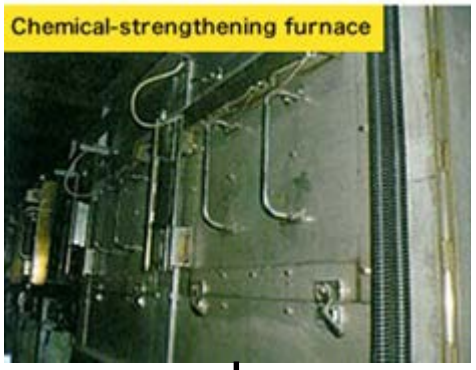
Understanding Variation and Statistical Process Control:
Process Variation and Statistical Process Control (SPC)

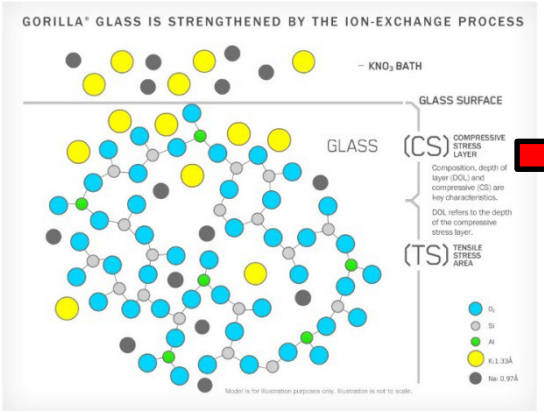
Outline

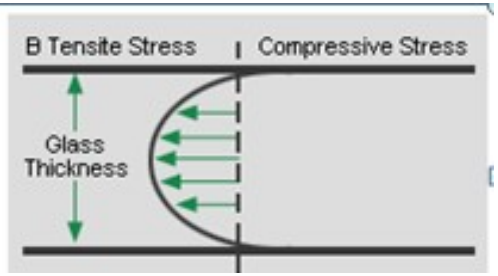
- Normal and Special Cause Variation
- Specification Limits vs Control Limits
- Calculations for the Individuals Chart.
- Nelson Rules to determine out-of-control signals (special cause variation) from process data.
- Calculations for the X bar & R Chart.
- Advantages of subgroup data collection.

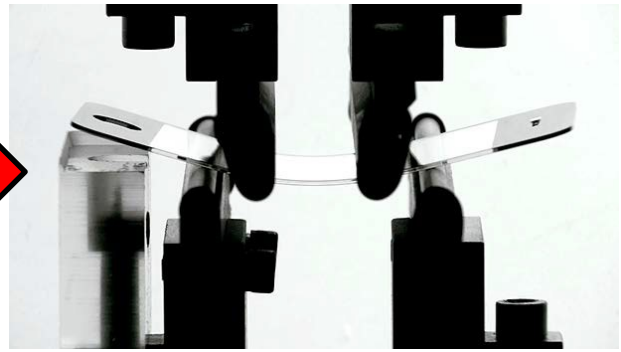
Corning Process to Manufacture Gorilla Glass

The proprietary fusion forming process delivers a product with superior surface quality in a scalable process that provides a reliable supply of thin glass.



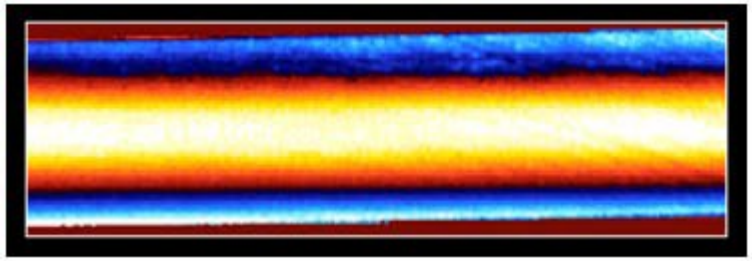


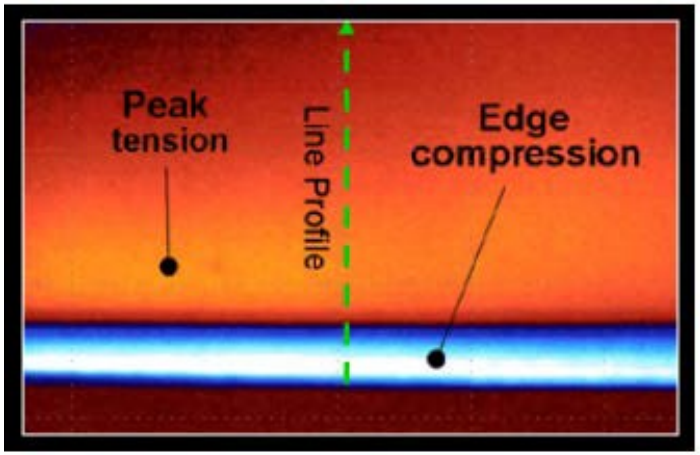




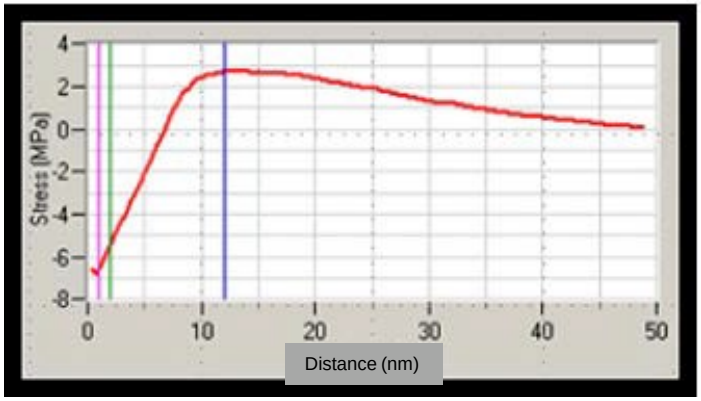
Quality = Strong, flexible, scratch resistant.

Measuring the Compression Layer in Glass

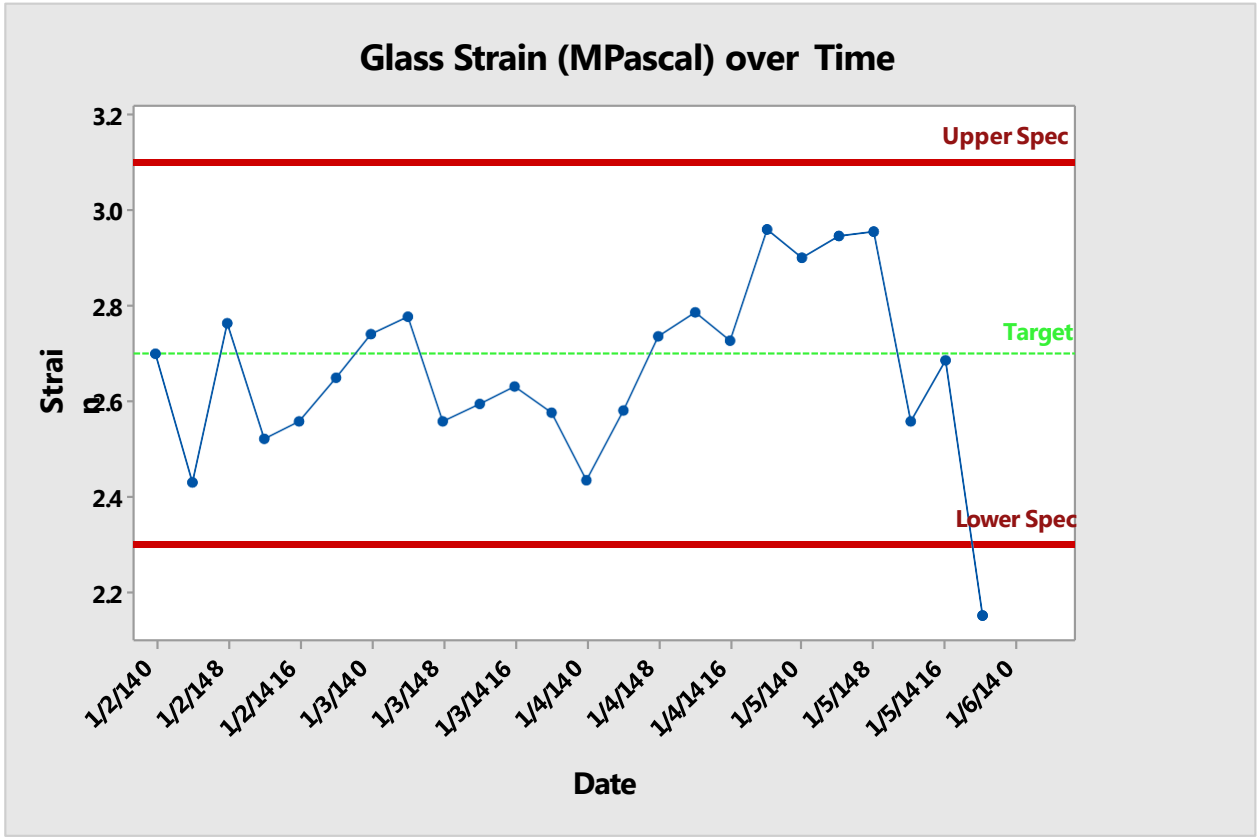




The quality of the ultra-thin glass used for phones and tablets is a function of the compression induced strength developed from the ion exchange treatment. With this compression, comes a band of tension just inside the compressive edge. It is important that this tension not exceed limits or flow too far into the glass where a simple scratch or check can turn into a run away crack. Gauges use the polarization of light passing through the glass to measure the level of compression / tension.



