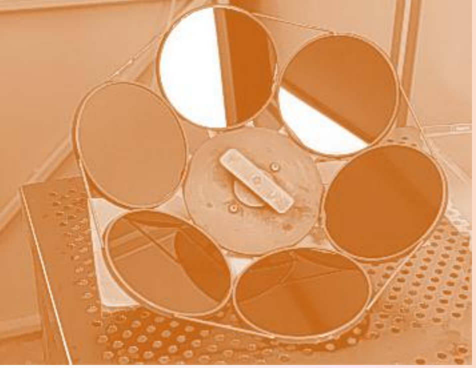
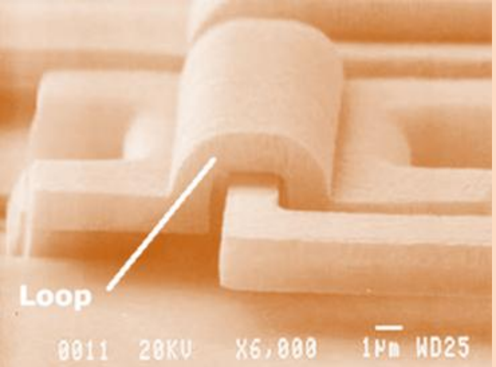


Statistical Process Control (SPC) For Technicians

Presented by

Southwest Center for
Microsystems Education
-SCME-
January 2013



Our Presenters

Barb Lopez

Research Engineer, University of New Mexico and Instructional Designer, SCME

Mary Jane (MJ) Willis

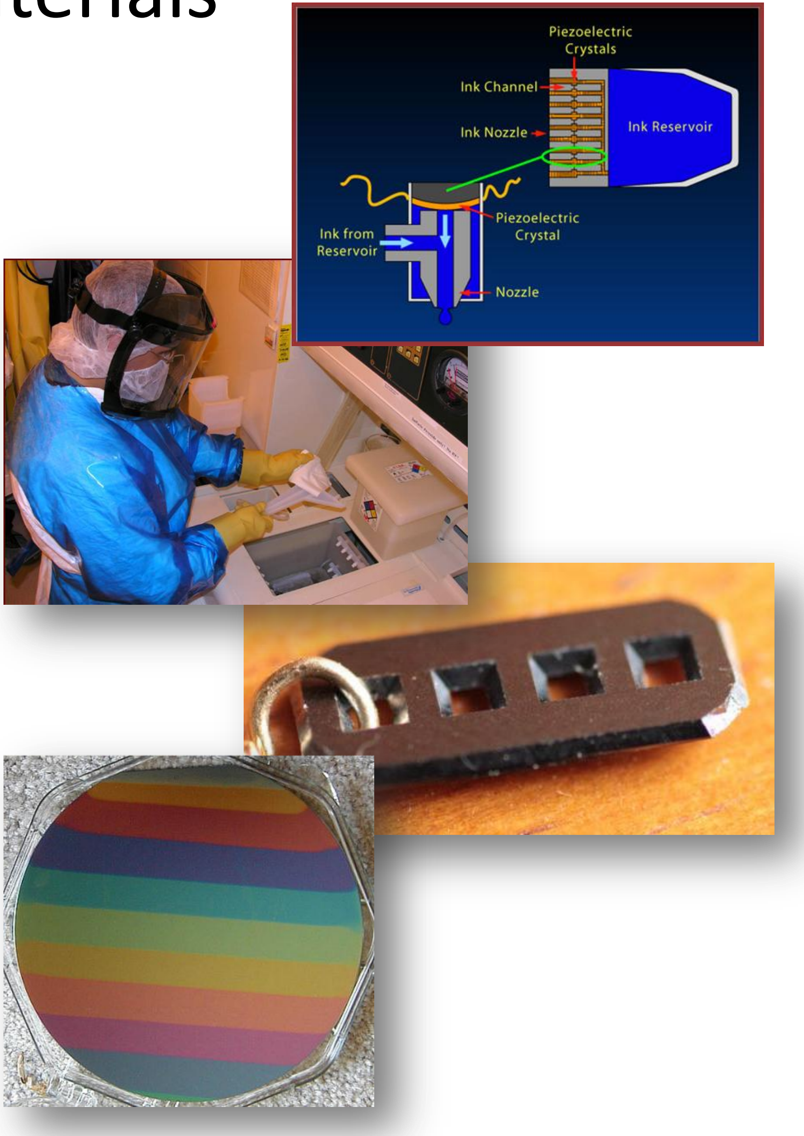
Instructional Designer, SCME and retired Chair for the Manufacturing Technology Program – Central New Mexico Community College

What will we cover today?

- What SCME can do for you
- Process variation and the need to identify special cause variation
- Statistical Process Control (SPC)
- Statistical tools necessary to employ SPC
- Normal distribution and how it is significant in $\overline{X}$-charts
- $\overline{X}$-charts and how to create them
- Interpreting Control Charts by applying the Shewhart rules

Educational Materials

- SCME Learning Modules
  - Informational Units / lessons
  - Supporting activities
  - Supporting assessments
- ~40 Modules in the areas of
  - Safety
  - Microsystems Introduction
  - Microsystems Applications
  - Bio MEMS
  - Microsystems Fabrication
- 11 Instructional Kits
- All are available @ scme-nm.org



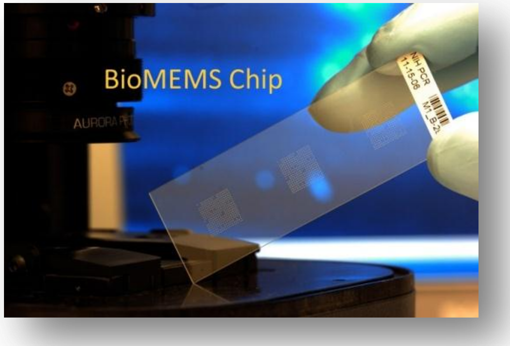
SCME
Southwest Center for
Microsystems Education

Professional Development

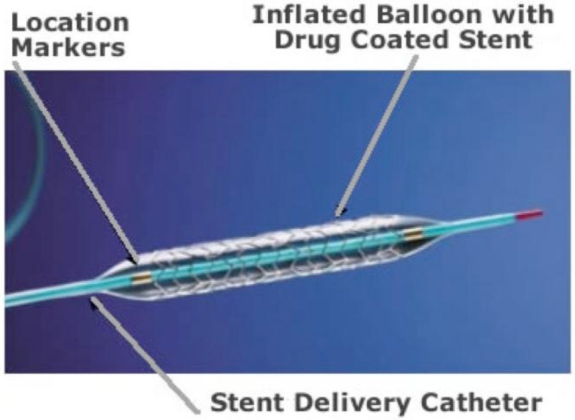
- 4 to 5-day workshops
- 2-day workshops
- 1-day workshop
- Conferences and conference workshops
- Create hubs at other colleges to teach our workshops
- Webinars
- SCME on YouTube (https://www.youtube.com/user/scme2012)

Why do we need (SPC)
Statistical Process Control?

Quality Product



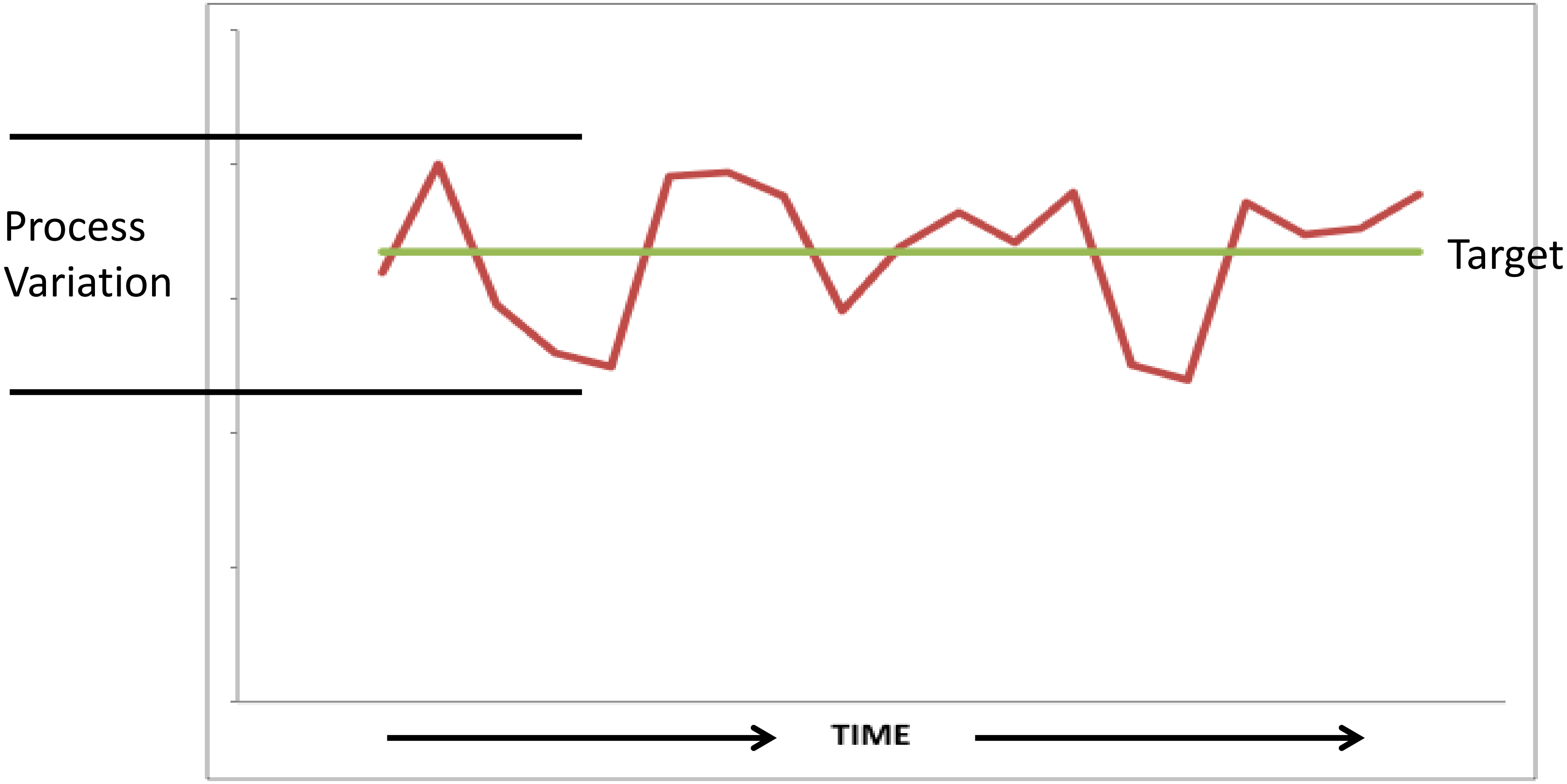
Biochip slide for testing protein arrays
[Image courtesy of Argonne National Laboratories]



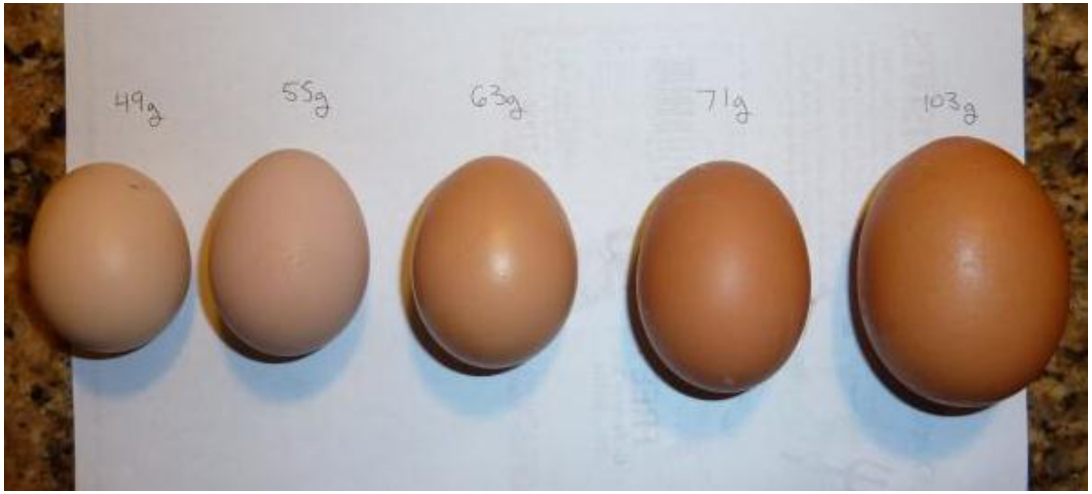
Drug-eluting Stent by Taxus [Image provided by the FDA]

Statistical Process Control (SPC)

SPC is about "control".

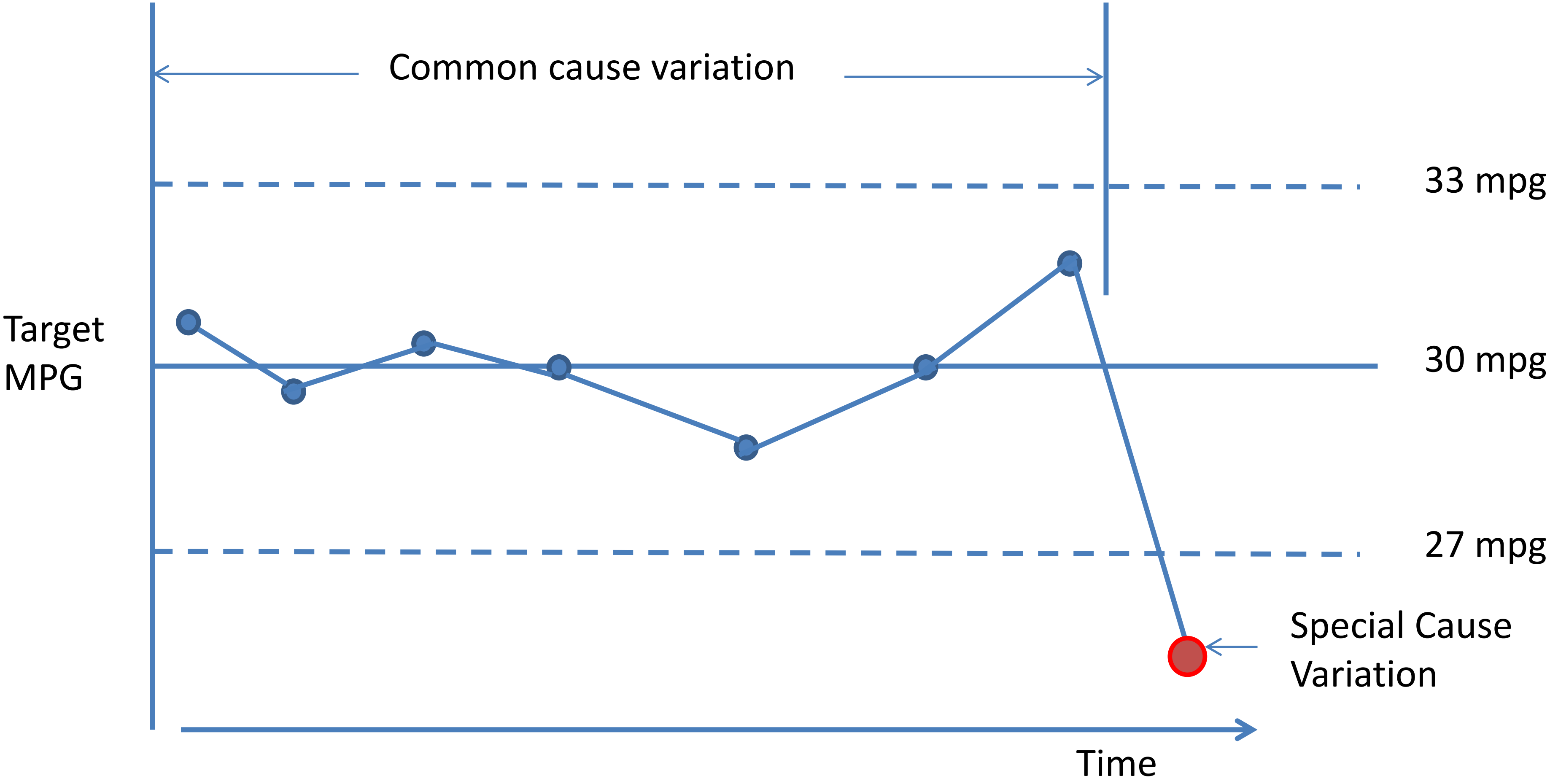


Inherent or Common Cause Variation

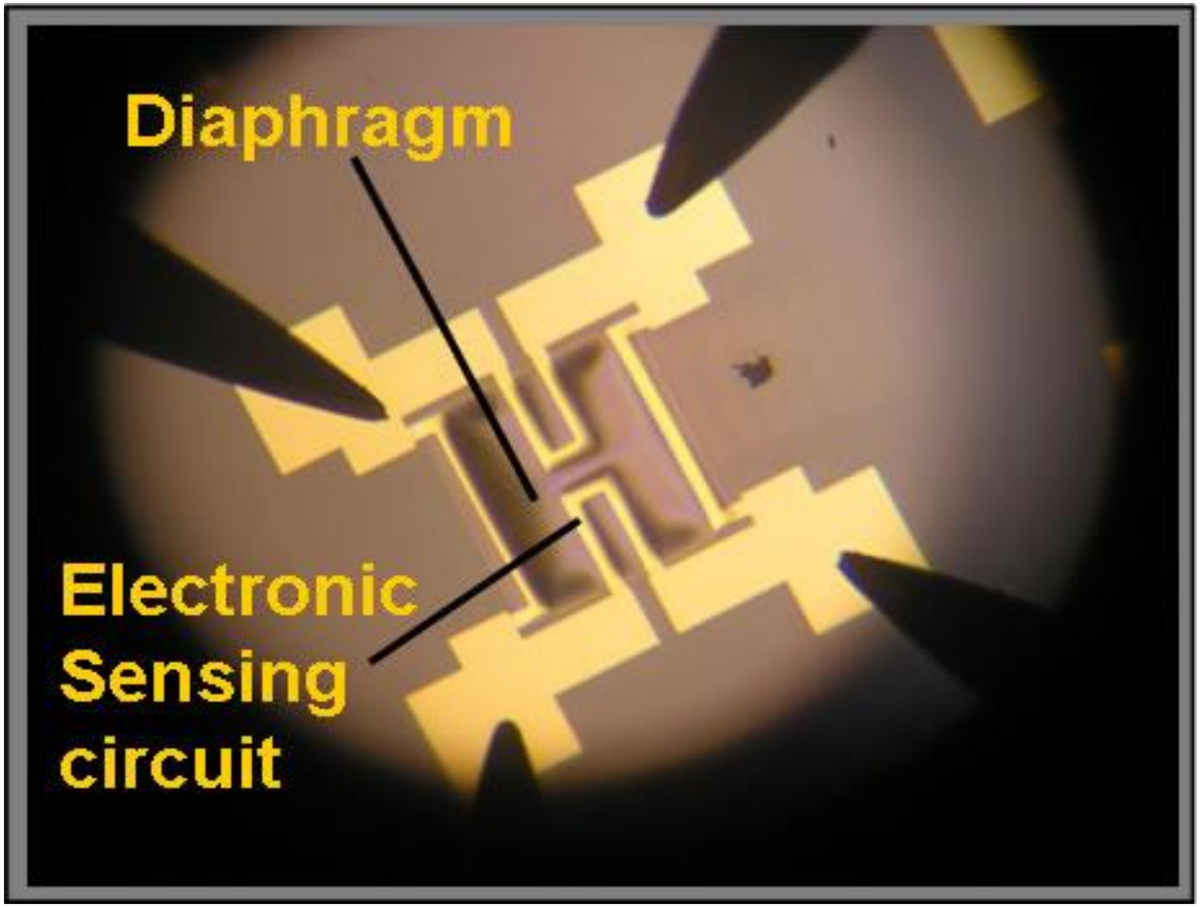


Special Cause Variation

Tracking Your Gas Mileage



Special Cause Variability

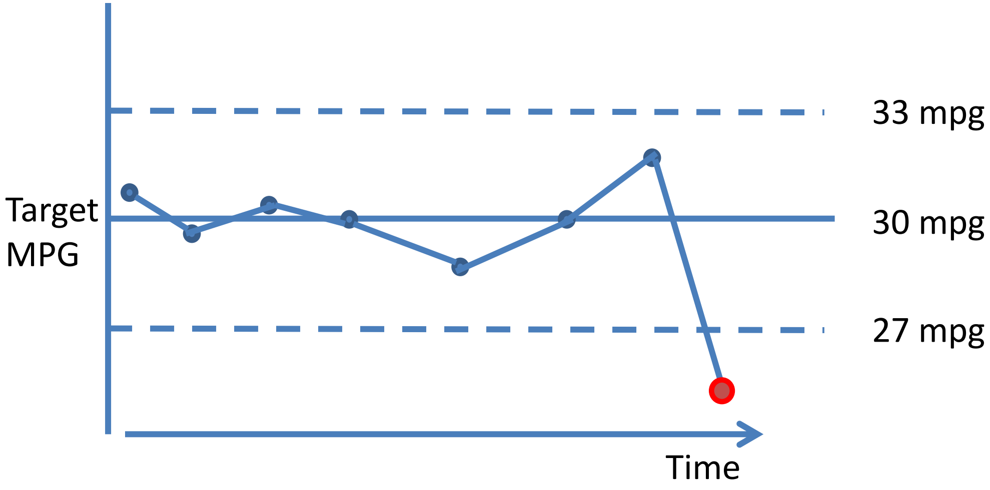


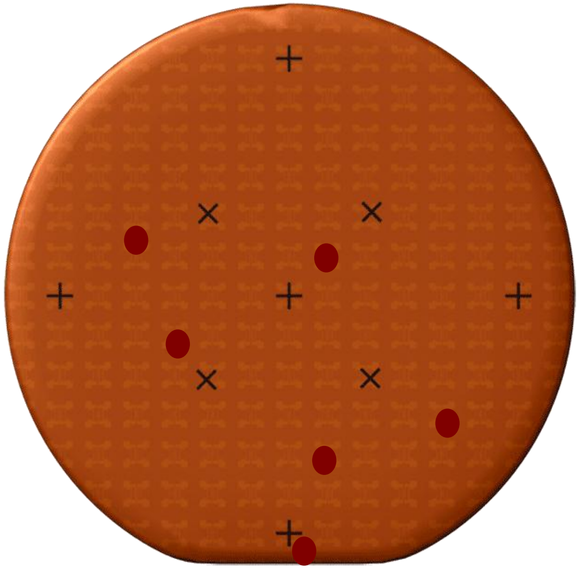
Process Steps:

