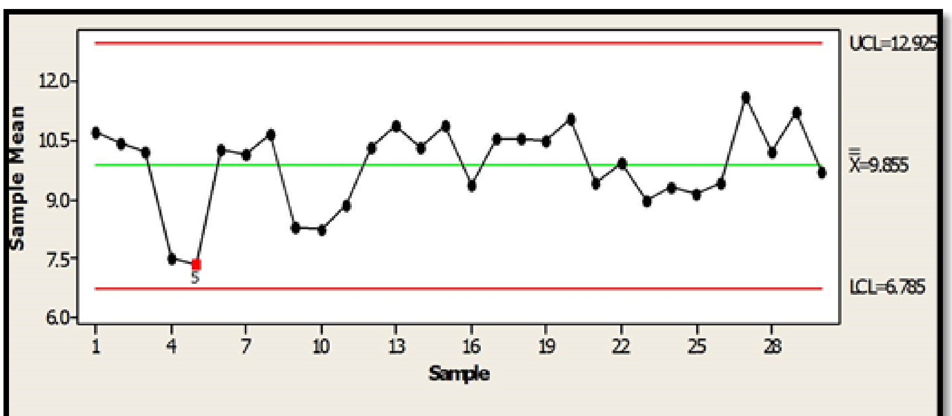
Out of Control Condition # 4

Fourteen points in a row alternating up and down (oscillation that may indicate tampering) signals an out-of-control condition. This test applies to both Attribute and Variables charts.



Out of Control Condition # 5

2 out of 3 points greater than 2s from the center line (same side) signals an out-of-control condition. This test applies only to Variables charts.



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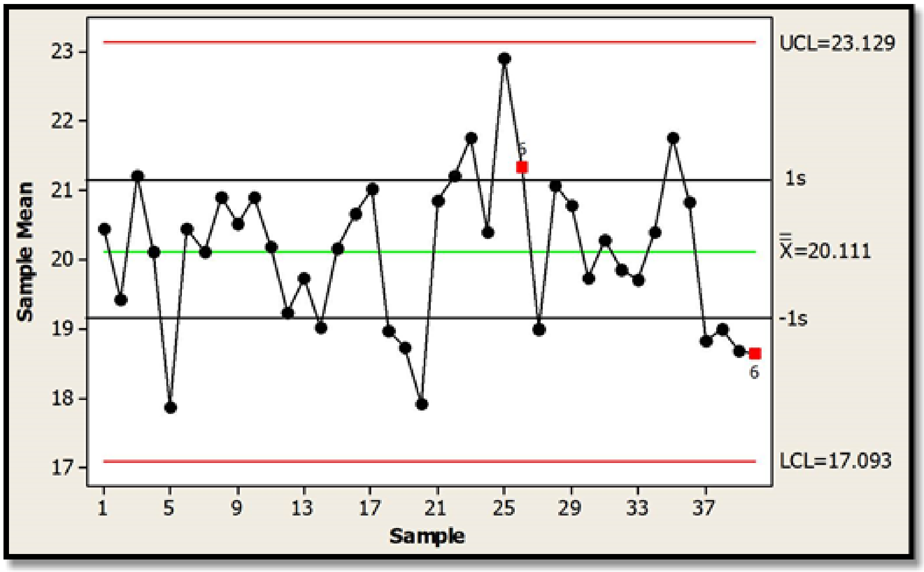
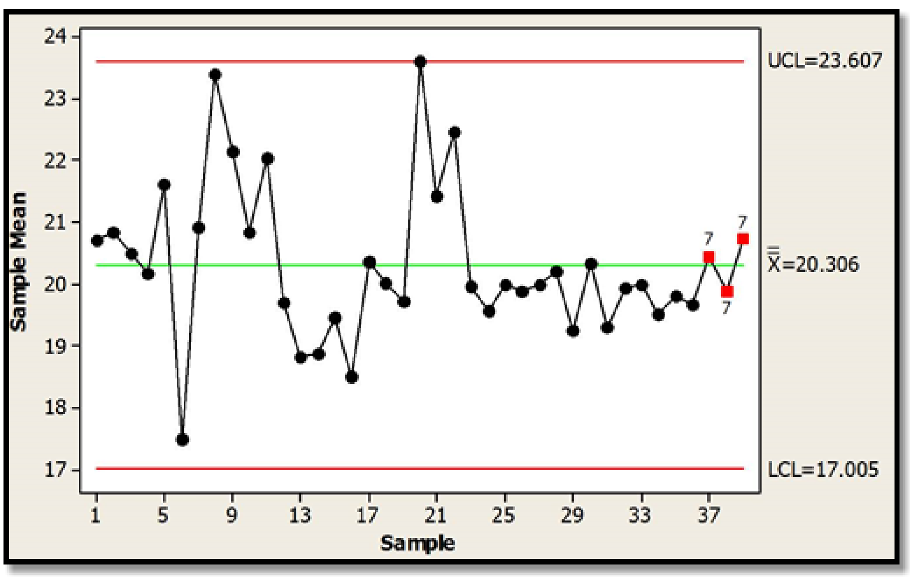
Out of Control Condition # 6

4 out of 5 points greater than 1s from the center line (same side) signals an out-of-control condition. This test applies only to Variables charts.



Out of Control Condition # 7

Fifteen points in a row within 1s of the center line (sudden reduction in variation) signals an out-of-control condition. This test applies only to Variables charts.



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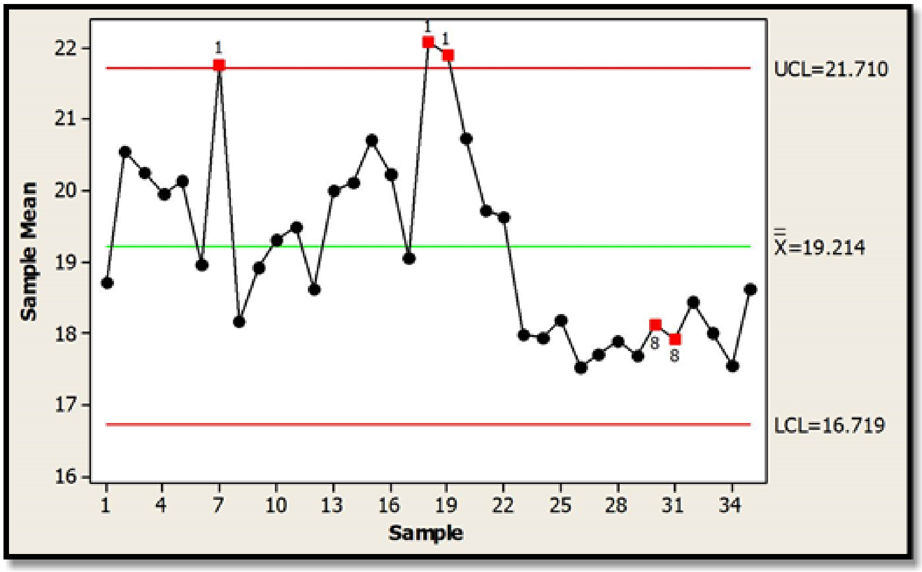
Out of Control Condition # 8

Eight points in a row greater than 1s from the center line (mean shift) signals an out-of-control condition. This test applies only to Variables charts.



When Should A Control Chart Be Used?

Control charts are used after project completion to hold the gains from the improvement.

Pitfalls to Avoid

There are many different control charts for many different situations. It is very easy to use the incorrect control chart, which can lead to an incorrect interpretation about the process.

Control charts can also be perceived by employees as a judgement on their performance, even when this is not really the case. This can effect employee morale and performance. Proceed with caution.

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