Responding to Variation in the Process



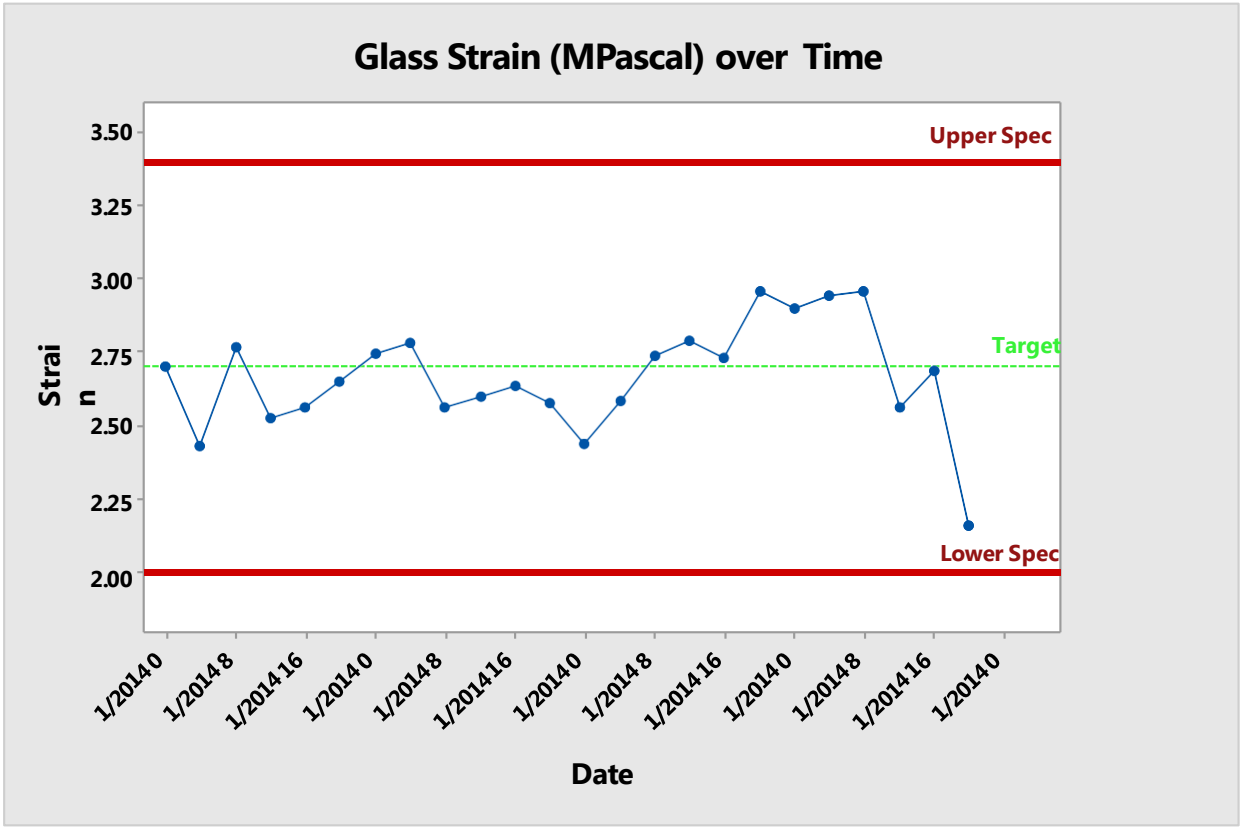
Take another measurement

Wait for the next 4 hr sample

Shut down & adjust process

Adjust minor input

Responding to Variation in the Process



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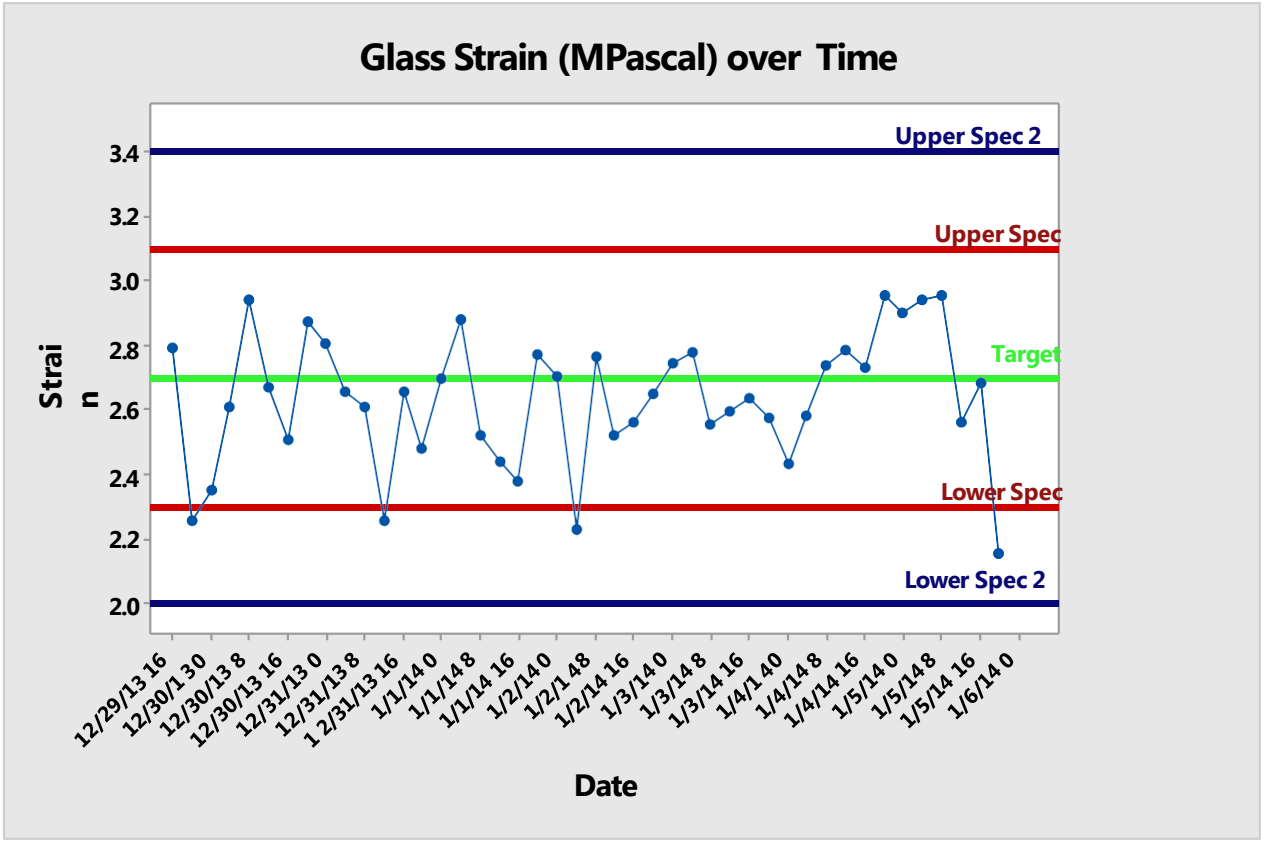
Adjust minor input