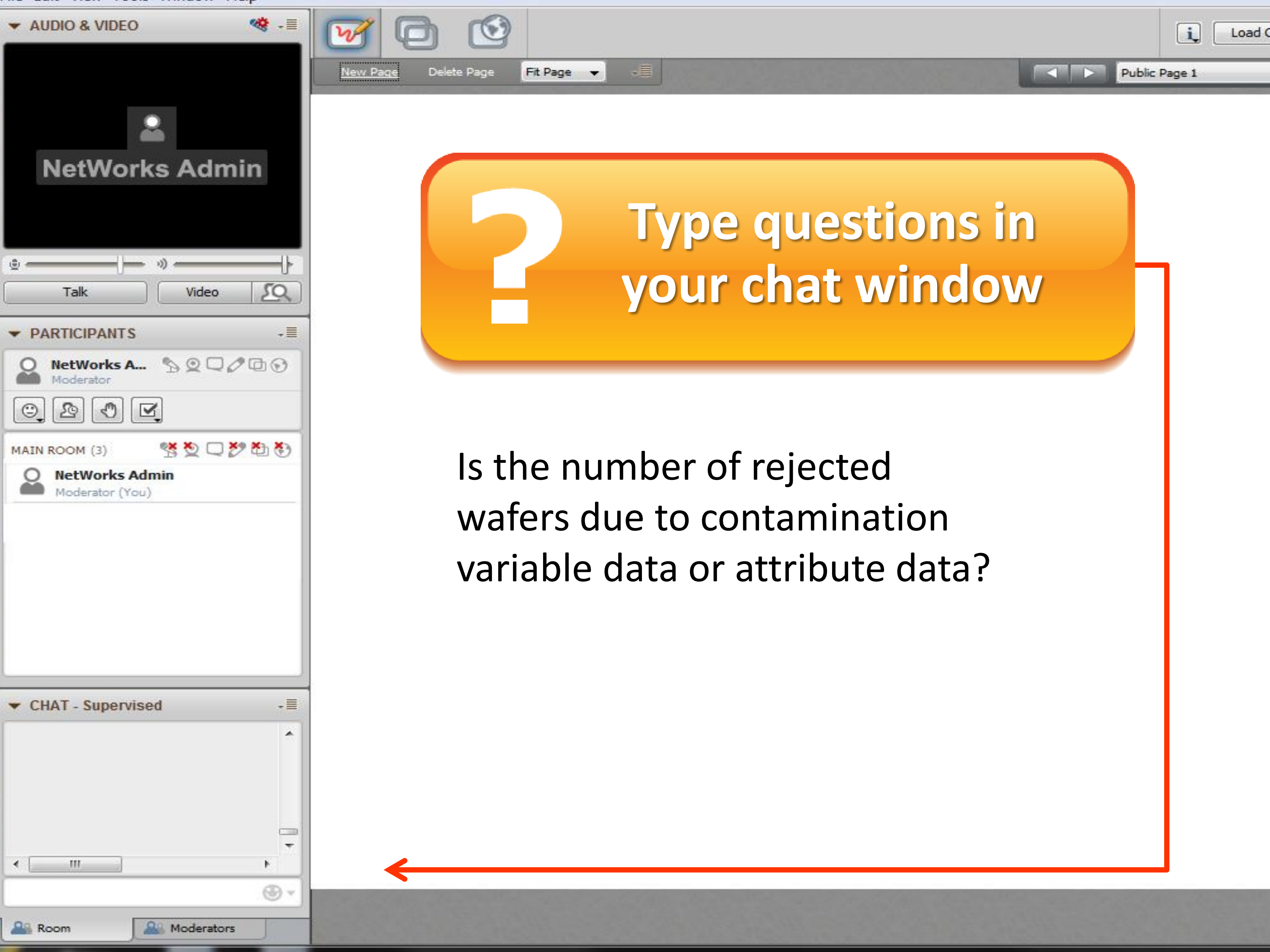
1. Silicon Nitride Deposition
2. Lithography for chamber
3. Lithography for sensing circuit
4. Metal deposition for circuit
5. Metal Removal
6. Etch reference chamber

Types of data

- Variable Data
  - Data Based upon measurements
  - Length, time, weight, temperature, pressure, film thickness
- Attribute Data
  - Data based upon counts (discrete)
  - Either there or not
  - Number of defects, acceptable or unacceptable

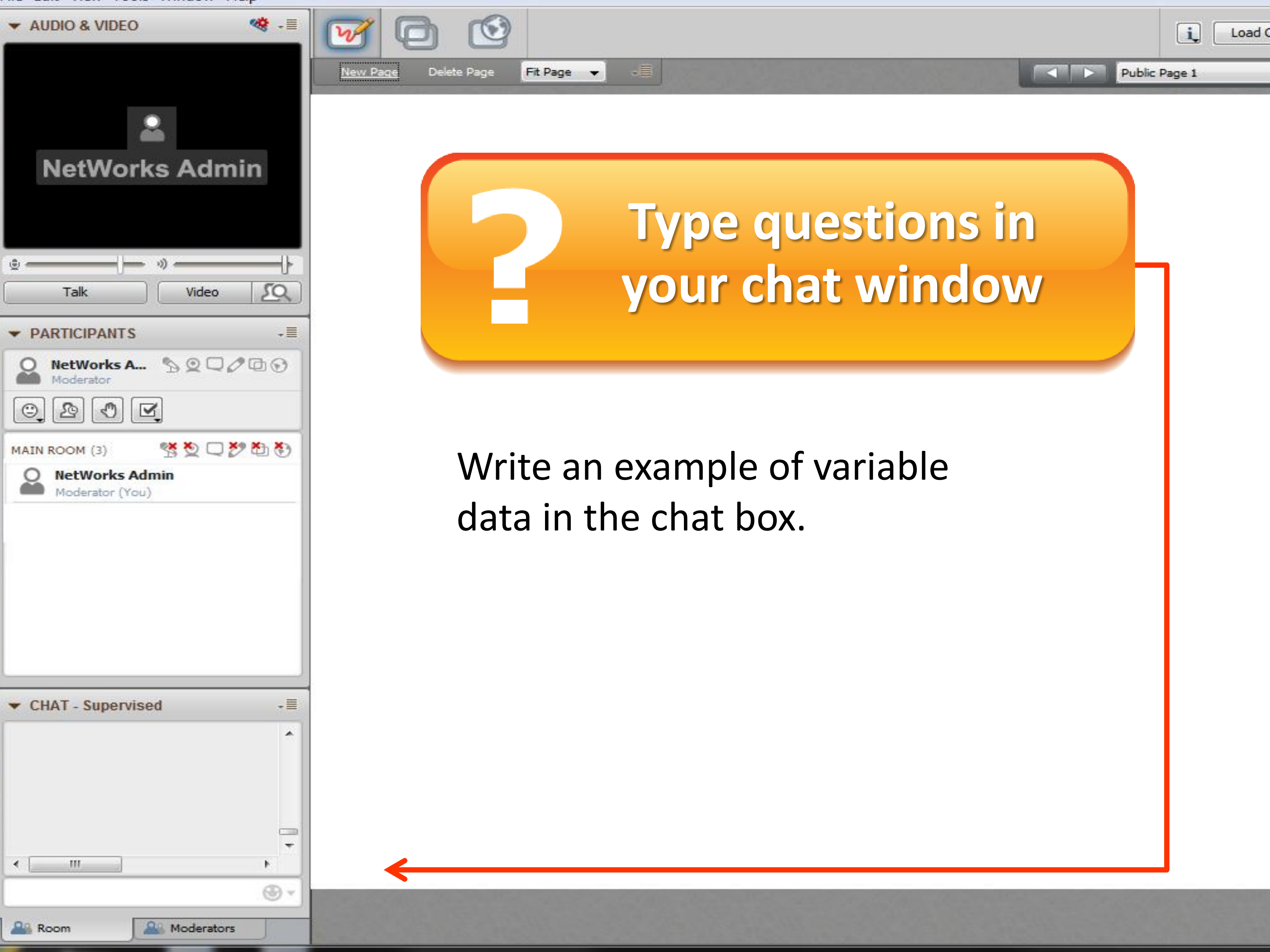






? Type questions in your chat window

Is the number of rejected wafers due to contamination variable data or attribute data?

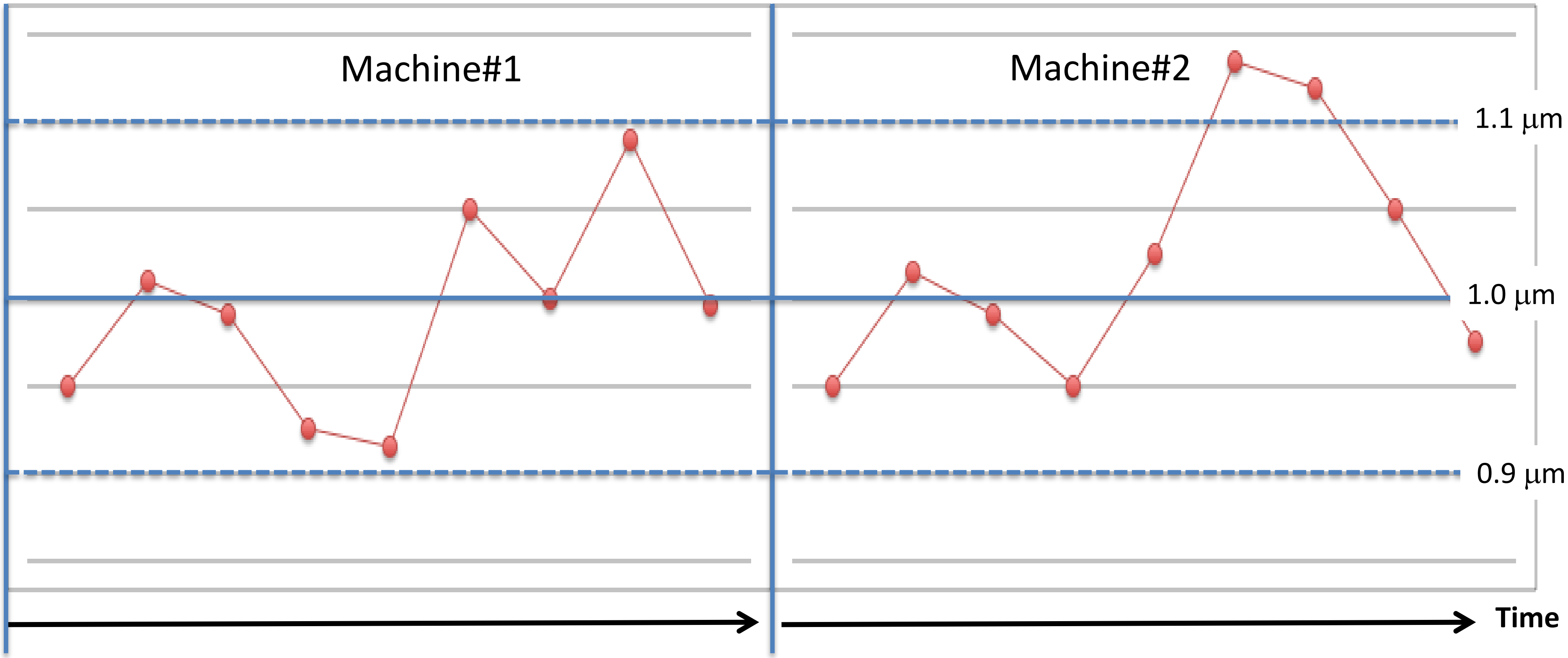


? Type questions in your chat window

Write an example of variable data in the chat box.