Limits to the Process vs Specification Limits



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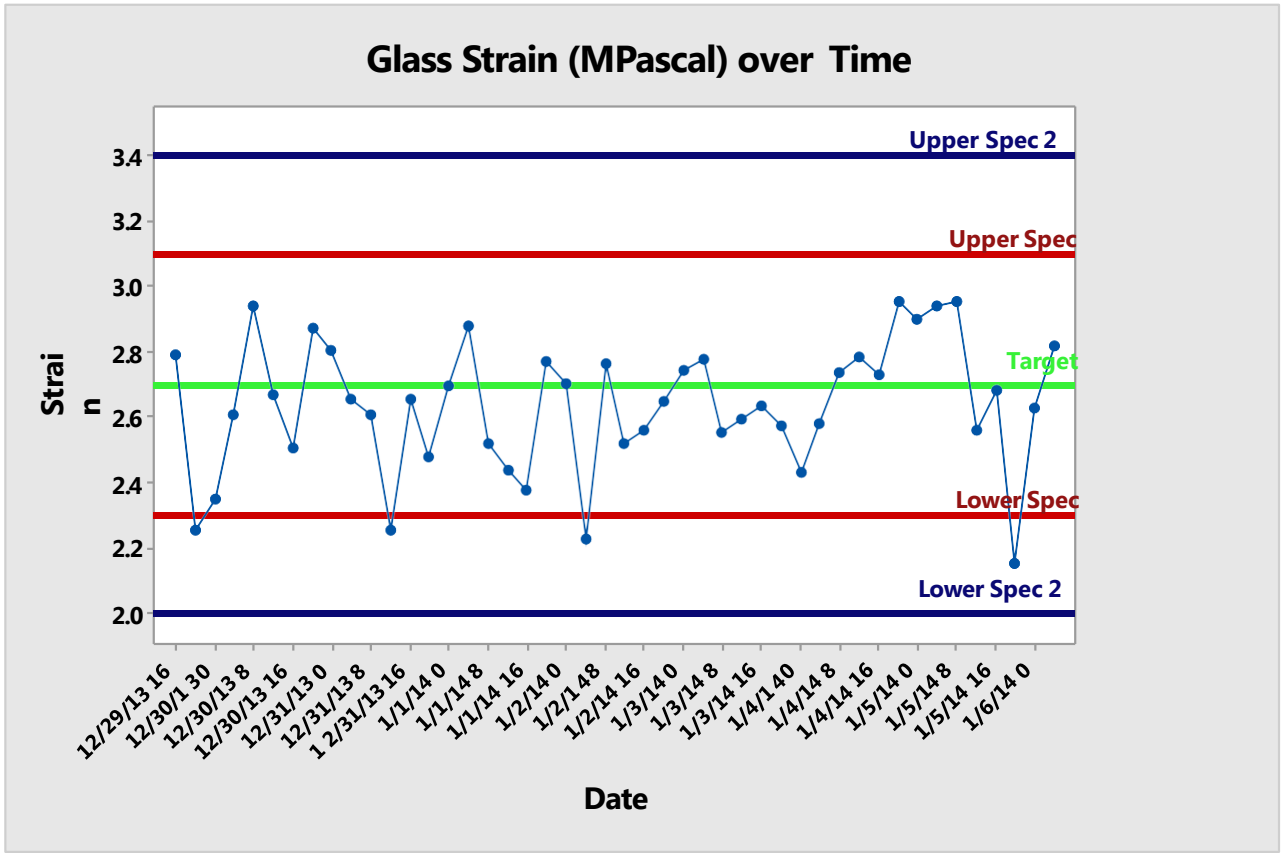

Take another measurement

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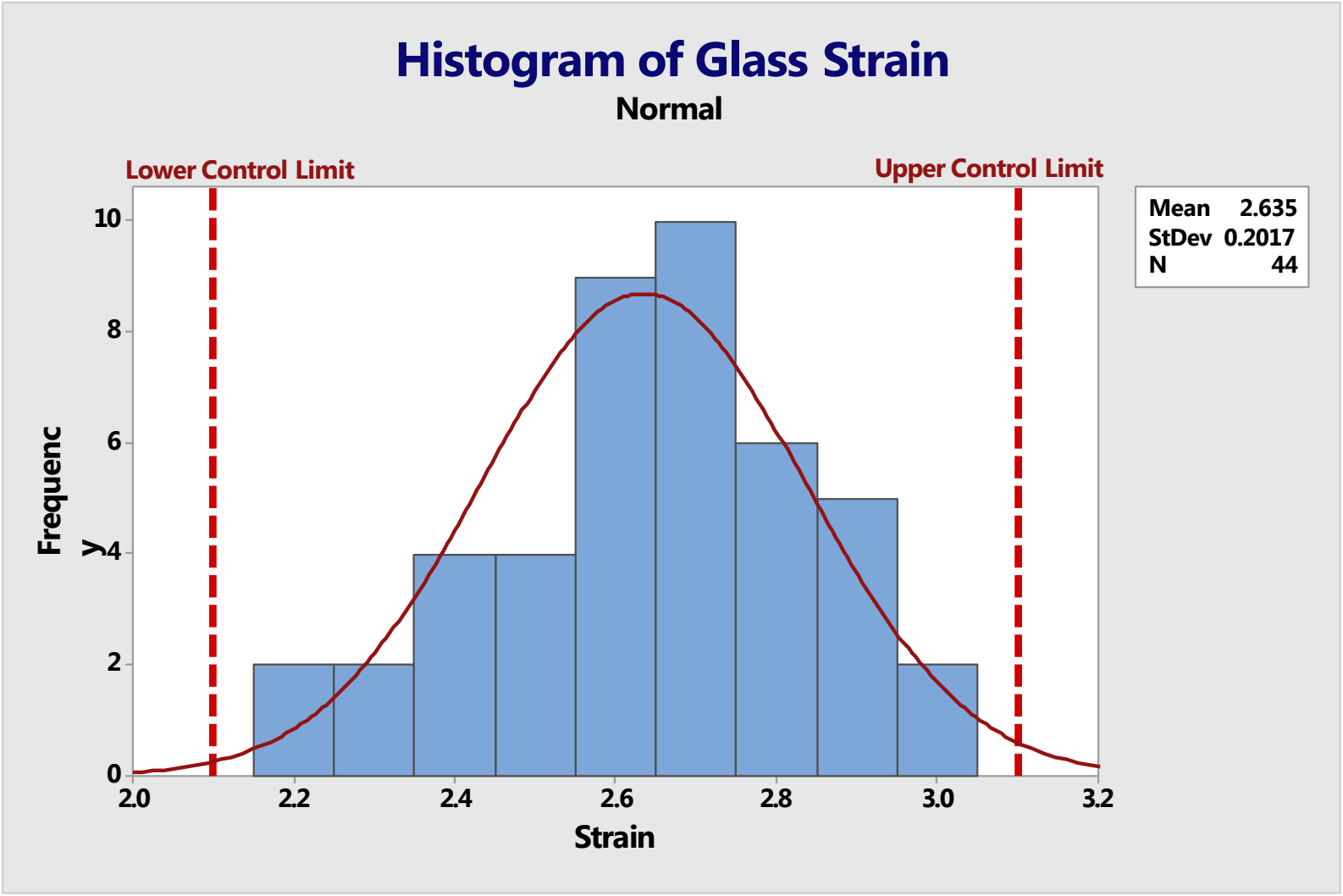
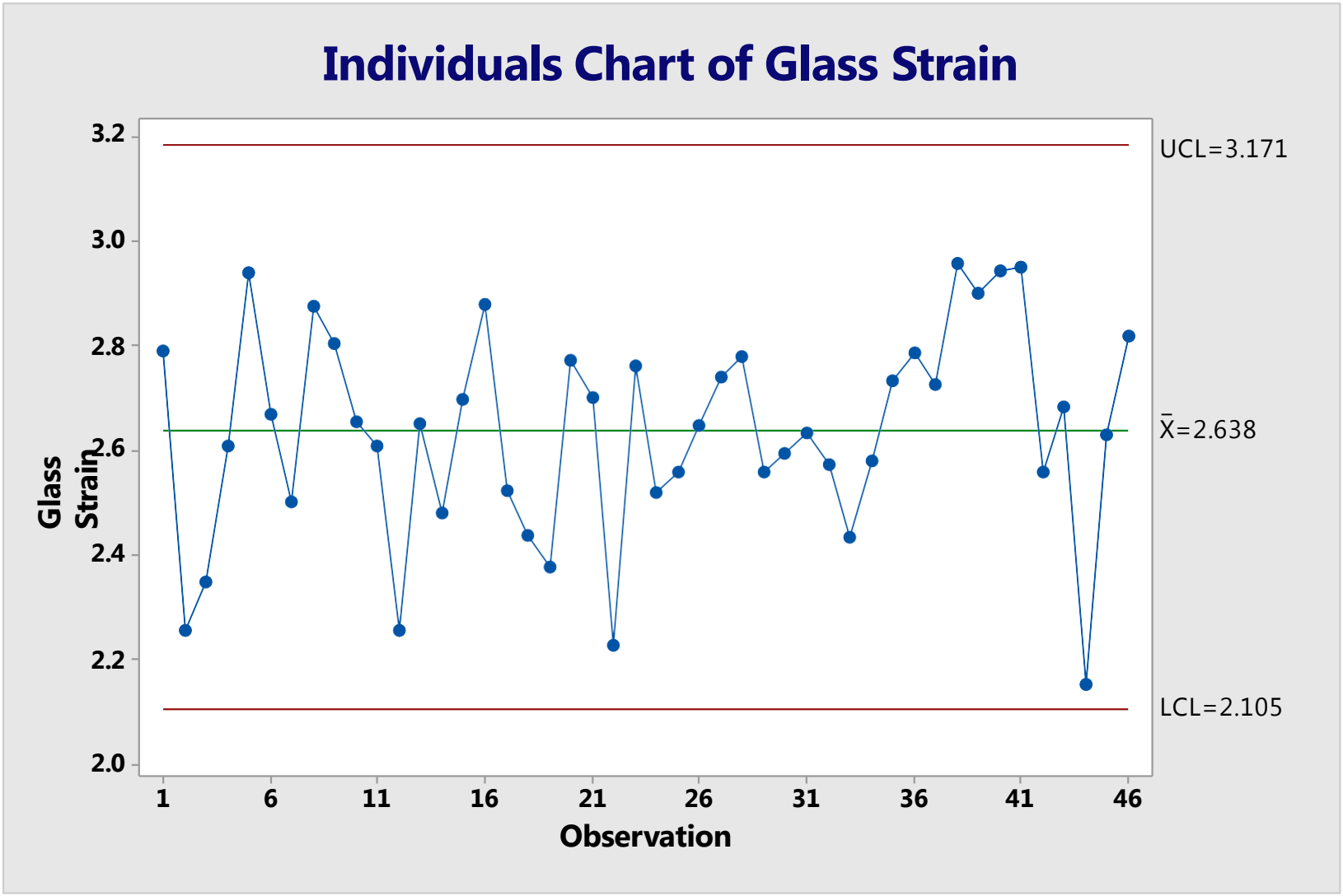
Shut down & adjust process