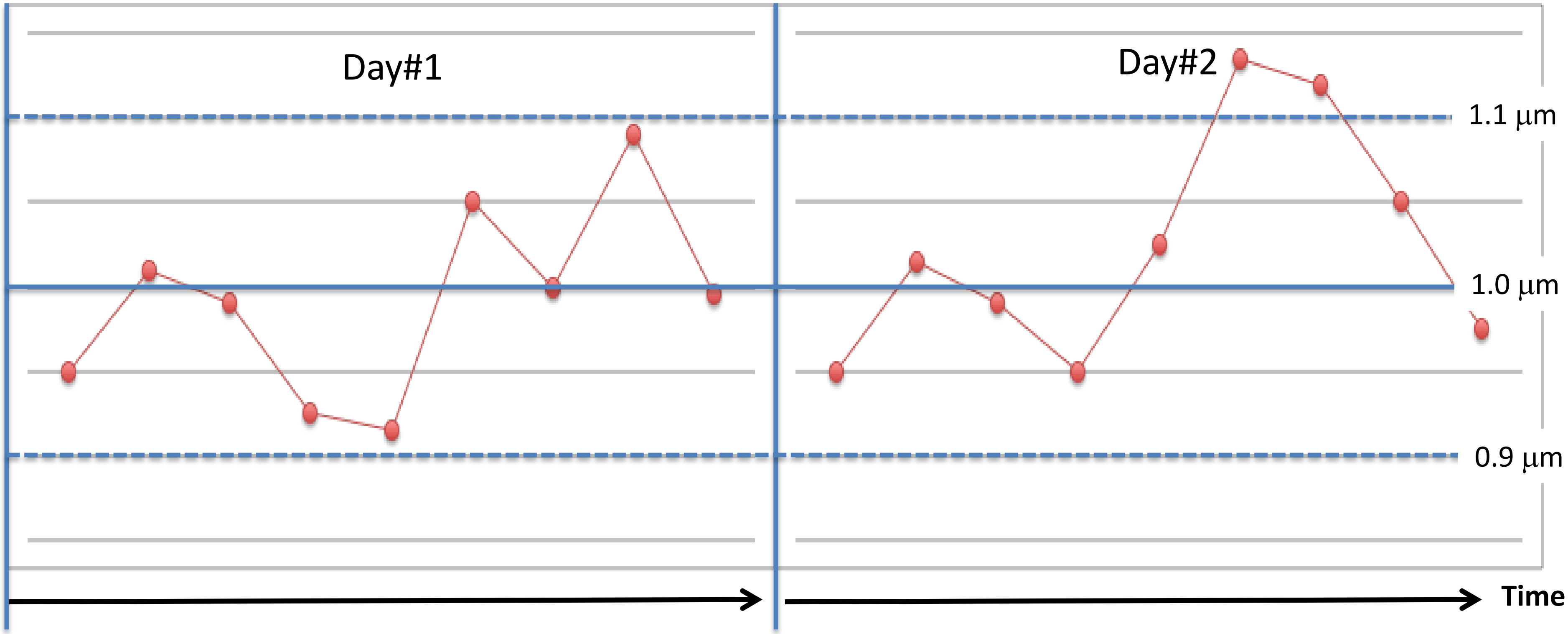
Variability

Photoresist Thickness



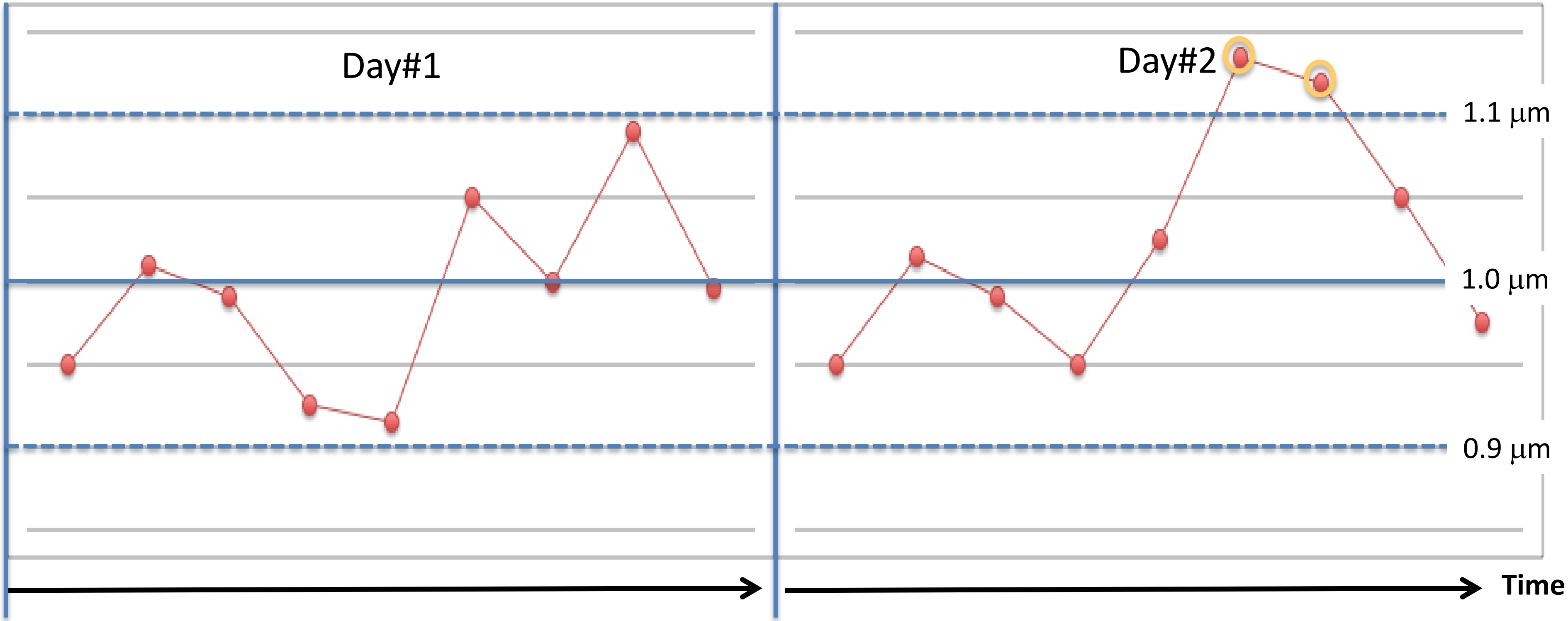
Variability

Photoresist Thickness



Variability

Photoresist Thickness

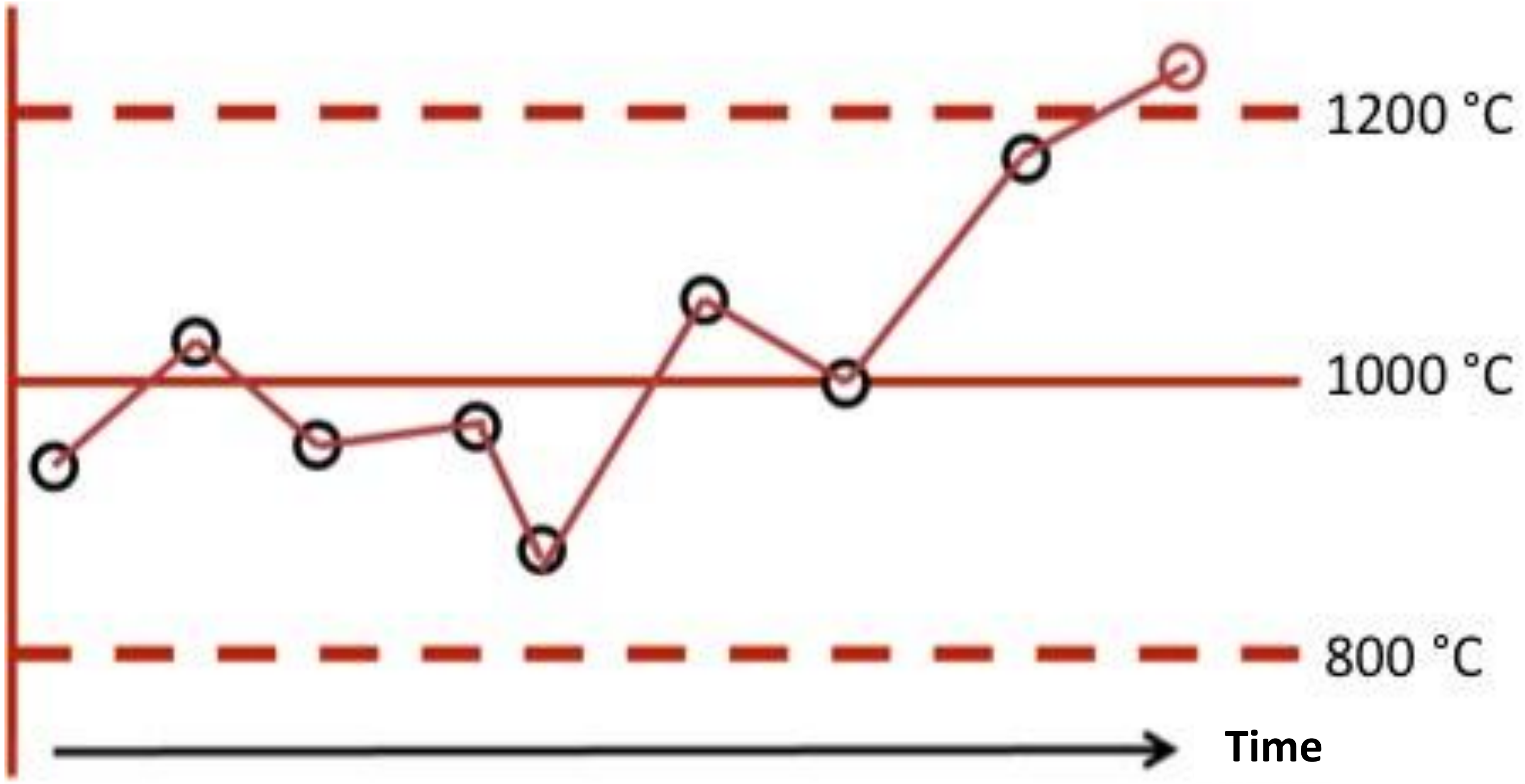


Common Cause Variation
Controlled Variation

Special Cause Variation
Uncontrolled Variation

Another Example

Process Temperature



Desired Variation

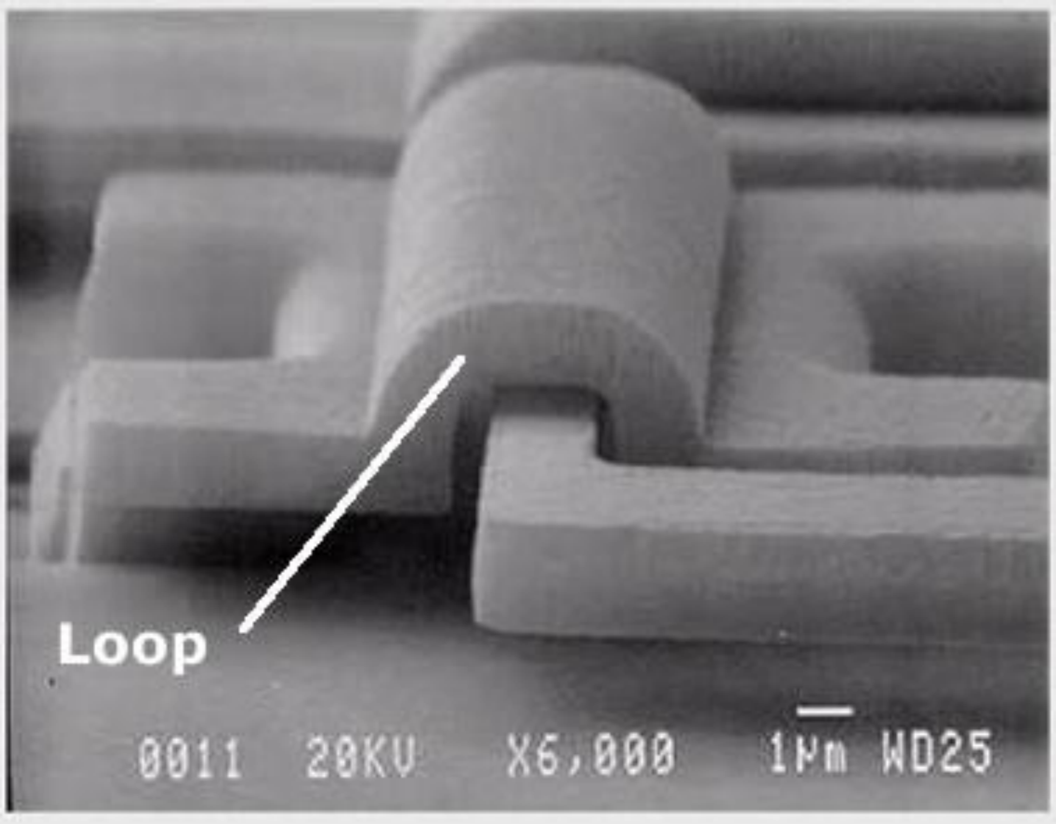
Can you think of a product where a certain amount of variation is acceptable?

Desired Variation

Can you think of a product where a certain amount of variation is acceptable?

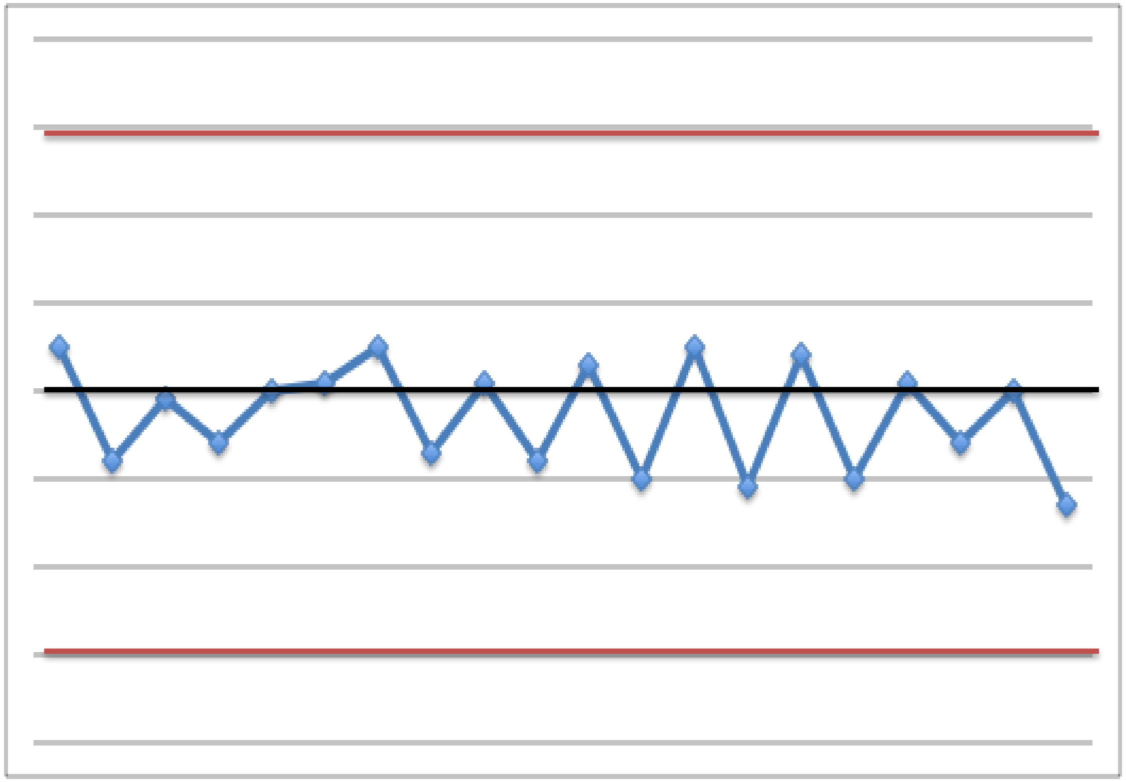
Variation in Microsystems

Hinge System



[Image courtesy of Sandia National Laboratories]

Statistical Process Control and Variation

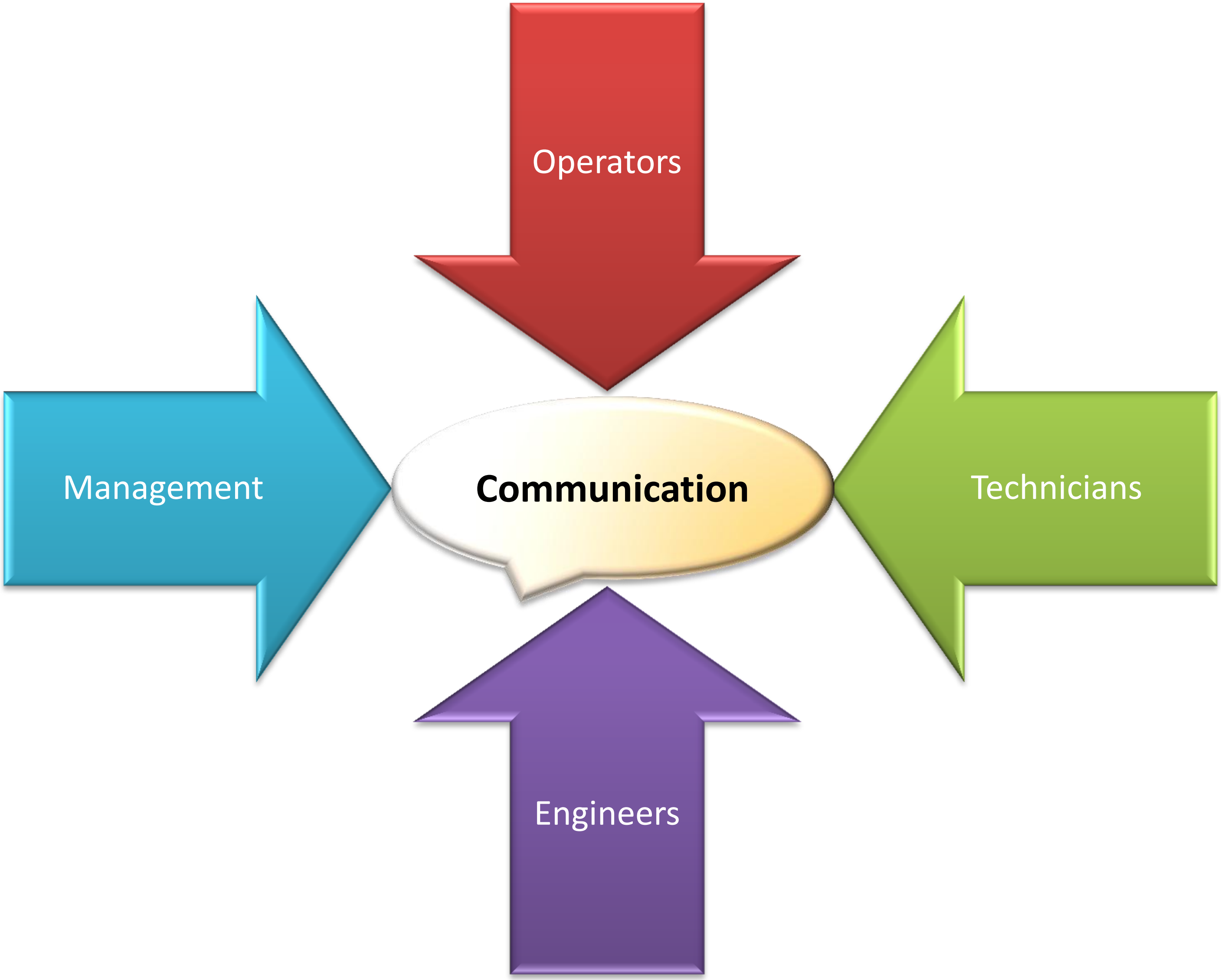


Upper Control Limit

Centerline

Lower Control Limit

Communication is KEY!



Operators

Management

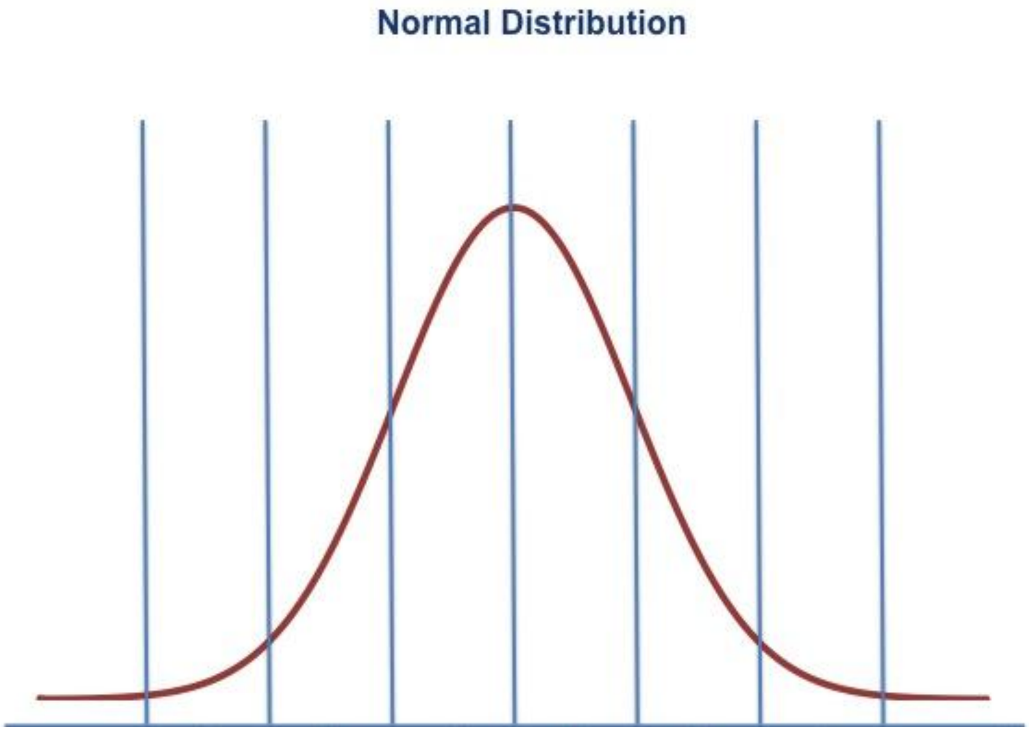
Communication

Technicians

Engineers

Statistics for Statistical Process Control

- Statistics for Central Tendency
  - Sample Median
  - Sample Mean
- Statistics for Variability
  - Sample Range
  - Sample Variance
  - Sample Standard Deviation



Sample Median – Central Tendency

Sample Median

- Represents the data value that is “physically” in the middle of the sample set when arranged in numerical order.

Example:

- Given the data set: 2,4,1,5,3
- Order the data: 1,2,3,4,5
- **Question: What is the Median?**

Sample Median – Central Tendency

Sample Median

- Represents the data value that is “physically” in the middle of the sample set when arranged in numerical order.

Example:

- Given the data set: 2, 4, 1, 5, 3
- Order the data: 1,2,**3**,4,5

Example:

- Given the data set: 2, 4 ,1, 5, 1 ,3
- Order the data: 1, 1, 2, 3, 4, 5
- Median is the average of the 2 middle #’s: 2 and 3
- Median = **2.5**

Sample Mean – Central Tendency

Mean

- Universal or Arithmetic Mean = μ
- Sample Mean = $\overline{X}$
- Mean of a collection of sample Means = $\overline{\overline{X}}$

Calculation of Mean

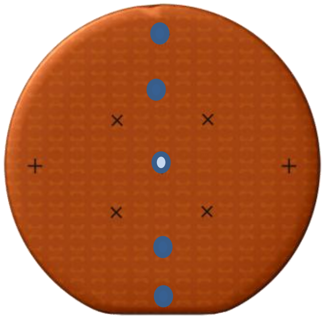
$$\mu = \frac{\Sigma x_n}{n}$$

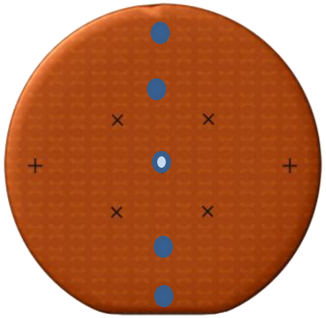
5 Resist Thickness Values: 2.87, 2.99, 3.01, 3.15, 2.98 Microns

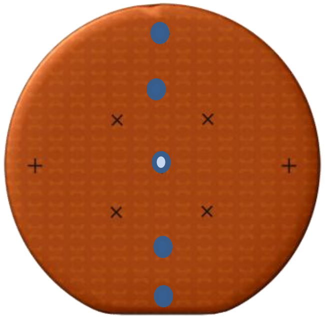
$$\mu = \overline{X} = \frac{2.87 + 2.99 + 3.01 + 3.15 + 2.98}{5} = 3.00 \text{ microns}$$

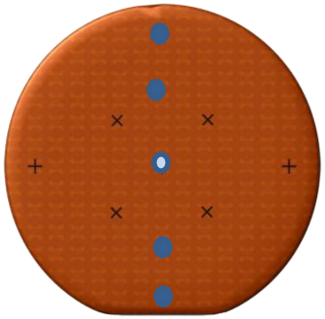
Sample Mean

What is $\bar{\bar{X}}$?









Wafer #1	Wafer #2	Wafer #3	Wafer#4
3.23	3.43	3.74	2.52
3.09	4.29	2.01	2.49
4.82	1.95	1.58	1.68
4.16	4.55	4.89	4.18
2.11	2.37	1.38	1.61
Wafer #1 Sample Mean	Wafer #2 Sample Mean	Wafer #3 Sample Mean	Wafer #4 Sample Mean
$\bar{X}$ = 3.48 microns	$\bar{X}$ = 3.32 microns	$\bar{X}$ = 2.72 microns	$\bar{X}$ = 2.49 microns

$$\bar{\bar{X}} = \frac{3.48 + 3.32 + 2.72 + 2.49}{4} = 3.00 \text{ microns}$$

Sample Range
Statistics for Variability

Statistics for Variability

- Sample Range
- Sample Variance
- Sample Standard Deviation

- *Sample Range*
  - The difference between the maximum value minus the minimum value.

2.87, 2.99, 3.01, 3.15, 2.98

Question – What is the Sample Range?

Sample Range
Statistics for Variability

Statistics for Variability

  - Sample Range
  - Sample Variance
  - Sample Standard Deviation

- *Sample Range*
  - The difference between the maximum value minus the minimum value.

2.87, 2.99, 3.01, 3.15, 2.98

3.15 – 2.87 = 0.28 Sample Range

Sample Variance
Statistics for Variability

- *Sample Variance*
  - How far a set of numbers are spread out.

$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1}$$

- 5 Resist Thickness Values: 2.87, 2.99, 3.01, 3.15, 2.98 microns
- Mean = 3.00 micros

- σ^2 = 0.01 Square Microns

Sample Standard Deviation
Statistics for Variability

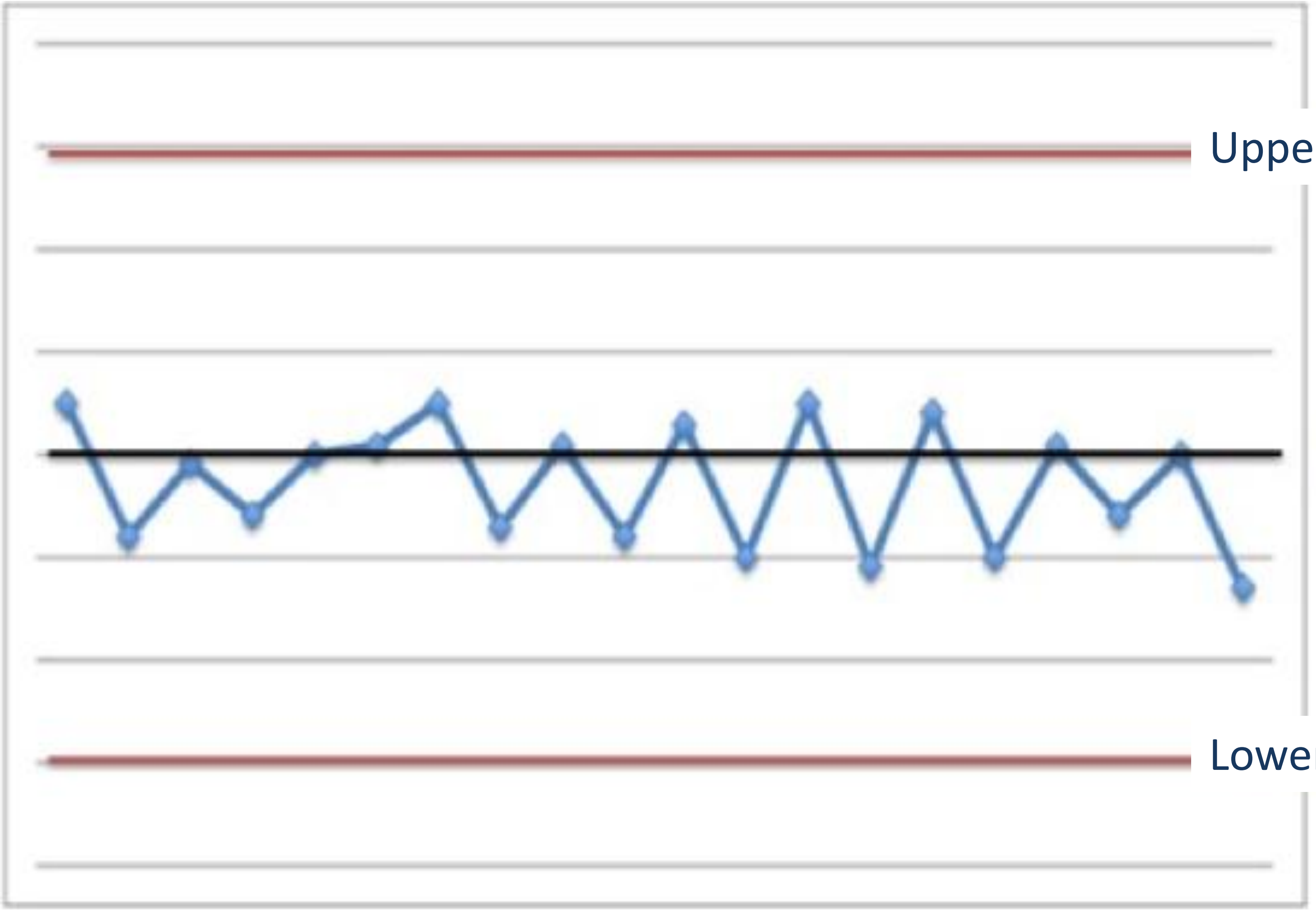
- *Sample Standard Deviation*
  - Measurement of how the data are distributed around the sample mean and within a range of values.

$$\sigma = \sqrt{\sigma^2} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1}}$$

  - $\sigma^2 = 0.01$ micron^2
  - $\sigma = 0.1$ micron

Let’s Have Fun with Control Charts!

$\overline{X}$-Chart

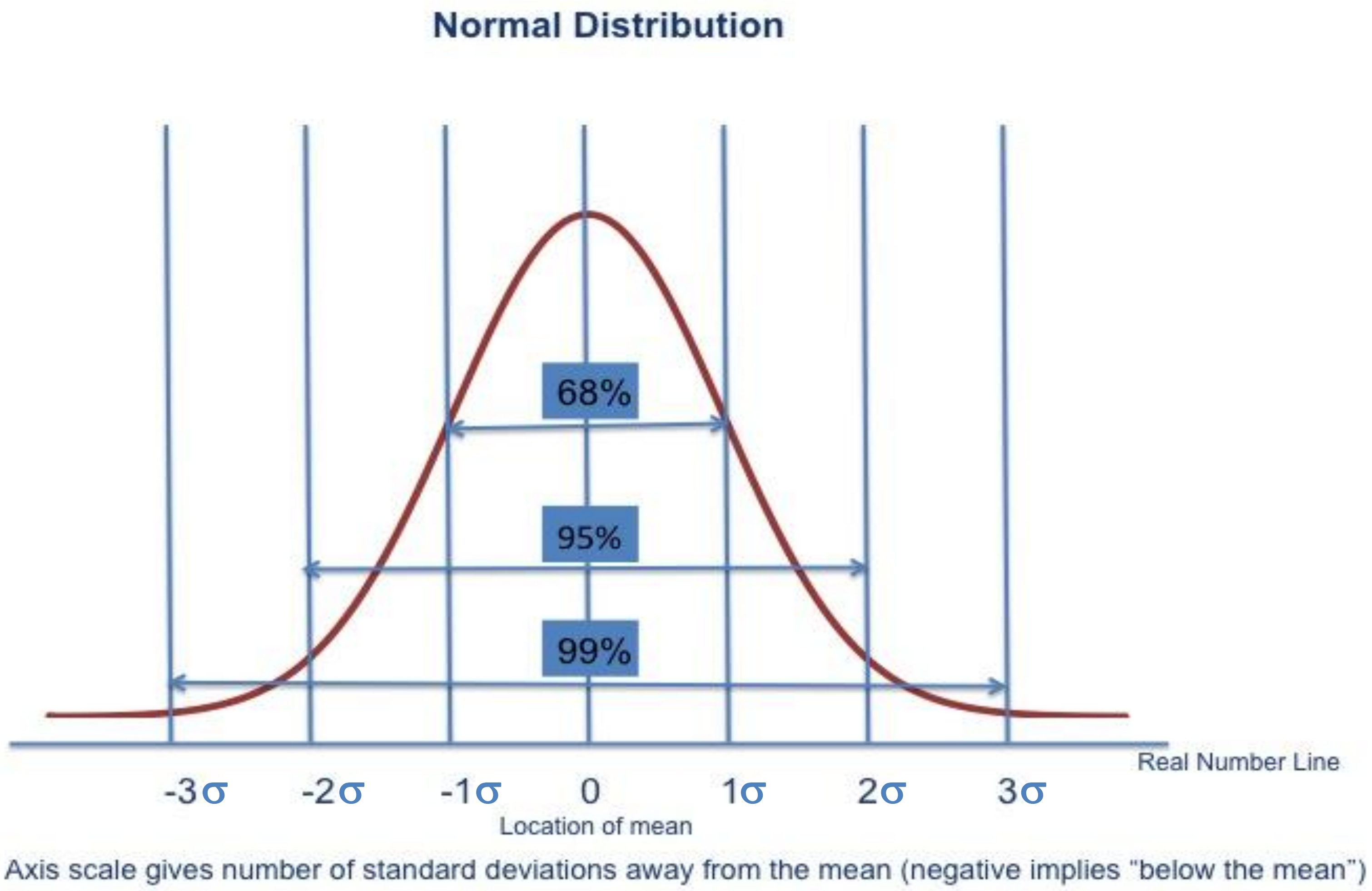


Upper Control Limit

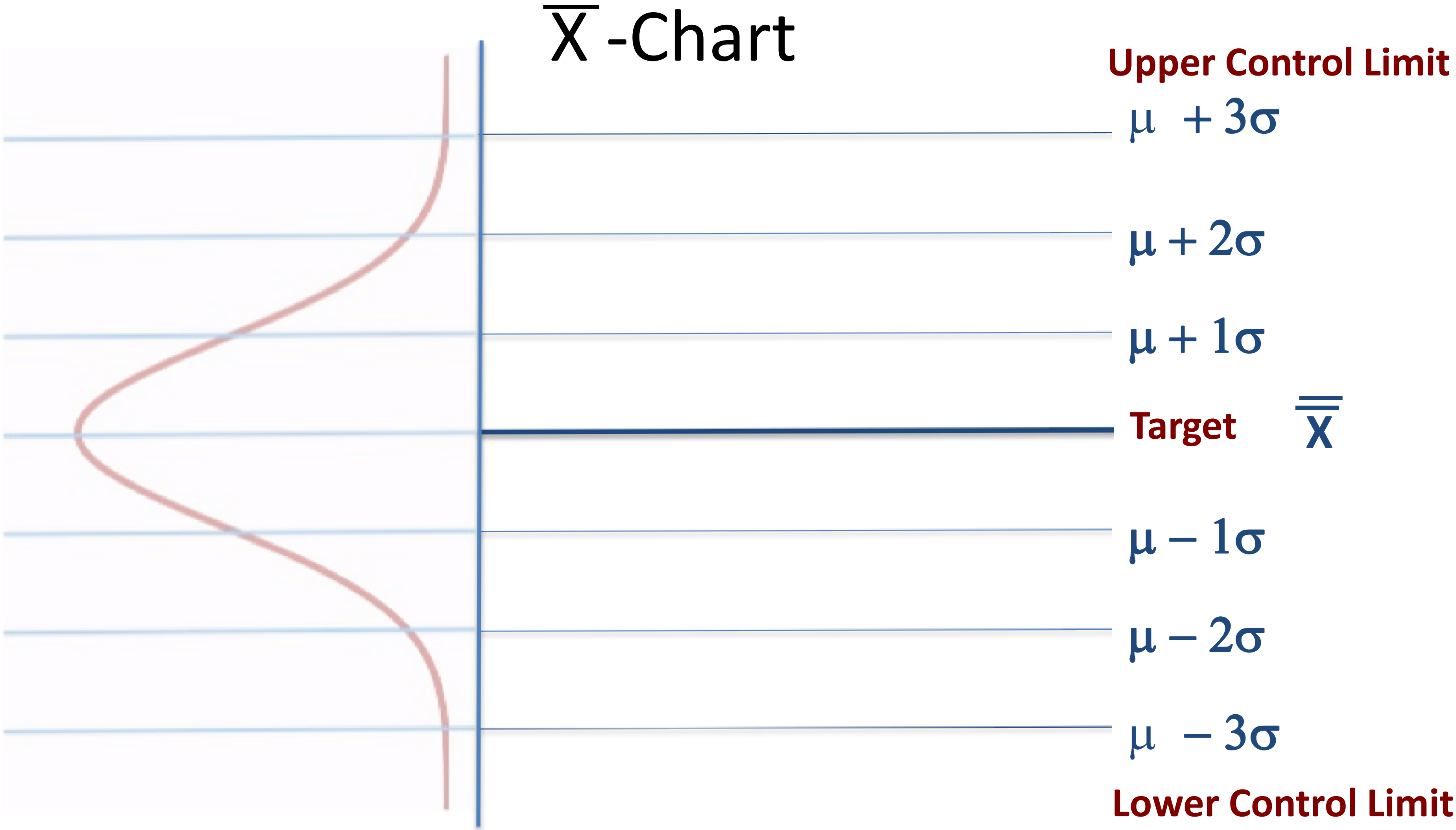
Centerline $\overline{\overline{X}}$
(Target)

Lower Control Limit

Normal Distribution
Yes, it does matter



Control Chart Basics



$\overline{X}$-Chart

Upper Control Limit

$\mu + 3\sigma$

$\mu + 2\sigma$

$\mu + 1\sigma$

Target $\overline{\overline{X}}$

$\mu - 1\sigma$

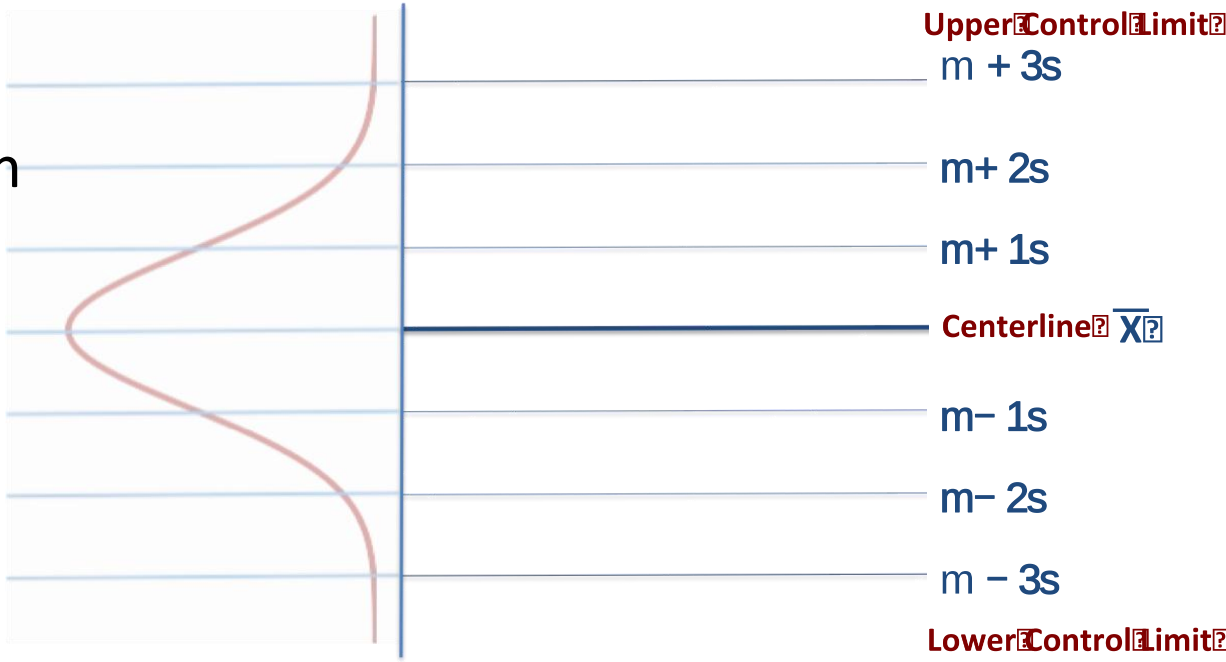
$\mu - 2\sigma$

$\mu - 3\sigma$

Lower Control Limit

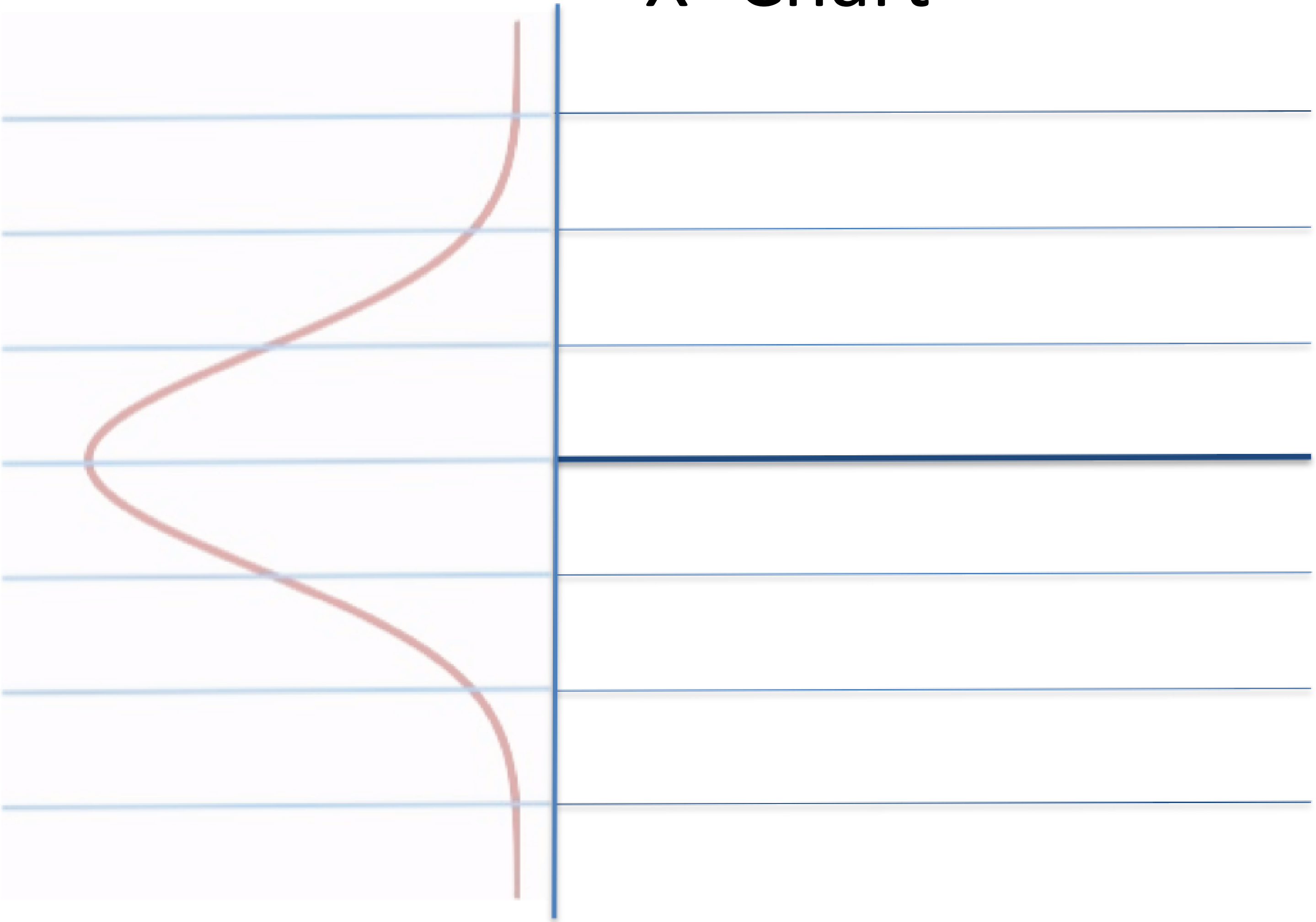
Control Chart Basics

- X axis is time based
- Monitors process to detect special cause variation and manage common cause variation
- Common Cause Variation
  - Due to room temperature change
  - Line personnel
- Special Cause Variation
  - Changes in process
  - Unexpected events
  - Change in vendors of a product ingredient
  - Leaks in a vacuum line