Adjust minor input

Histogram of the Glass Strain Data



Histogram Converted to a Control Chart



Characteristics of a Control Chart

- **Control Chart** – a time series plot for process monitoring which allows one to tell common cause variation from special cause variation by identifying the natural variation in the process with control limits.

- **Control Limits** – a range of values that contain the natural variation of the process. One must collect process data and calculate the standard deviation to determine the control limits.

    1. Data within the control limits is normal variation. One data point outside the limits must have been caused by something special.
    2. Control charts also test each data point for the formation of patterns which would not occur under normal random variation. Any of these eight patterns indicate that something special occurred, beyond normal random variation.

Sources of Variation – Time to Drive to Work

1. Stoplights in your favor (or not).
2. Slow driver in front of you.
3. Have to drop off your spouse at their work (or not).
4. Forgot; wallet, keys, coffee mug, phone, daughter, etc.
5. Flat tire.
6. Number of cars on the road (congestion).
7. Construction on your typical route.
8. You're in the mood for some speed.
9. Accident; other guy's fault, of course.

Sources of Variation – Common or Special?

Special Cause Variation

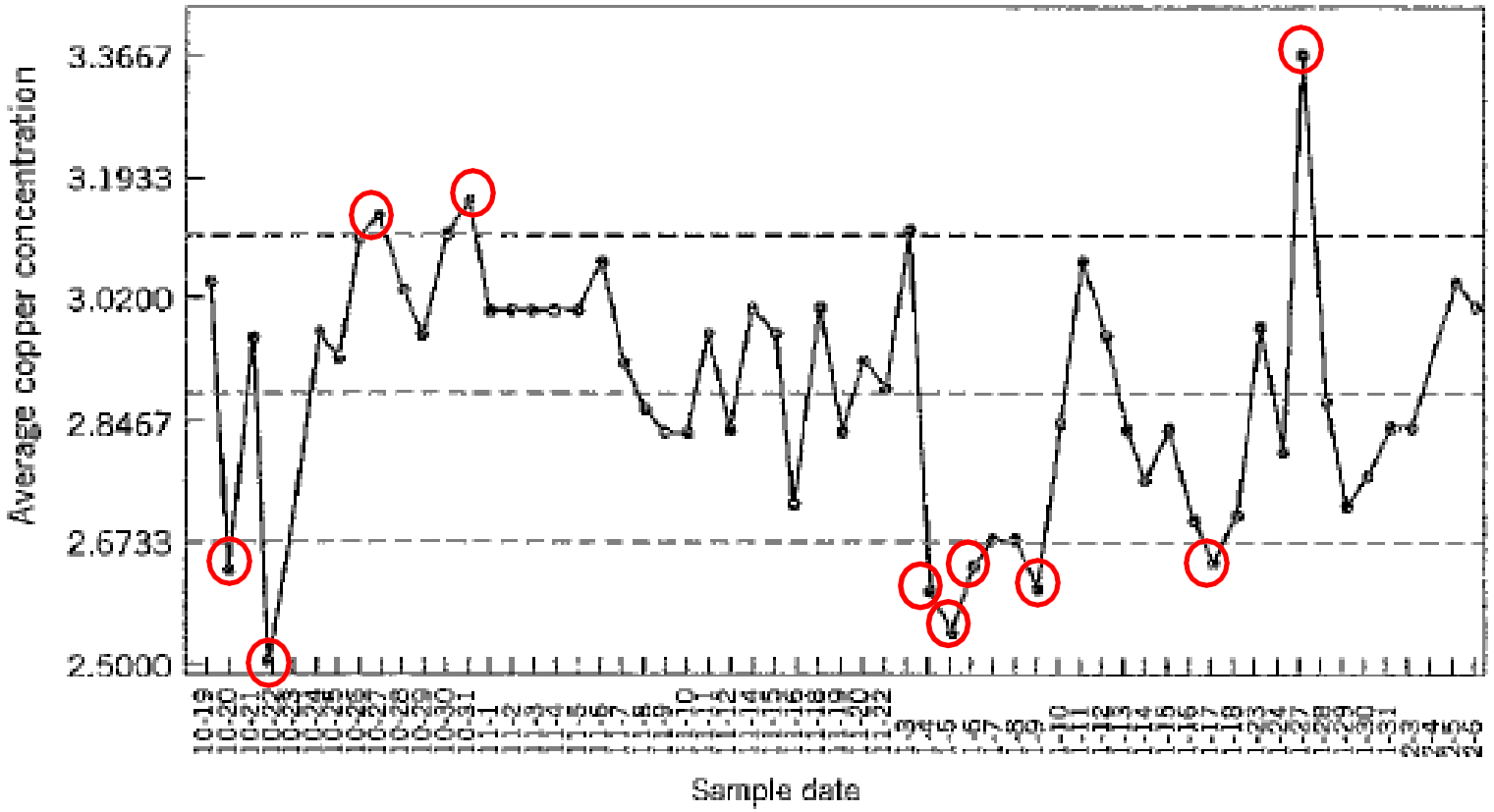
1. Non-normal Variation, Does not follow a bell curve
2. Out-of-control
3. Larger changes
4. Fast (spike)
5. Often, single known source
6. Does not occur most of the time
7. Can not be predicted
8. Most likely, you should respond and fix

Common Cause Variation

1. Normal Variation, Follows a bell curve
2. In-control, stable
3. Smaller changes
4. Slow (drift)
5. Unknown source, sum of many small contributors
6. Occurs all the time
7. Can be quantified as having a certain size
8. Responding will most likely make it worse

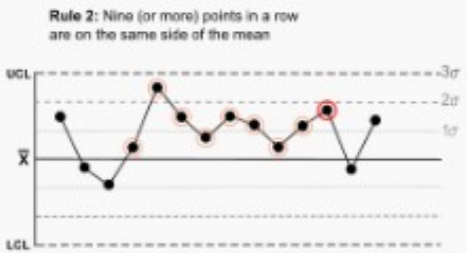
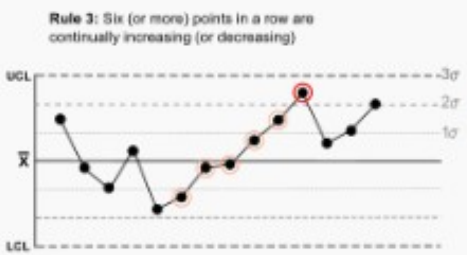
Identifying Special Cause Variation

What patterns in the data in the copper concentration shown below seem to identify special cause variation in the average copper concentration?