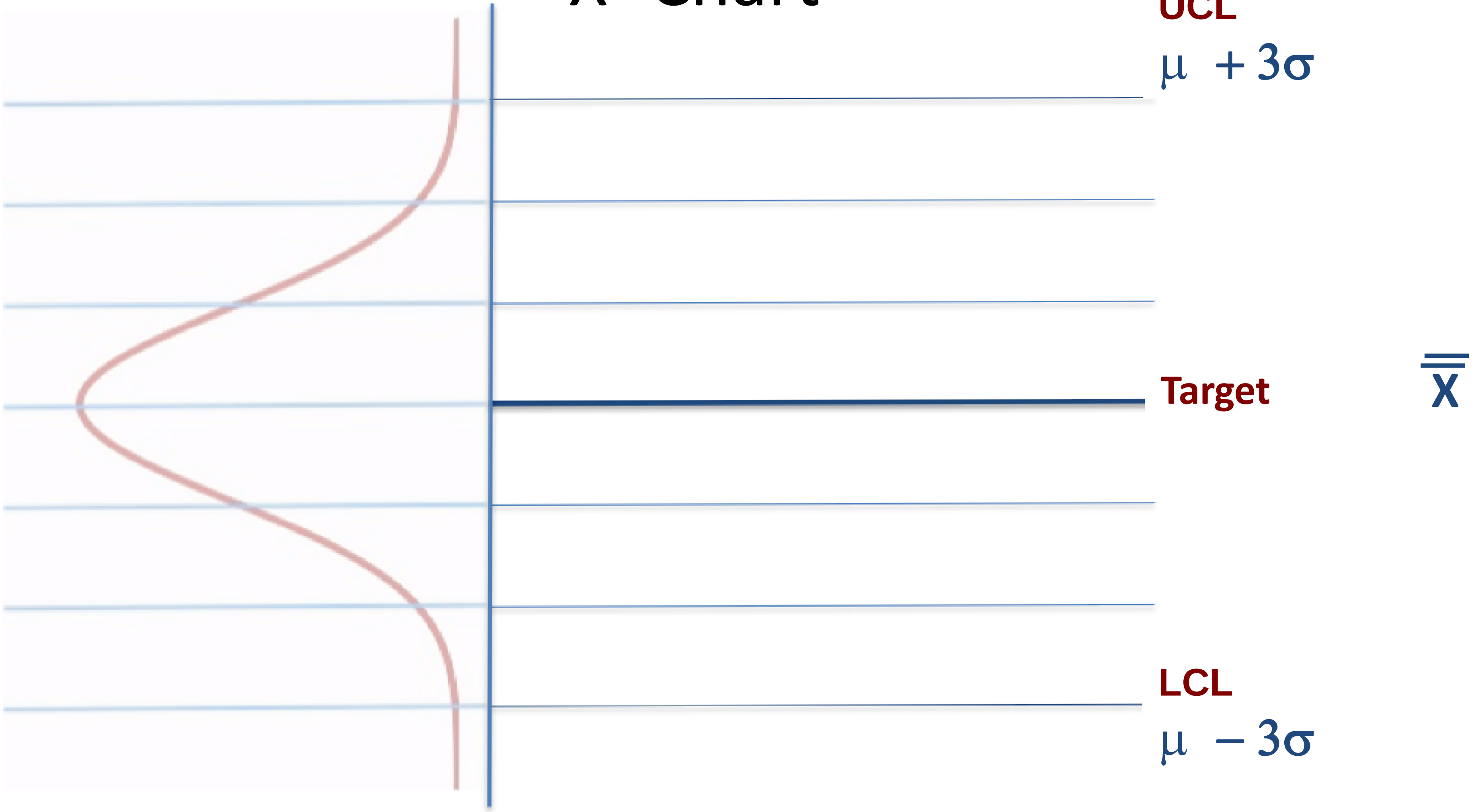
Control Chart Basics

$\overline{X}$ -Chart



Control Chart Basics

$\overline{X}$-Chart



UCL

$\mu + 3\sigma$

Target

$\overline{\overline{X}}$

LCL

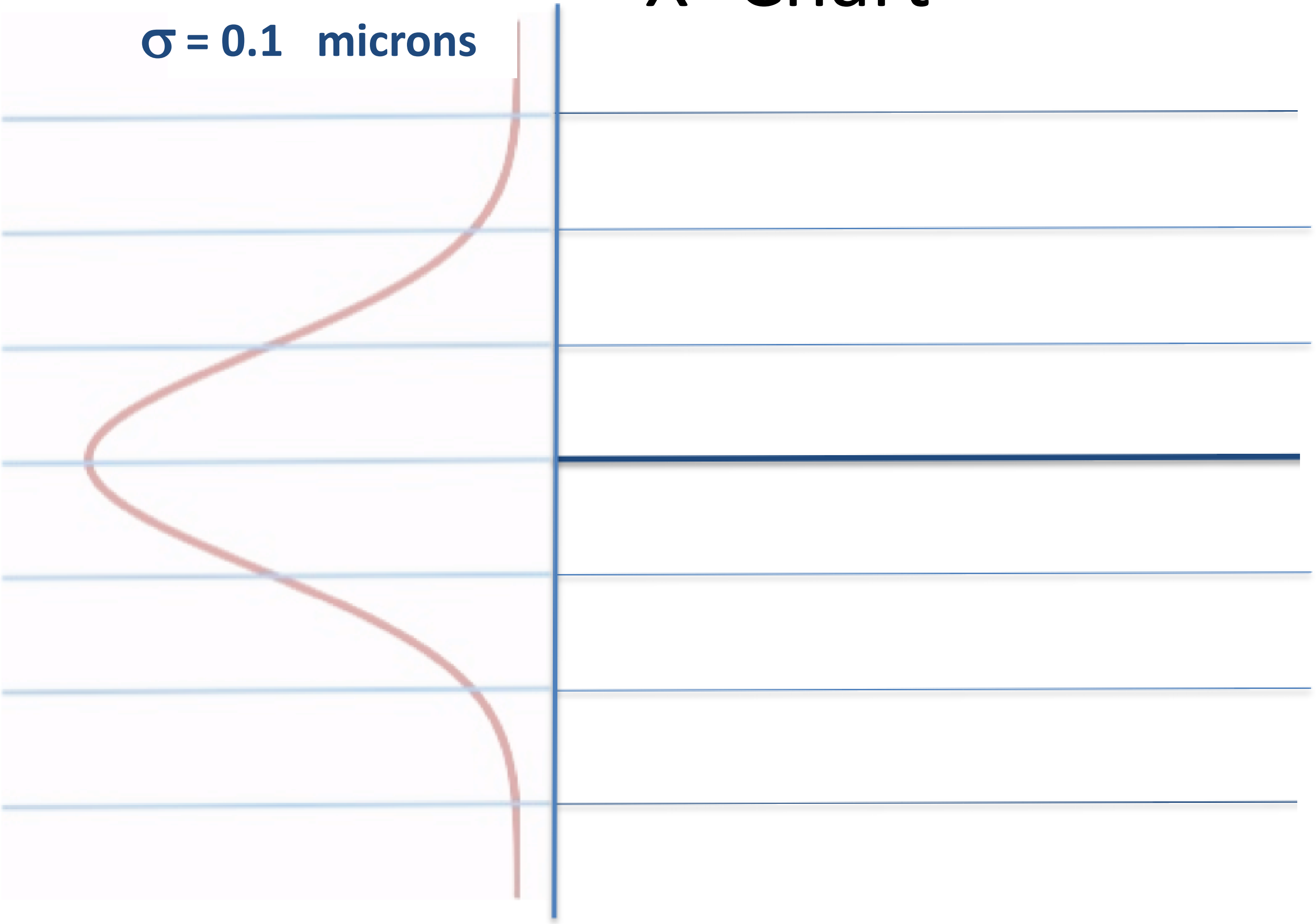
$\mu - 3\sigma$

Control Chart Basics

$\overline{X}$ or μ = 3.00 microns

σ = 0.1 microns

$\overline{X}$-Chart



UCL

$\mu + 3\sigma$

3 + (3*0.1)= 3.03

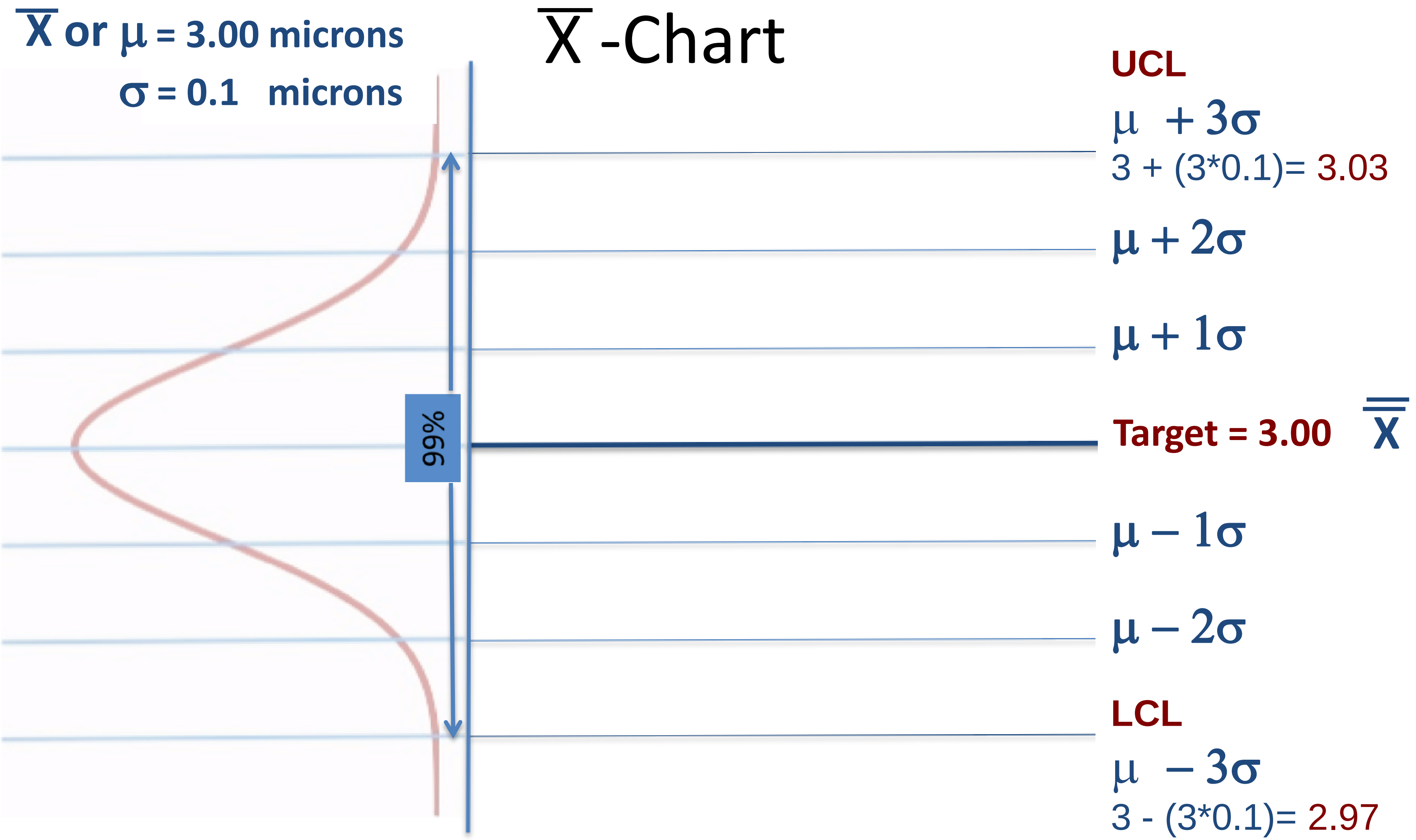
Target = 3.00 $\overline{\overline{X}}$

LCL

$\mu - 3\sigma$

3 - (3*0.1)= 2.97

Control Chart Basics



$\bar{X}$ or μ = 3.00 microns

σ = 0.1 microns

$\bar{X}$-Chart

99%

UCL

$\mu + 3\sigma$

3 + (3*0.1)= 3.03

$\mu + 2\sigma$

$\mu + 1\sigma$

Target = 3.00 $\bar{\bar{X}}$

$\mu - 1\sigma$

$\mu - 2\sigma$

LCL

$\mu - 3\sigma$

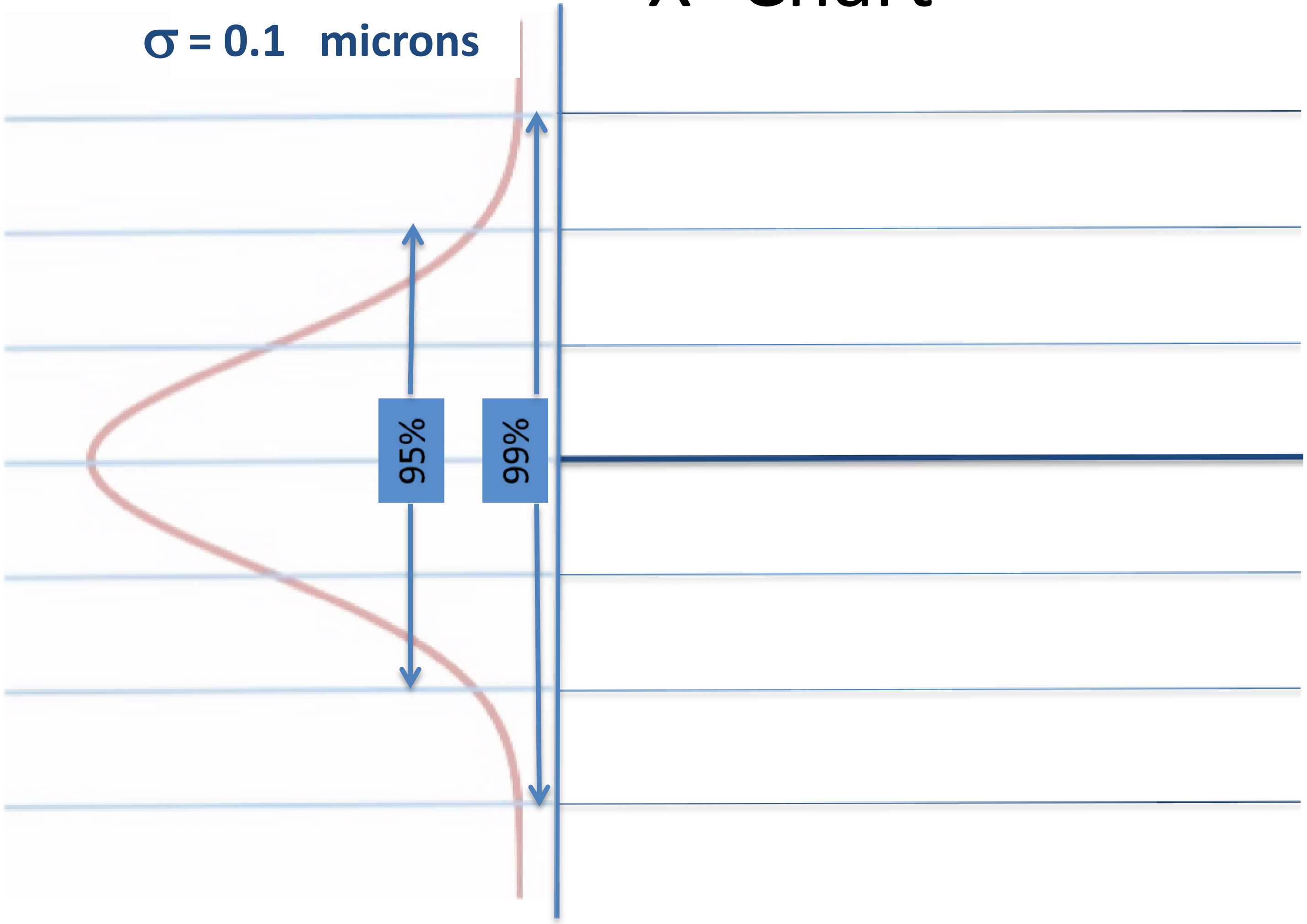
3 - (3*0.1)= 2.97

Control Chart Basics

$\bar{X}$ or μ = 3.00 microns

σ = 0.1 microns

$\bar{X}$-Chart



UCL

$\mu + 3\sigma$

3 + (3*0.1)= 3.03

$\mu + 2\sigma$

$\mu + 1\sigma$

Target = 3.00 $\bar{\bar{X}}$

$\mu - 1\sigma$

$\mu - 2\sigma$

LCL

$\mu - 3\sigma$

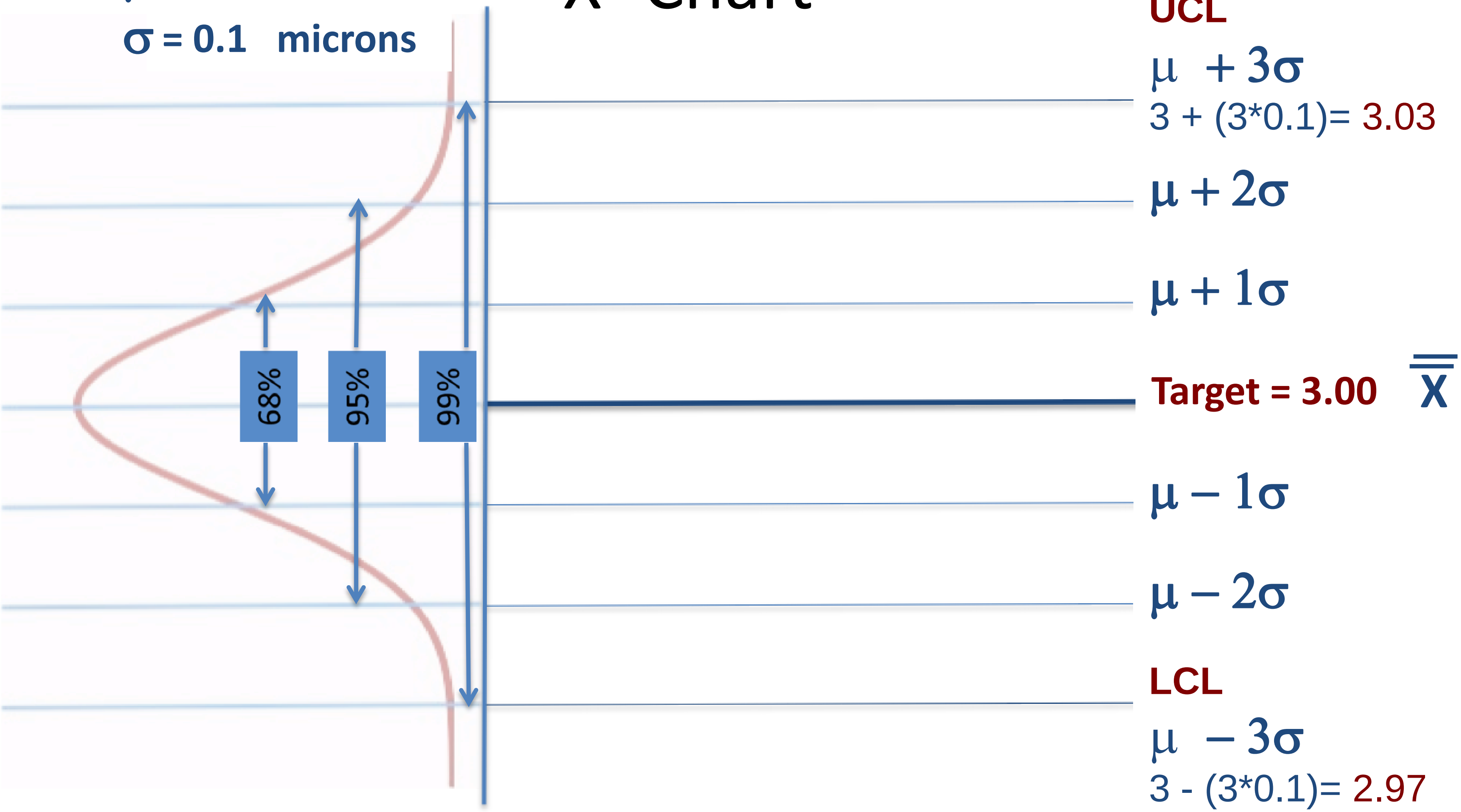
3 - (3*0.1)= 2.97

Control Chart Basics

$\bar{X}$ or μ = 3.00 microns

σ = 0.1 microns

$\bar{X}$-Chart



UCL

$\mu + 3\sigma$

3 + (3*0.1)= 3.03

$\mu + 2\sigma$

$\mu + 1\sigma$

Target = 3.00 $\bar{\bar{X}}$

$\mu - 1\sigma$

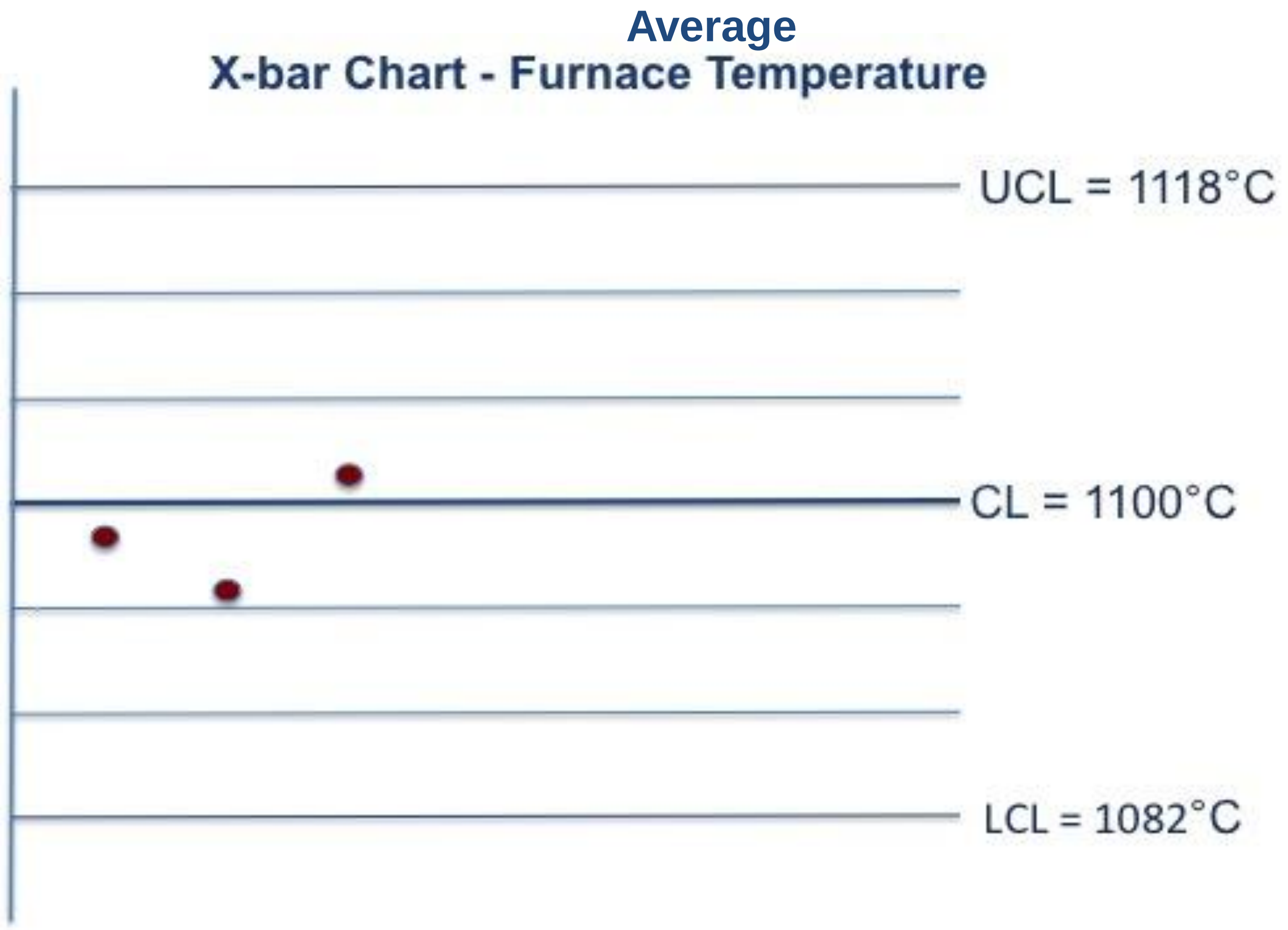
$\mu - 2\sigma$

LCL

$\mu - 3\sigma$

3 - (3*0.1)= 2.97

Control Chart Basics



Shewhart Rules
aka Western Electric Rules (WECO)

8 Rules to Signal an Out of Control Process

- Developed by a Western Electric Engineer – Walter Shewhart

Rule 1: A single point outside the $\mu \pm 3\sigma$ zone.

Rule 2: Two out of three successive points outside $\mu \pm 2\sigma$ zone.

Rule 3: Four out of five successive points outside $\mu \pm 1\sigma$ zone.

Rule 4: Eight or more successive numbers either strictly above or strictly below the mean (the center).

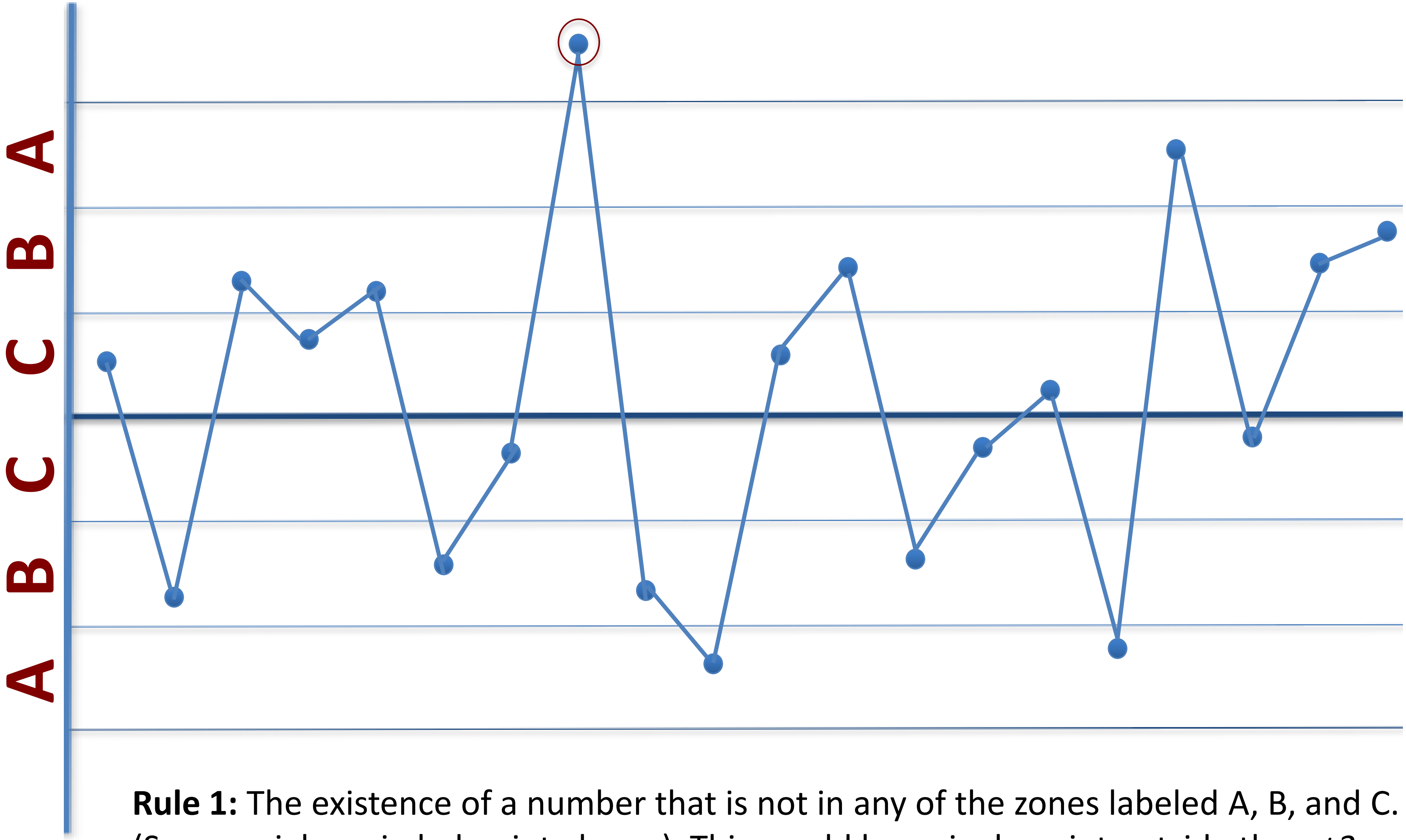
Rule 5: Six or more successive numbers showing a continuous increase or continuous decrease.

Rule 6: Fourteen or more successive numbers that oscillate in size (i.e. smaller, larger, smaller, larger)

Rule 7: Eight or more successive numbers that avoid $\mu \pm 1\sigma$ zone.

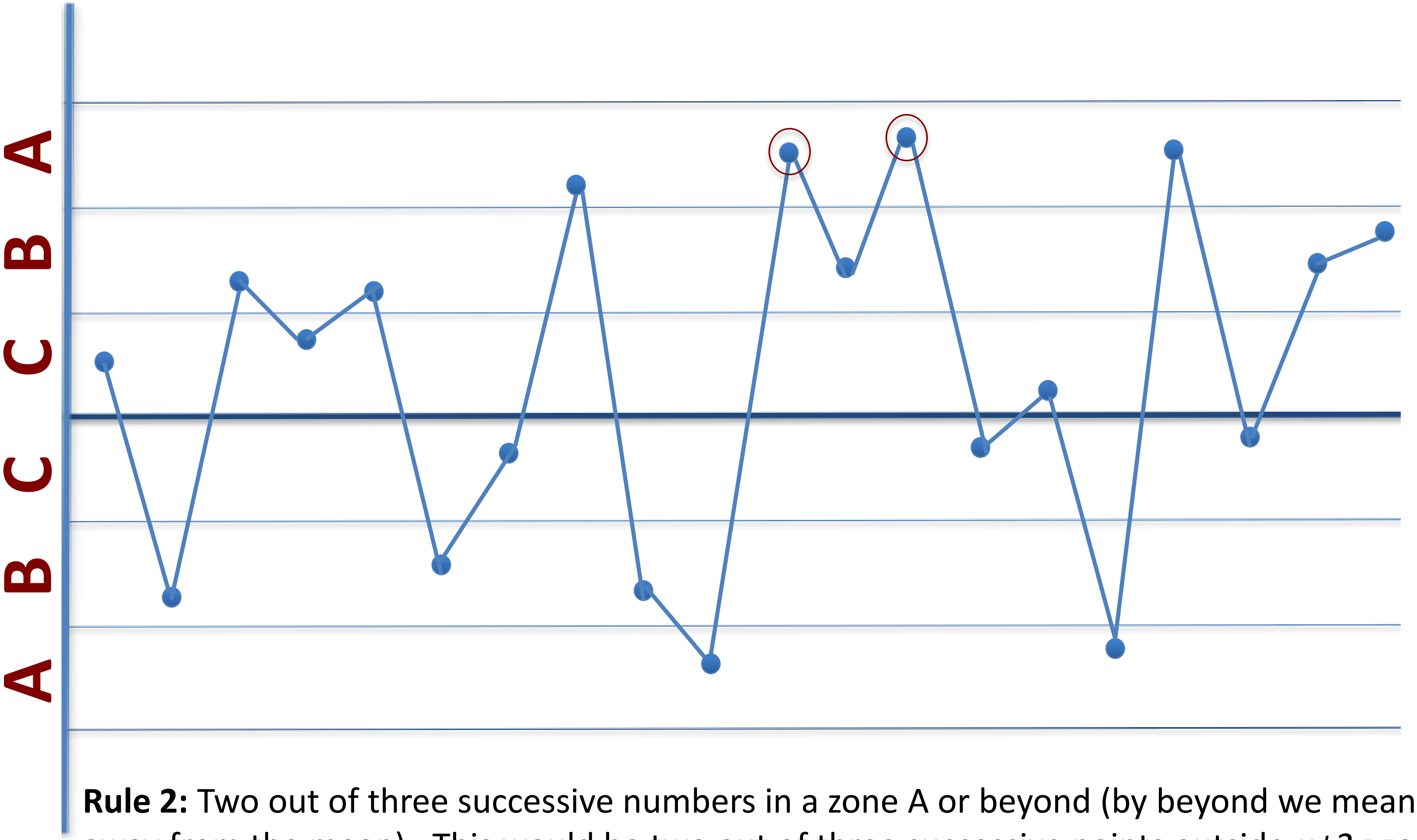
Rule 8: Fifteen successive points fall into $\mu \pm 1\sigma$ zone only, to either side of the centerline.

Shewhart Rules – Rule #1



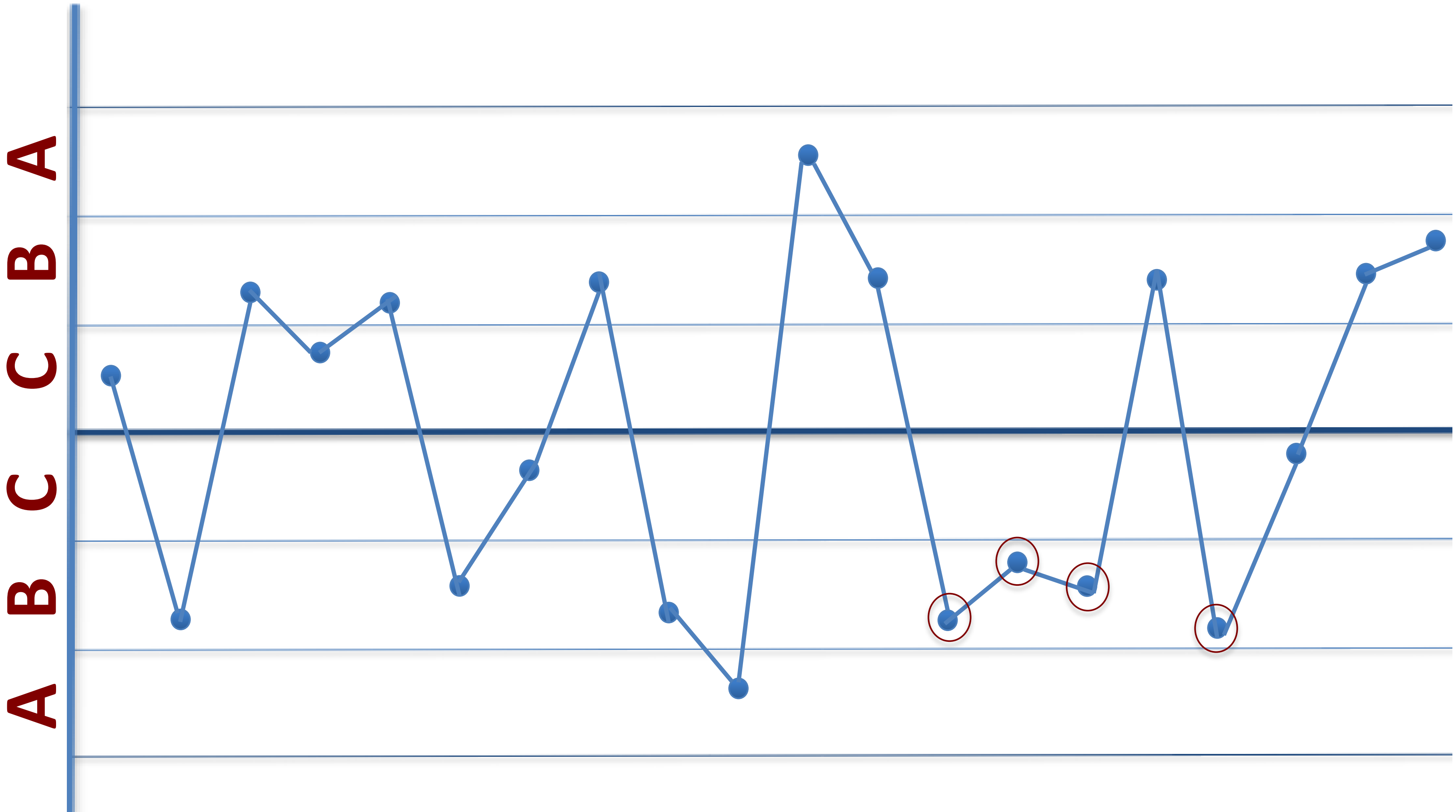
Rule 1: The existence of a number that is not in any of the zones labeled A, B, and C. (See special, encircled point above.) This would be a single point outside the *$\mu \pm 3\sigma$* zone.

Shewhart Rules – Rule #2



Rule 2: Two out of three successive numbers in a zone A or beyond (by beyond we mean away from the mean). This would be two out of three successive points outside $\mu \pm 2\sigma$ zone.