Additional Unusual or Non-random Patterns

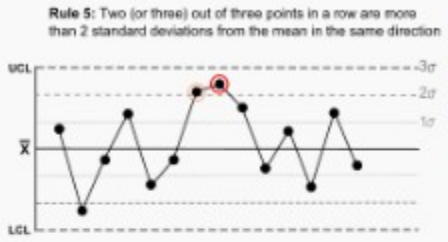
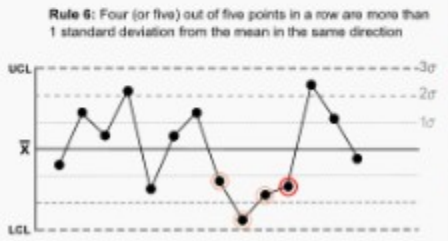
In 1984, Lloyd Nelson published 8 patterns that you won't seen in the data if there is only normal random variation at play. These are based on the original Shewhart 5 patterns which later became the Western Electric 6 patterns. Some more commonly used tests are;

Rule 2	Nine (or more) points in a row are on the same side of the mean.		Some prolonged bias exists.
Rule 3	Six (or more) points in a row are continually increasing (or decreasing).		A trend exists.

Lloyd S. Nelson, "Technical Aid", *Journal of Quality Technology,* Vol.16, No.4, 1984, p238-239

Additional Unusual or Non-random Patterns

In 1984, Lloyd Nelson published 8 patterns that you won't seen in the data if there is only normal random variation at play. These are based on the original Shewhart 5 patterns which later became the Western Electric 6 patterns. Some more commonly used tests are;

Rule 5	Two (or three) out of three points in a row are more than 2 standard deviations from the mean in the same direction.		There is a medium tendency for samples to be mediumly out of control. The side of the mean for the third point is unspecified.
Rule 6	Four (or five) out of five points in a row are more than 1 standard deviation from the mean in the same direction.		There is a strong tendency for samples to be slightly out of control. The side of the mean for the fifth point is unspecified.

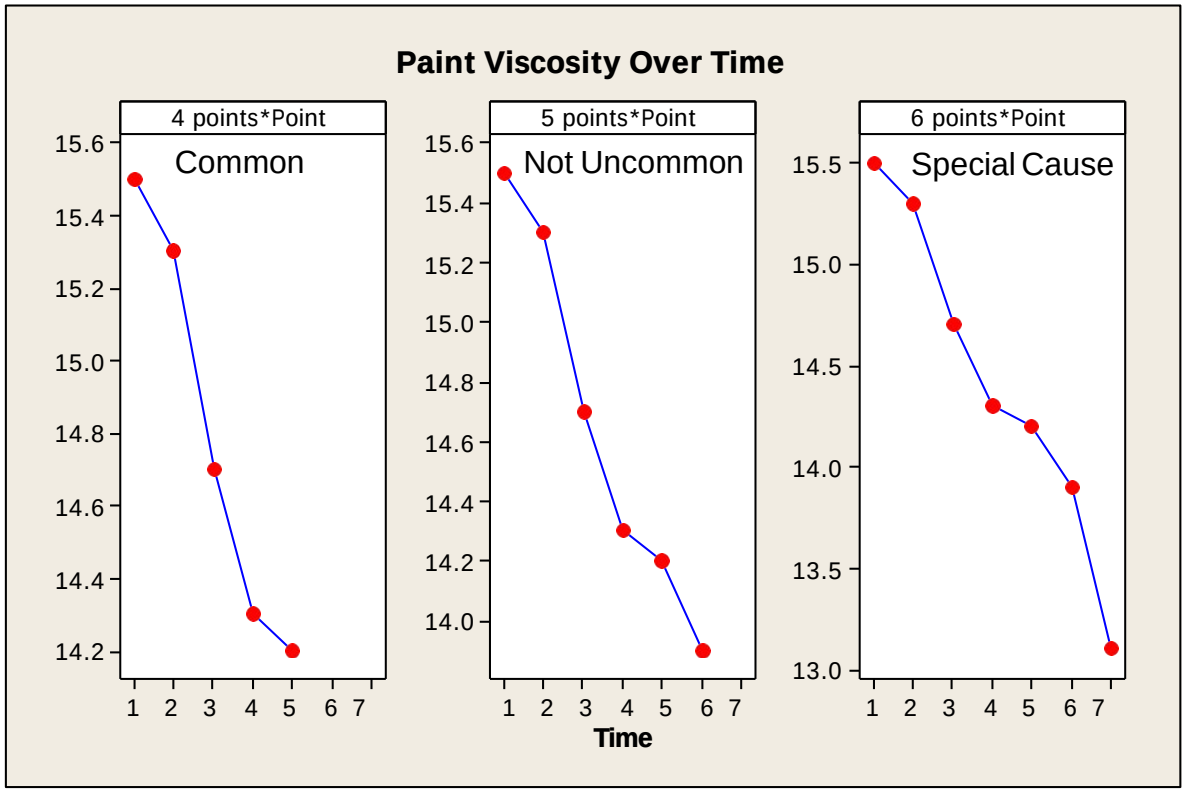
Lloyd S. Nelson, "Technical Aid", *Journal of Quality Technology,* Vol.16, No.4, 1984, p238-239

Determining Patterns from Special Cause Variation

How common is each pattern?

6 points trending will only occur about .27% ** of the time under normal random variation.