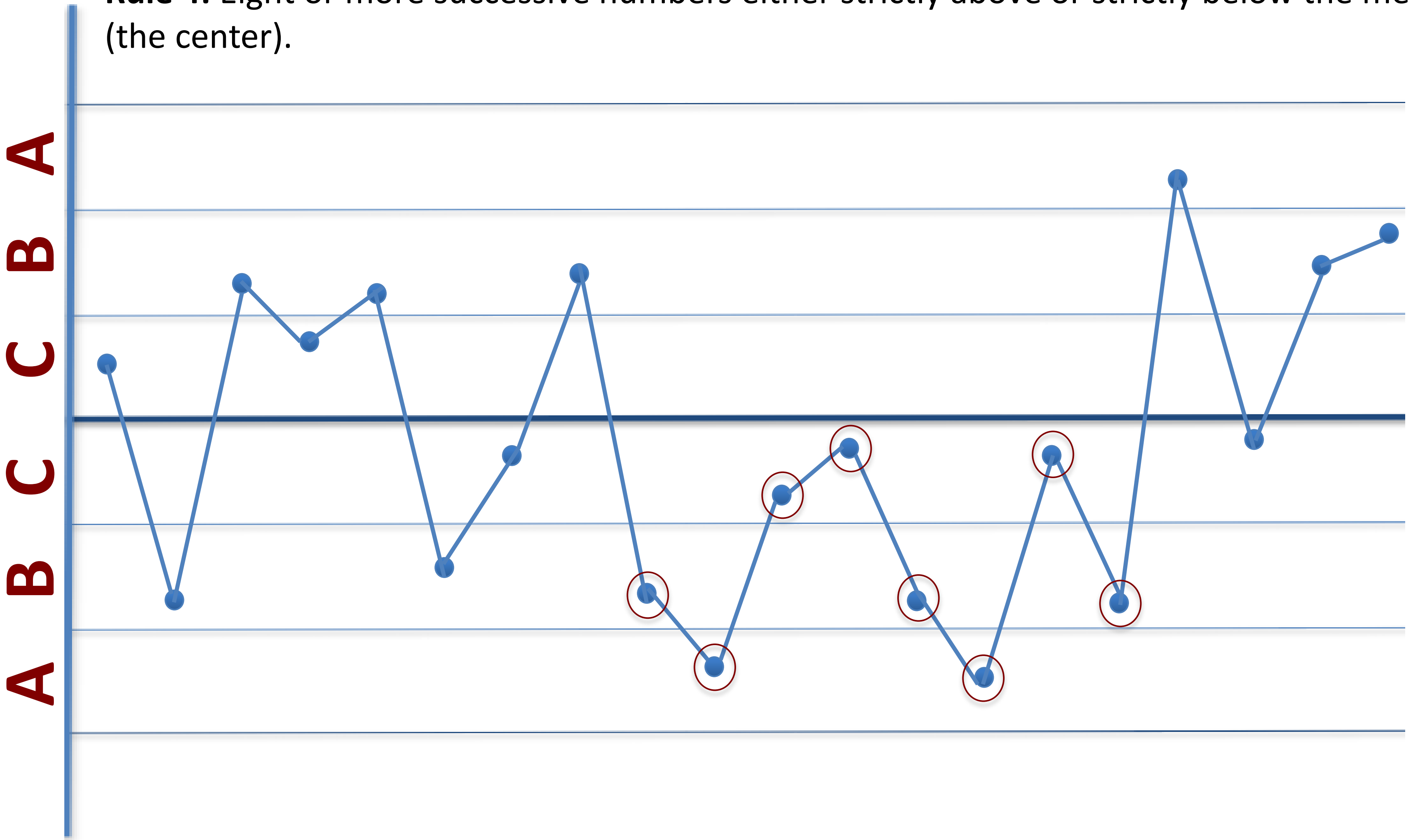
Shewhart Rules – Rule #3



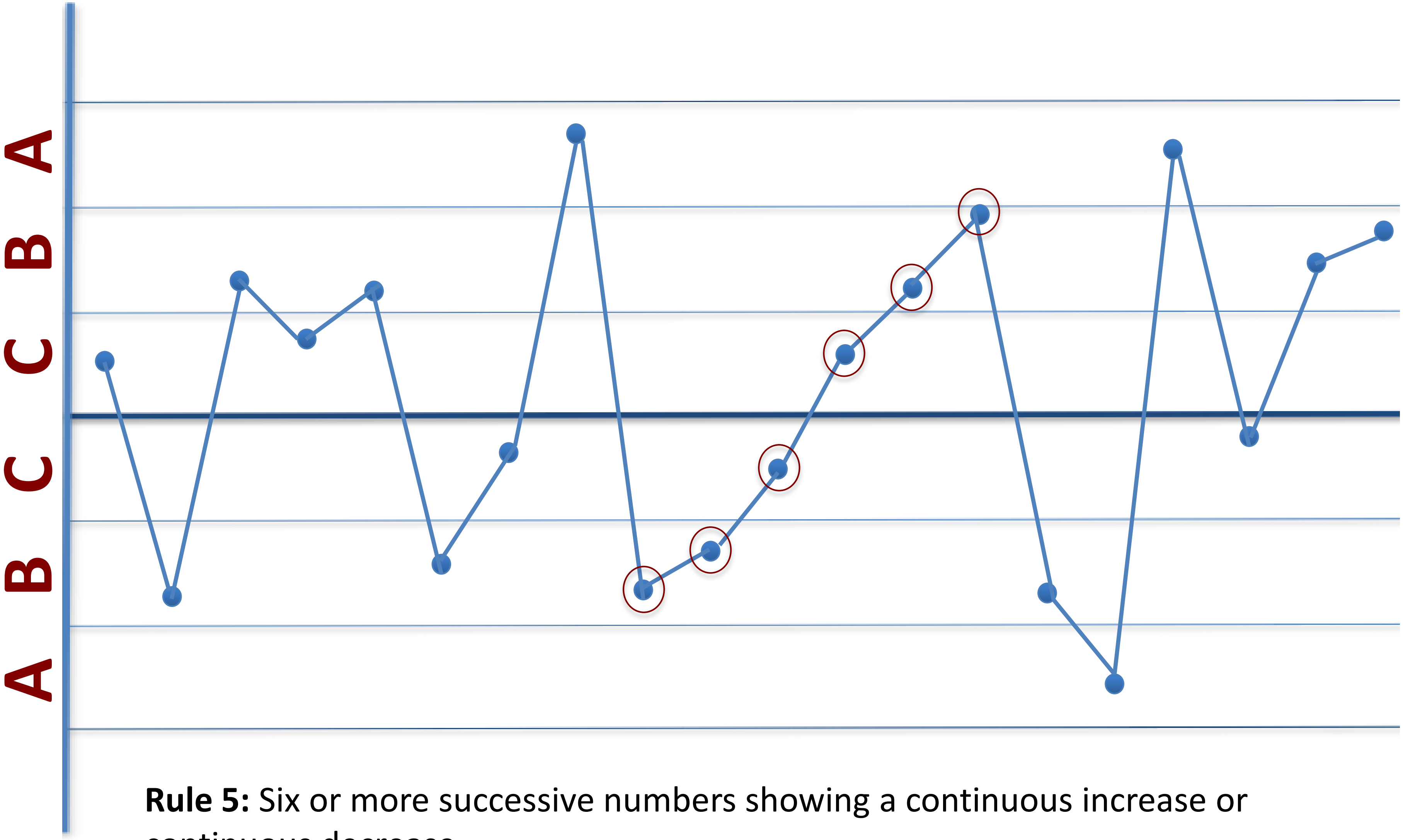
Rule 3: Four out of five successive numbers in a zone B or beyond. This would be four out of five successive points outside *μ±1σ* zone.

Shewhart Rules – Rule #4

Rule 4: Eight or more successive numbers either strictly above or strictly below the mean (the center).



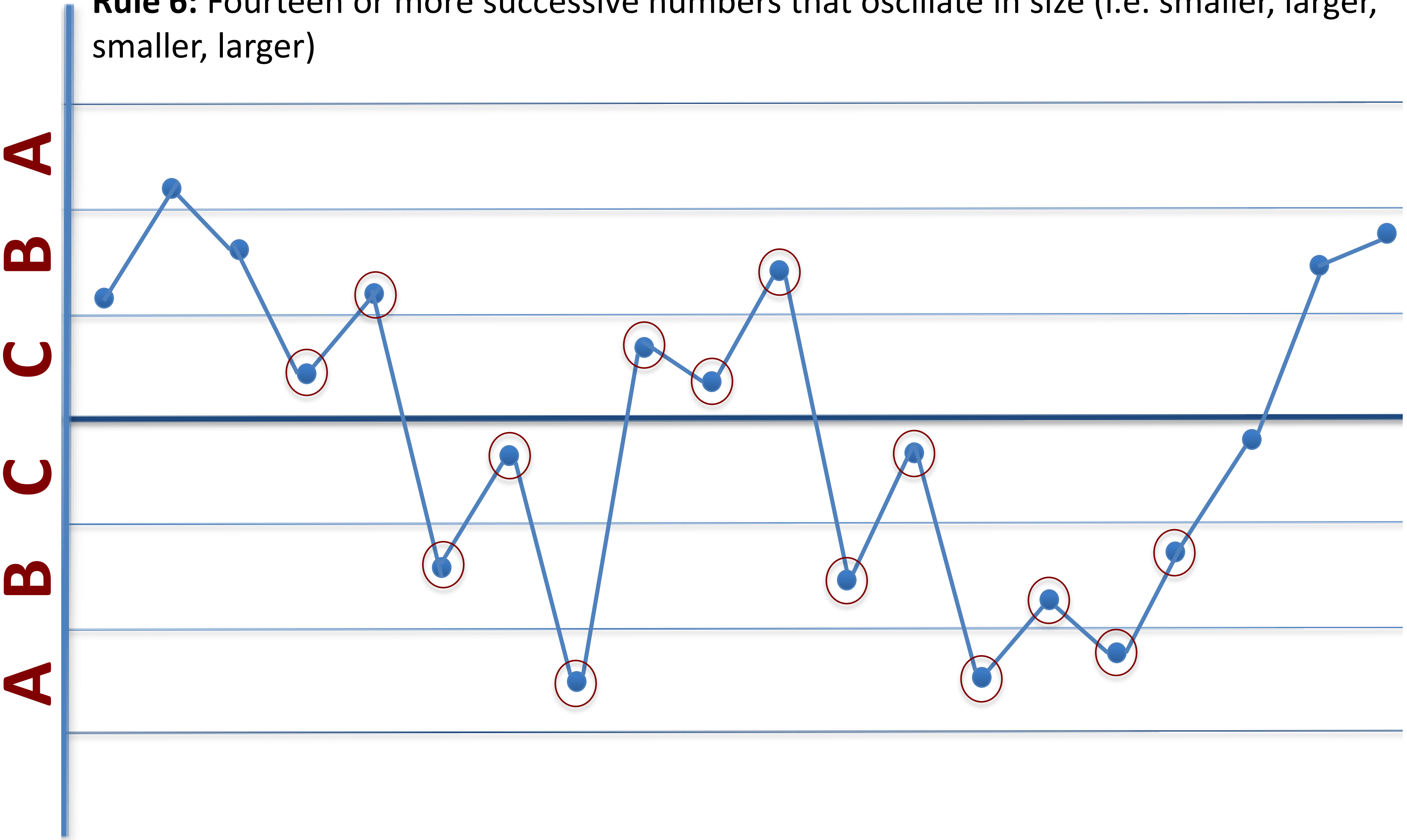
Shewhart Rules – Rule #5



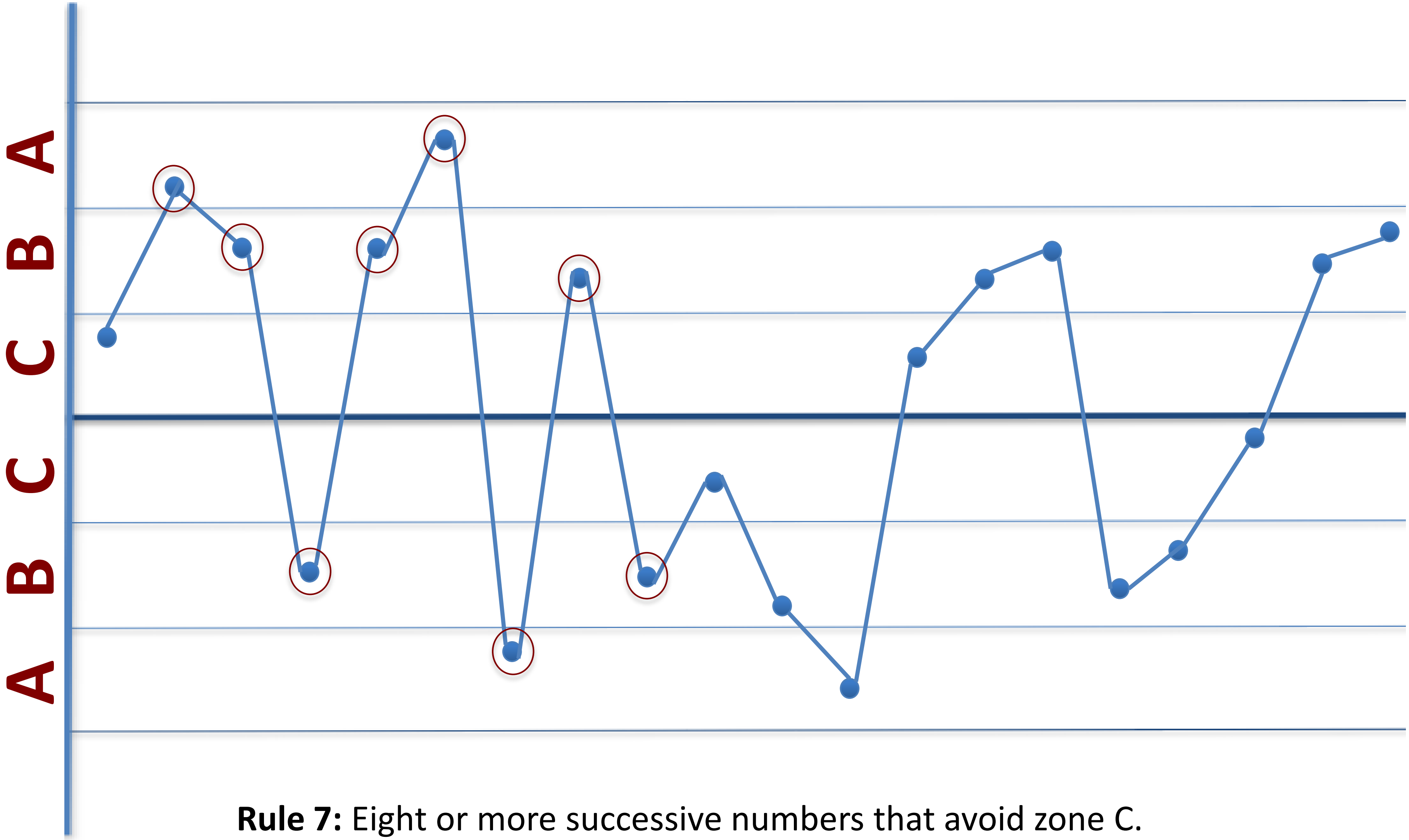
Rule 5: Six or more successive numbers showing a continuous increase or continuous decrease.

Shewhart Rules – Rule #6

Rule 6: Fourteen or more successive numbers that oscillate in size (i.e. smaller, larger, smaller, larger)



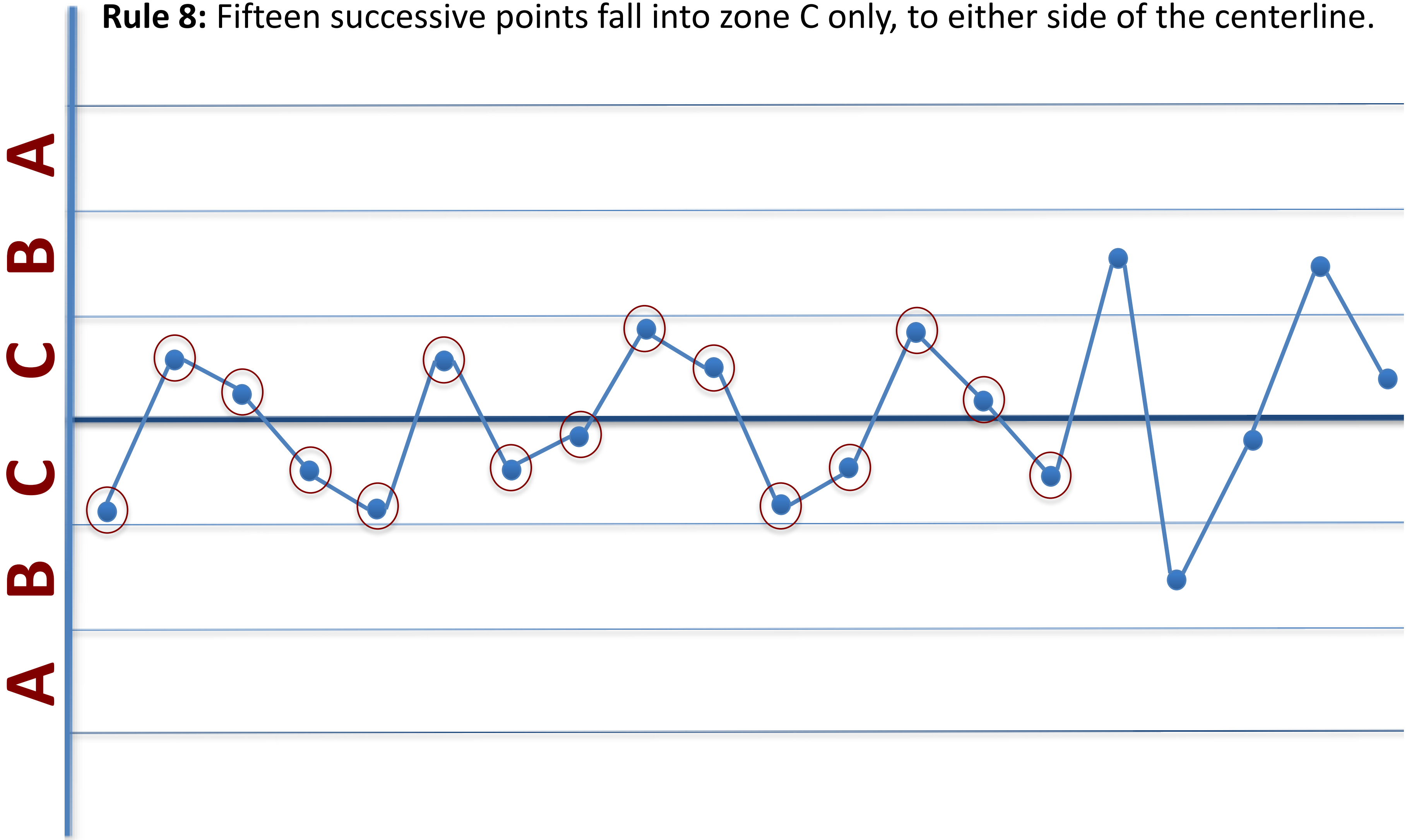
Shewhart Rules – Rule #7



Rule 7: Eight or more successive numbers that avoid zone C.

Shewhart Rules – Rule #8

Rule 8: Fifteen successive points fall into zone C only, to either side of the centerline.

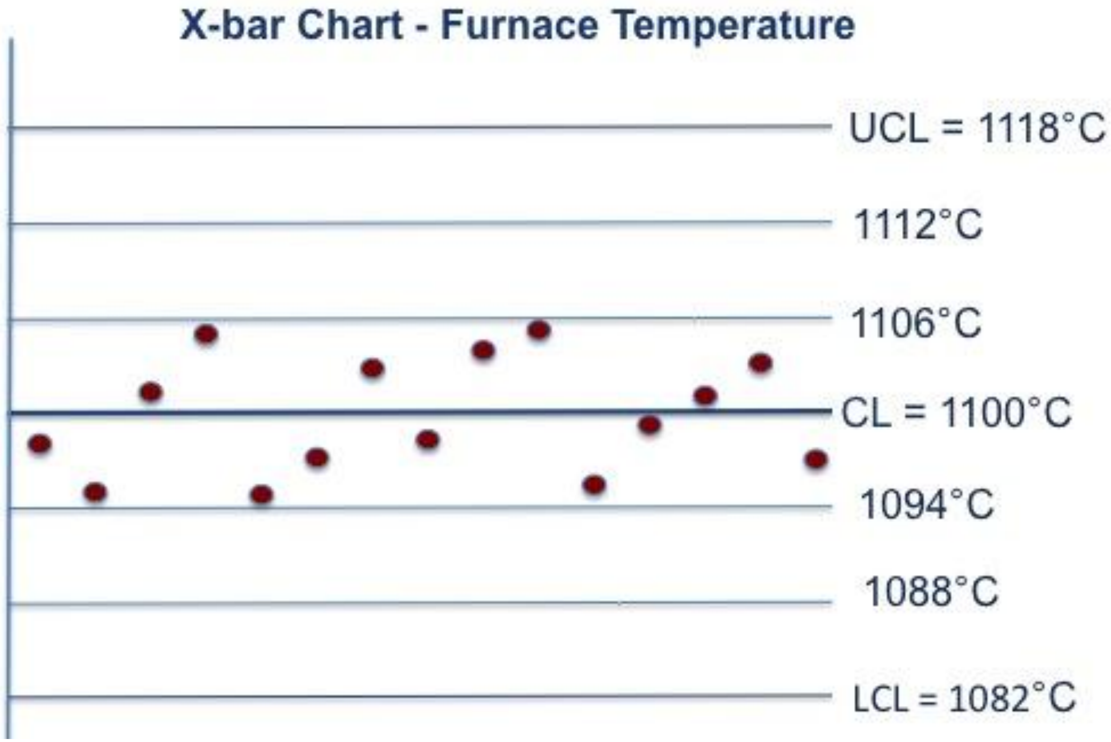


Type I and Type II Errors

- 2 Types of Errors: Type I and Type II
- Type I – False Alarm
    - Decision rules lead you to decide that special cause variation is present when in fact it is *not* present.
- Type II – Miss
    - Decision rules lead you *not* to decide that special cause variation is present when in fact it is present.