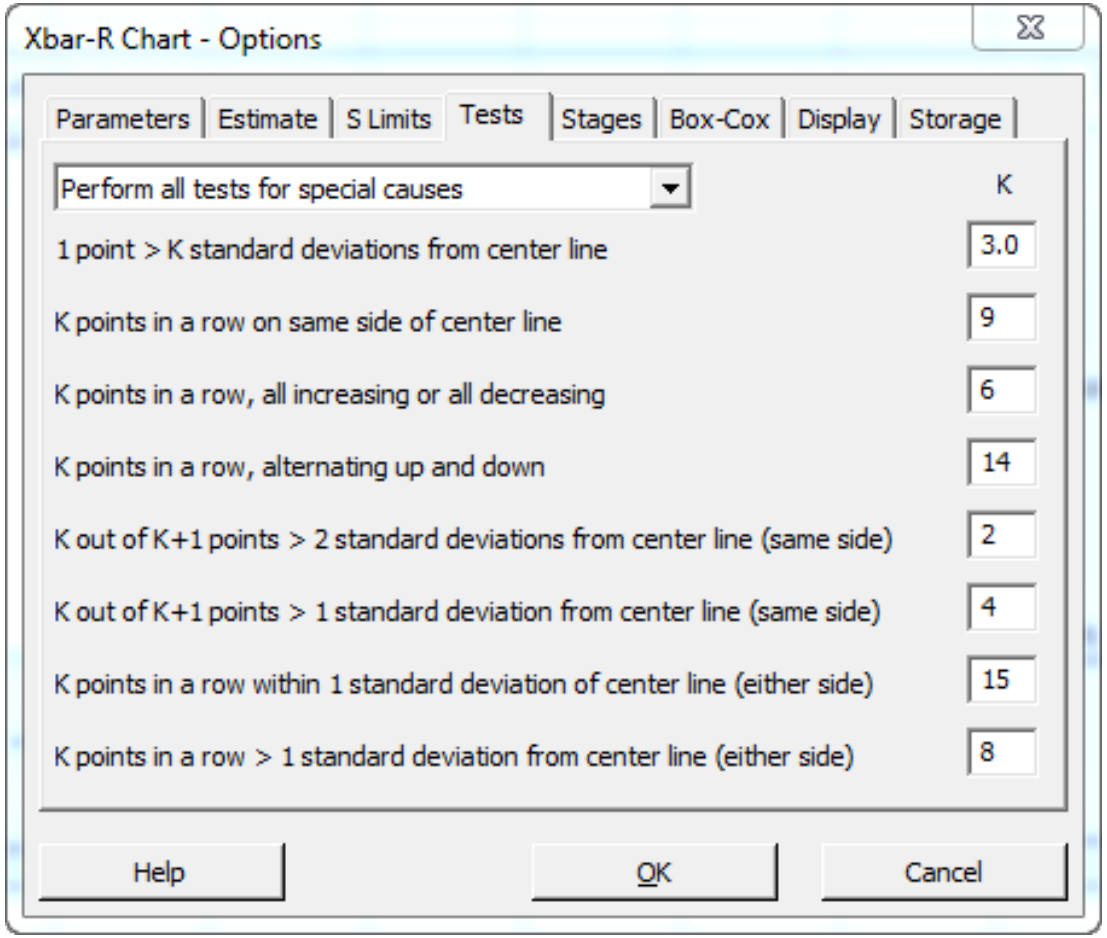
Test 3



** Montgomery, Douglas (2005)) , Introduction to Statistical Quality Control, 5th Edition

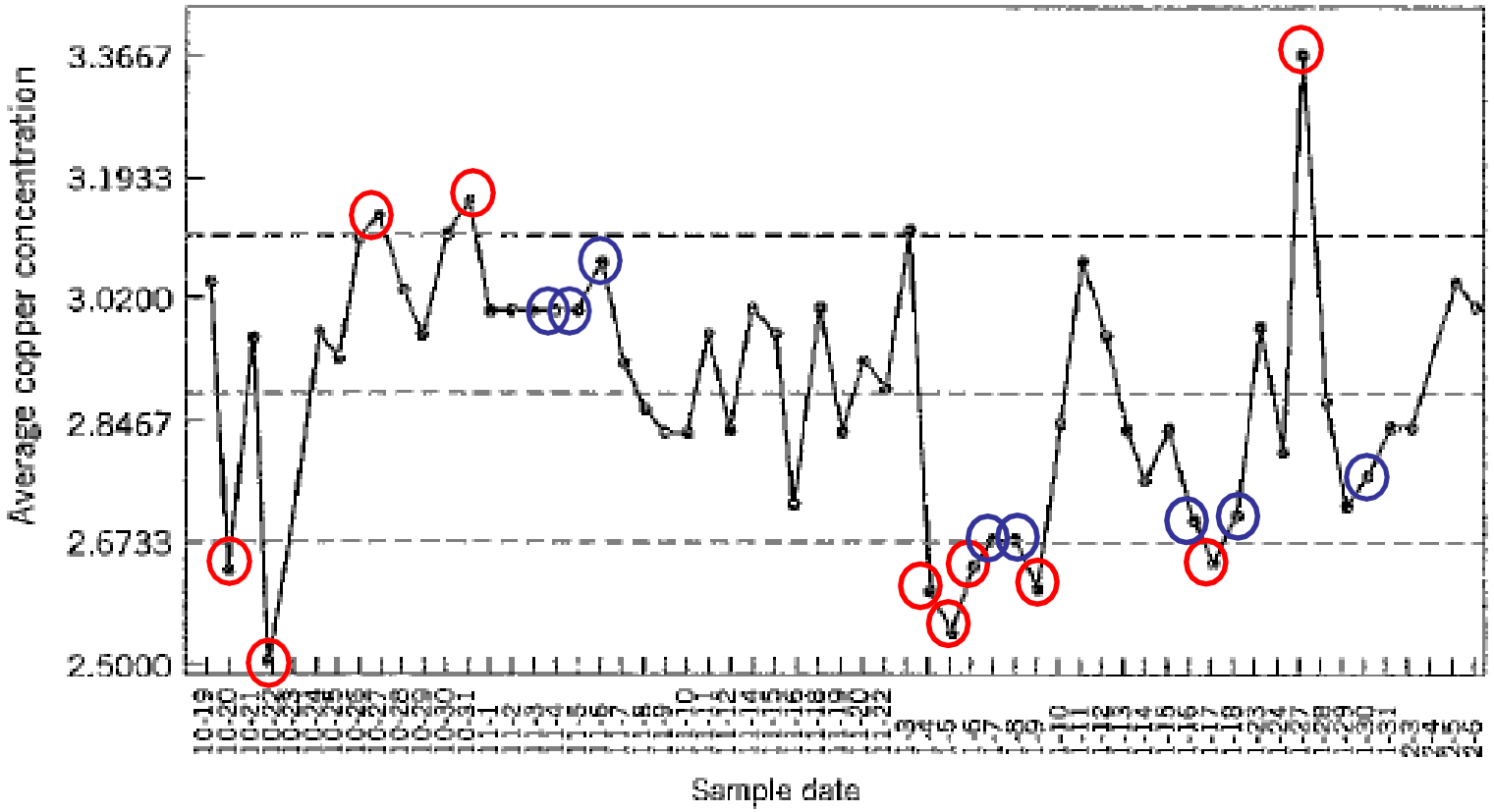
Eight Tests for Special Cause Variation

The probability that any one of these 8 patterns will be seen in the data if there is only normal random variation is very low. Therefore, if one of these patterns is seen, it was likely caused by a special source of variation.

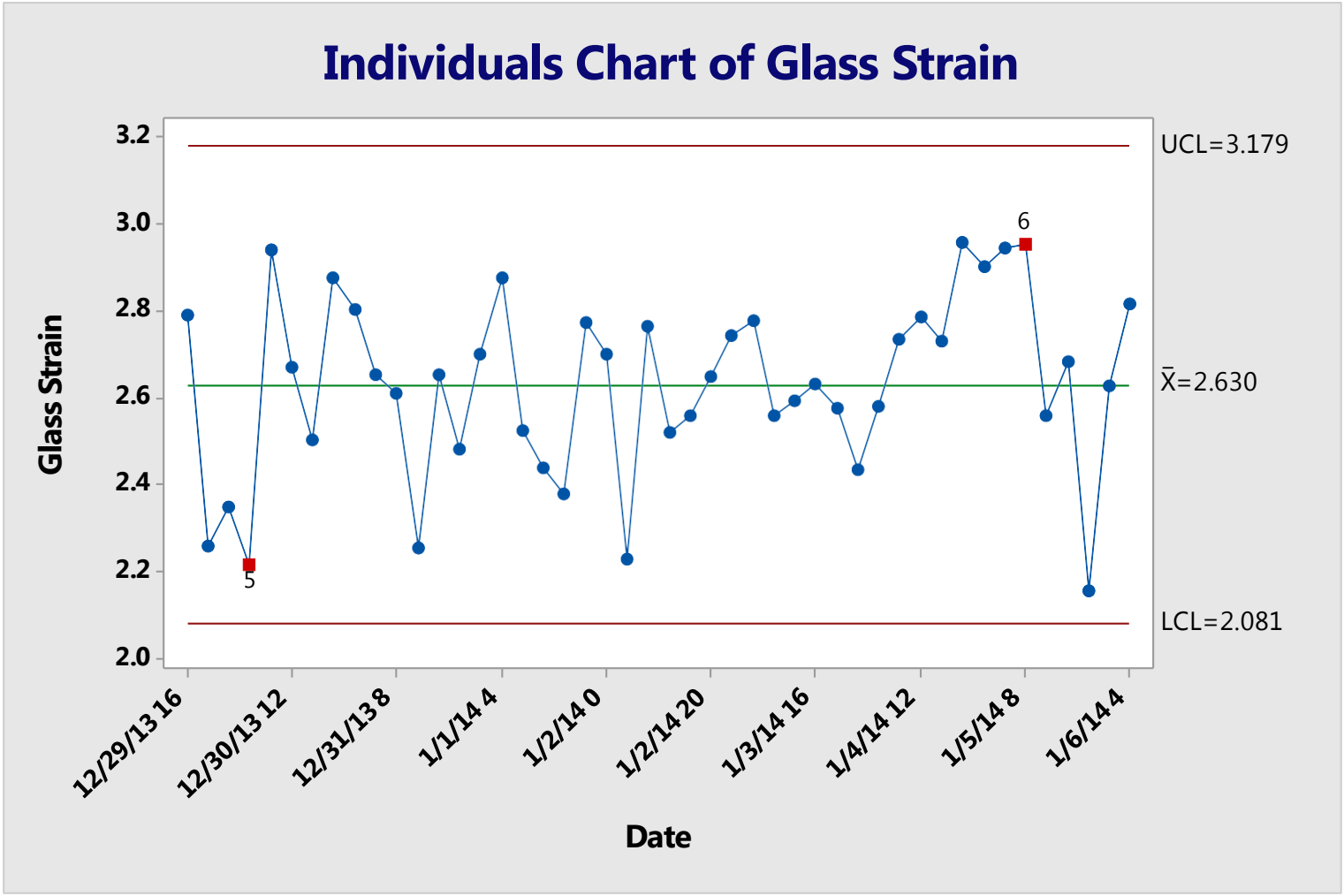


Identifying Special Cause Variation with 8 Tests

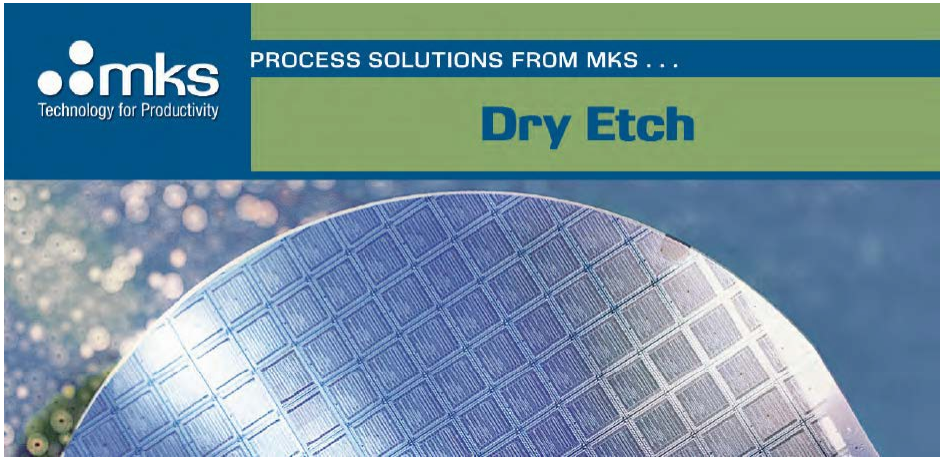
What patterns in the data shown below seem to identify special cause variation in the average copper concentration?



Identifying Special Cause Variation with 8 Tests



Dry Etch Process for Microprocessor Mfg



Isotropic Anisotropic

Dry etch technology has been greatly refined for today's advanced fabrication of integrated circuits. One etch quality characteristic that affects the performance of the semiconductor product is anisotropy, a high level of vertical etching vs horizontal etching. This is measured as the aspect ratio, the depth / the width of the etched area.

Problem: The aspect ratio of grooves from the dry etch process should have an aspect ratio of 1.00, but can vary from .9 to 1.1 and still meet specifications. Five wafers are sampled every 4 hours and the aspect ratio is measured to monitor the quality of the product from the etch process.

Value of Collecting Subgroup Data

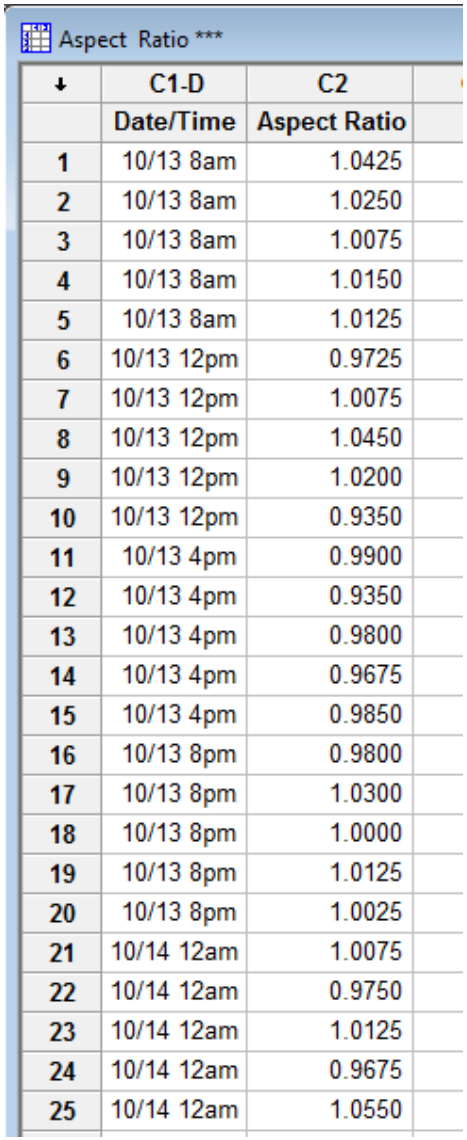
Create an X-bar (Mean) and R (Range) Chart

Range1/Mean1 Subgroup 1

Range2/Mean2 Subgroup 2

Range3/Mean3 Subgroup 3

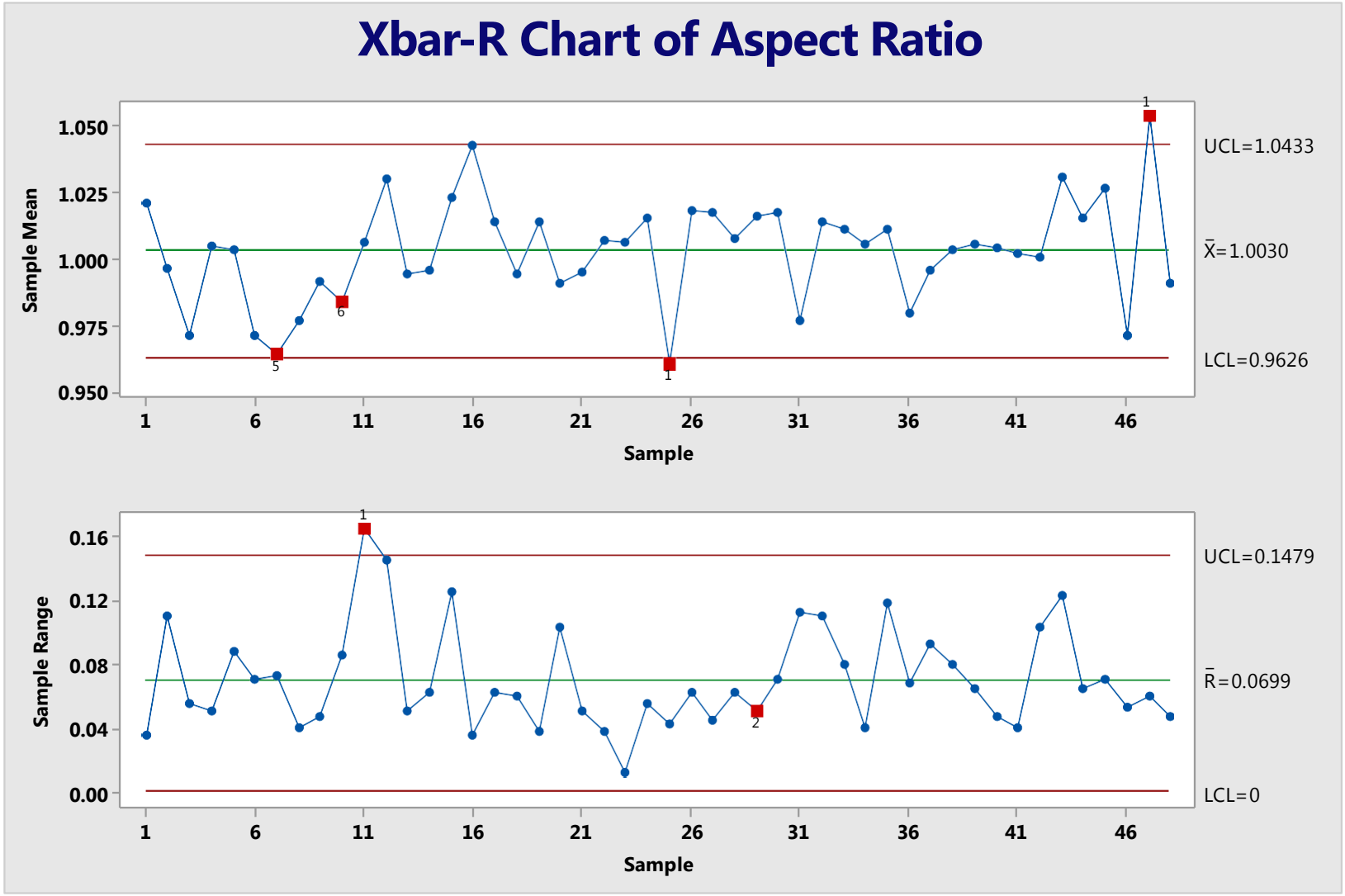
Range4/Mean4 Subgroup 4



Aspect Ratio ***

↓	C1-D	C2
	Date/Time	Aspect Ratio
1	10/13 8am	1.0425
2	10/13 8am	1.0250
3	10/13 8am	1.0075
4	10/13 8am	1.0150
5	10/13 8am	1.0125
6	10/13 12pm	0.9725
7	10/13 12pm	1.0075
8	10/13 12pm	1.0450
9	10/13 12pm	1.0200
10	10/13 12pm	0.9350
11	10/13 4pm	0.9900
12	10/13 4pm	0.9350
13	10/13 4pm	0.9800
14	10/13 4pm	0.9675
15	10/13 4pm	0.9850
16	10/13 8pm	0.9800
17	10/13 8pm	1.0300
18	10/13 8pm	1.0000
19	10/13 8pm	1.0125
20	10/13 8pm	1.0025
21	10/14 12am	1.0075
22	10/14 12am	0.9750
23	10/14 12am	1.0125
24	10/14 12am	0.9675
25	10/14 12am	1.0550

X-bar & R Chart of the Process



Identification of Out-of Control Subgroups

Test Results for Xbar Chart of Aspect Ratio

```
TEST 1. One point more than 3.00 standard deviations from center line.
Test Failed at points:  25, 47

TEST 5. 2 out of 3 points more than 2 standard deviations from center line (on
     one side of CL).
Test Failed at points:  7

TEST 6. 4 out of 5 points more than 1 standard deviation from center line (on
     one side of CL).
Test Failed at points:  10
```

Test Results for R Chart of Aspect Ratio

```
TEST 1. One point more than 3.00 standard deviations from center line.
Test Failed at points:  11

TEST 2. 9 points in a row on same side of center line.
Test Failed at points:  29

* WARNING * If graph is updated with new data, the results above may no
          * longer be correct.
```

Advantages of the X-bar & R Chart over Individuals

- **Lower Variation – Clear Picture**

$$\text{Standard Deviation of the Average} = \frac{\text{Standard Deviation of the Individuals}}{\text{Sqrt (N)}}$$

- **Means are Normal** – the Central Limit Theorem dictates that the mean of several measurements will follow a normal distribution even if the individual readings do not. Normality is assumed for the 8 tests.

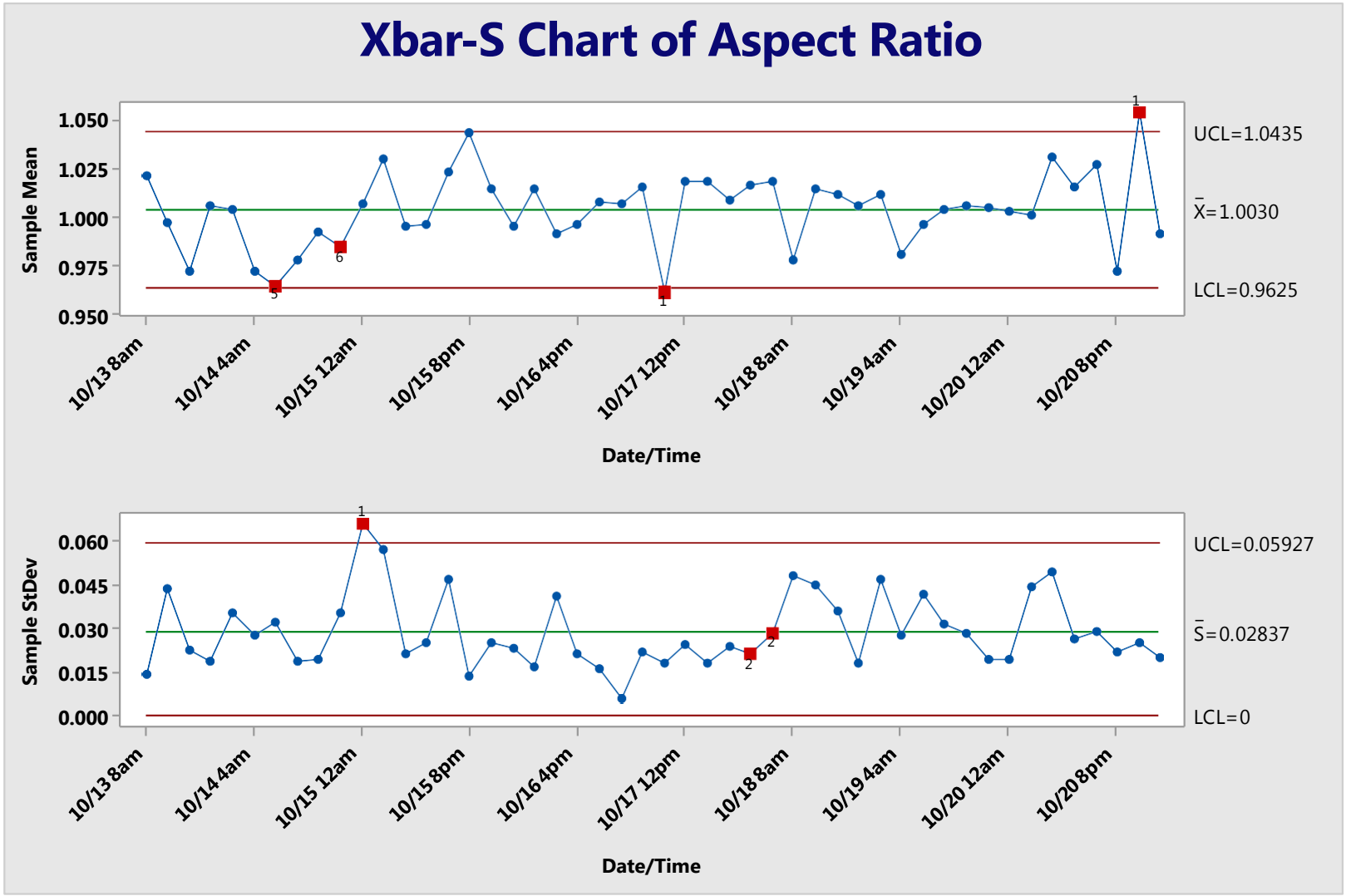
- **Monitor the Mean and Variation** – the X-bar chart monitors the center of the process distribution while the R or S chart monitors the variability. Both are important.

When to use the I- Chart

Individuals Control Chart (I-MR)

- Used when monitoring is a single continuous process.
- Common application; long, expensive or difficult measurement .
- Works best with low measurement variation.
- Works best with normally distributed data.

The Xbar and S Chart



When to use the S Chart

Xbar - S Control Chart

- Used when you have a calculator or computer generated chart.
- Equivalent to an X-bar & R with small subgroup sizes (5 or less) .
- Right choice for subgroup size 9 or larger.
- Right choice for unequal subgroup size.

Conclusions

- The complexity of modern nanoscale processes demand accurate control plans that minimize the false alarms and detect changes to the process that require remediation. Control charts are a key tool in these plans.
- Control limits define the normal variation in the process which does not require follow-up and distinguishes it from the special cause variation that should be addressed.
- Eight patterns in the response data from your process have been identified as having a low probability of occurrence without a special cause. Modern software can be used to identify these patterns in your data to trigger an appropriate response.
- If process data is collected in subgroups and analyzed using control charts for subgrouped data, the sensitivity of the chart to special cause variation and the information about the process are improved over the standard control chart of individual data points.

References

Automotive Industry Action Group, (2005). *Statistical Process Control 2nd Edition* . AIAG Press, Detroit, MI.

Hoyer, Robert W. and Ellis, Wayne C., "A Graphical Exploration of SPC", *Quality Progress,* May,1996, p65-73.

Lloyd S. Nelson, "Technical Aid", *Journal of Quality Technology,* Vol.16, No.4, 1984, p238-239.

Montgomery, Douglas (2005). *Introduction to Statistical Quality Control , 5th Edition.* John Wiley & Sons Inc. Hoboken NJ.

Wheeler, Donald J. and Chambers, David S. (1992). *Understanding Statistical Process Control. SPC Press: Knoxville, TN.*