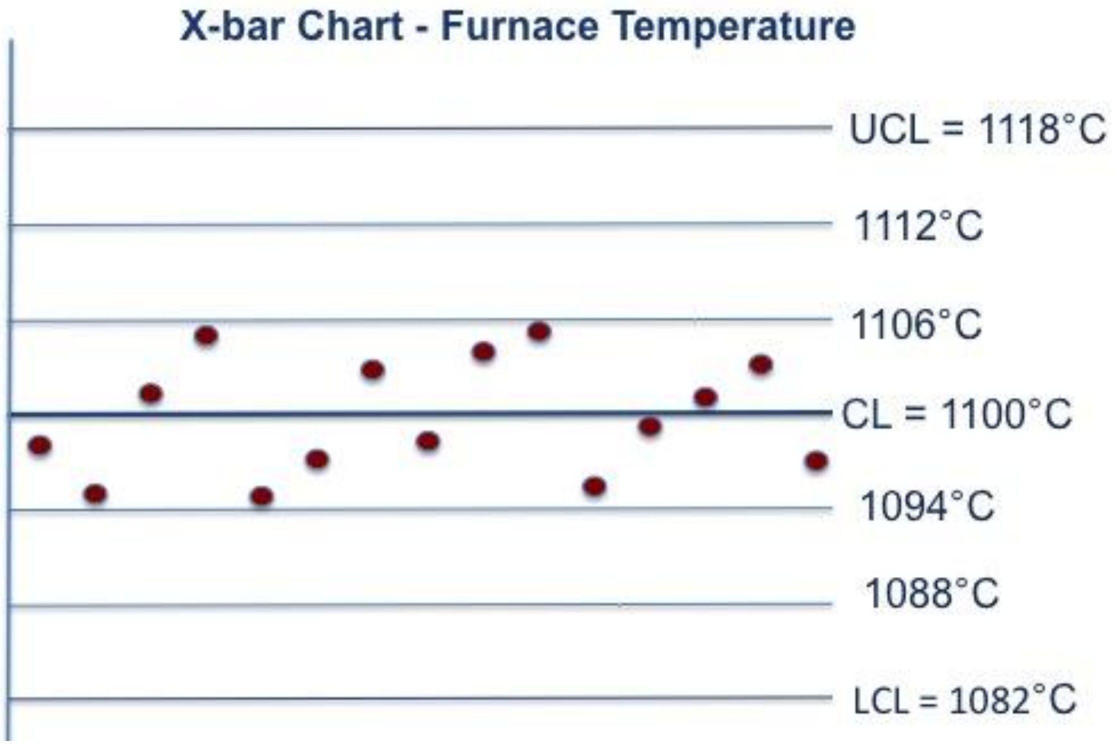
Question: Let’s test the rules

Rule 1: A single point outside the *μ±3σ* zone.
Rule 2: Two out of three successive points outside *μ±2σ* zone.
Rule 3: Four out of five successive points outside *μ±1σ* zone.
Rule 4: 8 or more successive numbers either strictly above or strictly below the mean.
Rule 5: 6 or more successive numbers showing a continuous increase or continuous decrease.
Rule 6: 14 or more successive numbers that oscillate in size (i.e. smaller, larger, smaller, larger)
Rule 7: 8 or more successive numbers that avoid *μ±1σ* zone.
Rule 8: 15 successive points fall into *μ±1σ* zone only, to either side of the centerline or target.



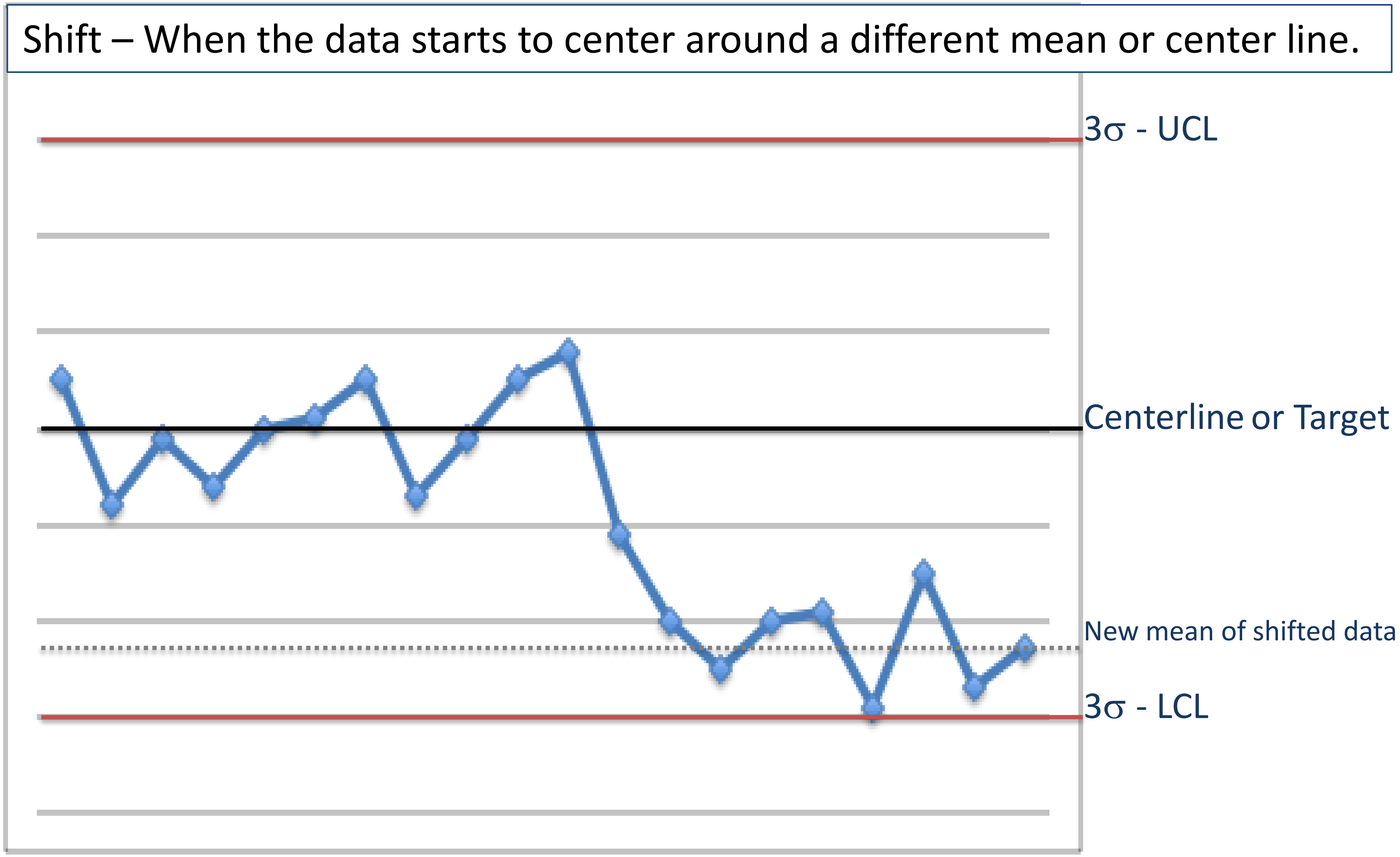
Question: Let’s test the rules

Rule 1: A single point outside the *μ±3σ* zone.
Rule 2: Two out of three successive points outside *μ±2σ* zone.
Rule 3: Four out of five successive points outside *μ±1σ* zone.
Rule 4: 8 or more successive numbers either strictly above or strictly below the mean.
Rule 6: 14 or more successive numbers that oscillate in size (i.e. smaller, larger, smaller, larger)
Rule 7: 8 or more successive numbers that avoid *μ±1σ* zone.
Rule 8: 15 successive points fall into *μ±1σ* zone only, to either side of the centerline or target.



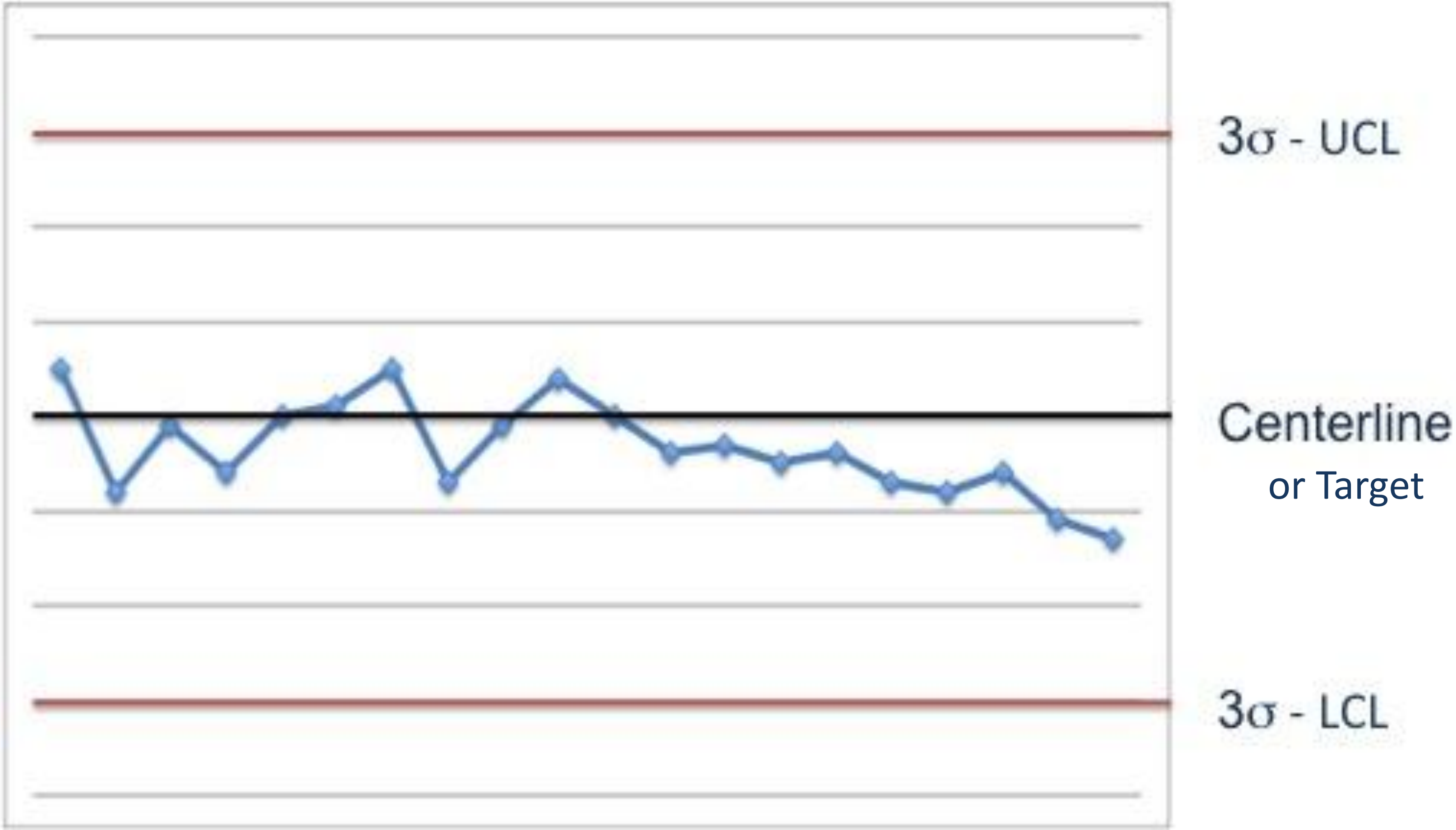
Process Changes - Shift

Shift – When the data starts to center around a different mean or center line.



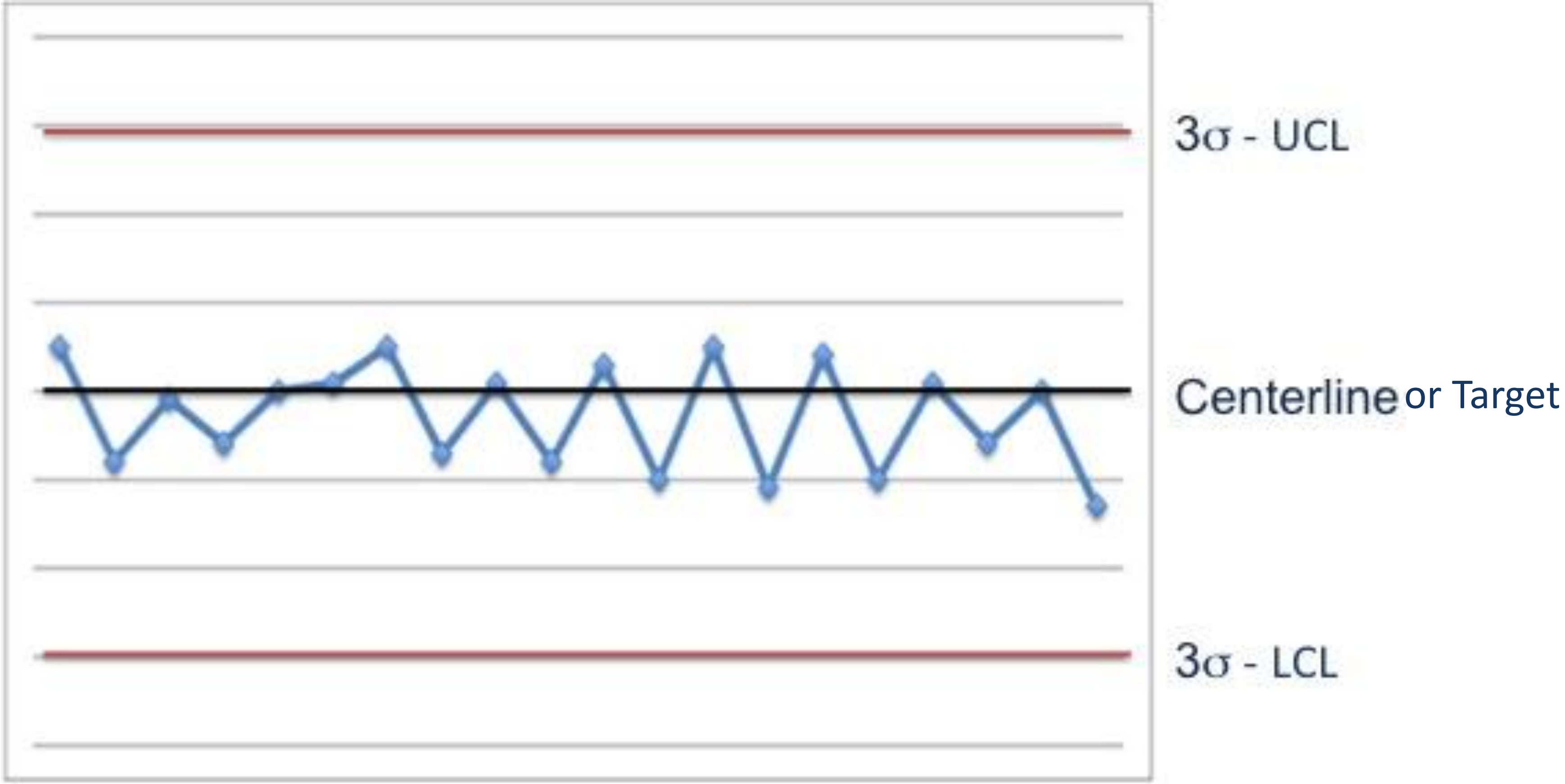
Process Changes - Trend

Trend – When the process mean begins to gradually move in one direction.



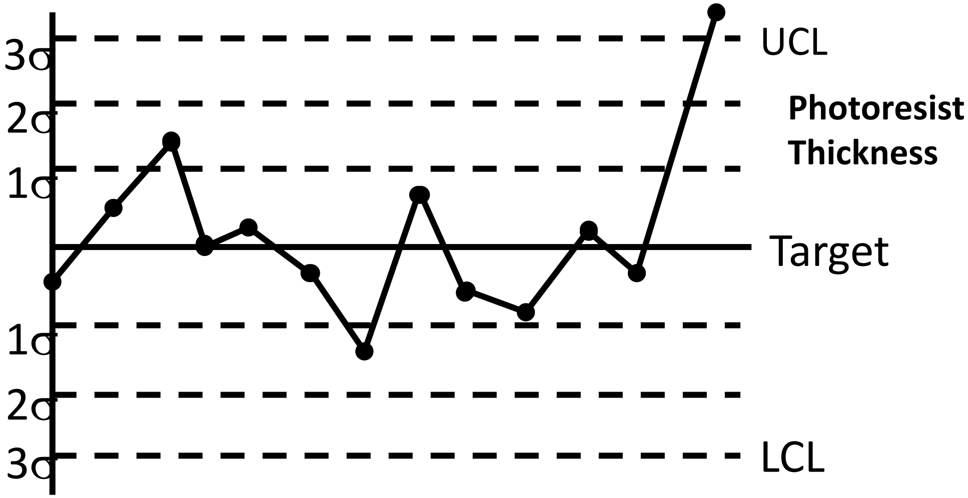
Process Changes - Cycle

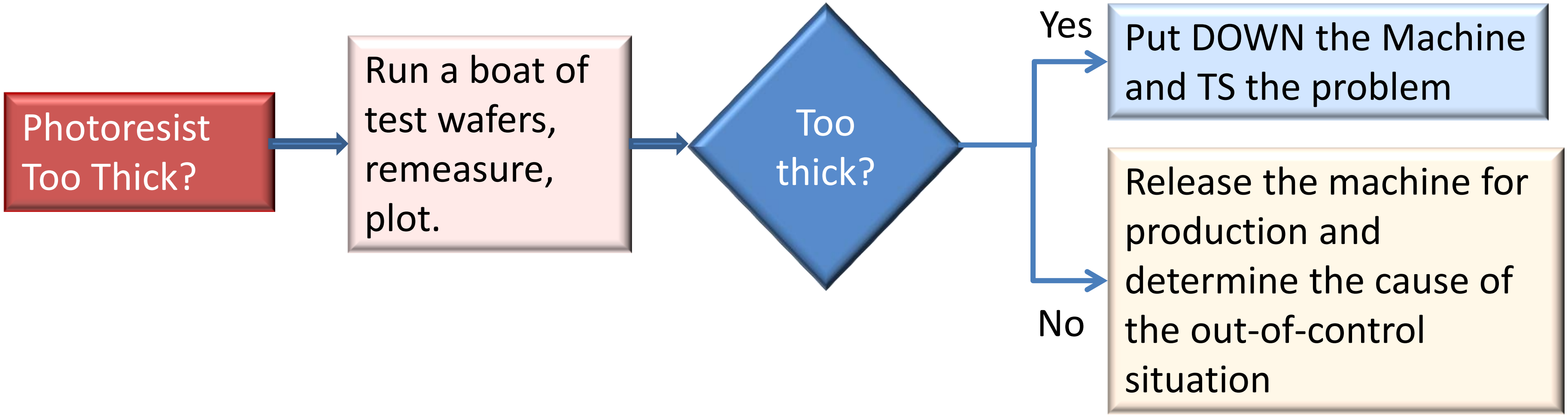
Cycle – When the data begins to increase or decrease in a cyclical or repetitive manner.



Out of Control Action Plan - OCAP

You are a technician in the photolithography aisle of a local MEMS fabrication facility. After randomly testing several wafers from the last processing batch and plotting the data on a control chart, you identify an out-of-control situation with resist thickness.





Photoresist Too Thick?

Run a boat of test wafers, remeasure, plot.

Too thick?

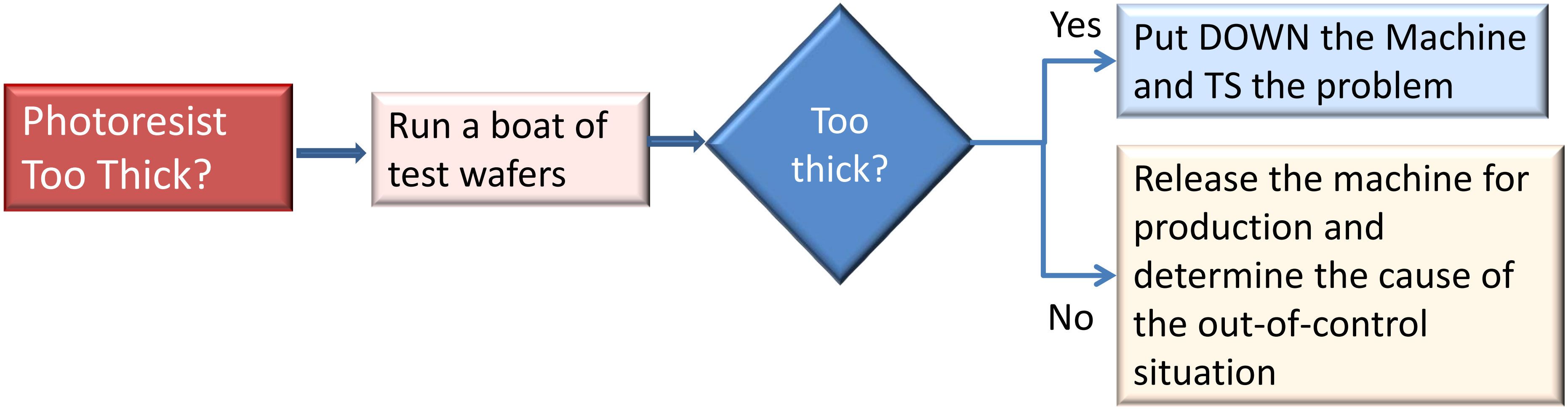
Yes

Put DOWN the Machine and TS the problem

No

Release the machine for production and determine the cause of the out-of-control situation

Out of Control Action Plan - OOCAP



Photoresist Too Thick?

Run a boat of test wafers

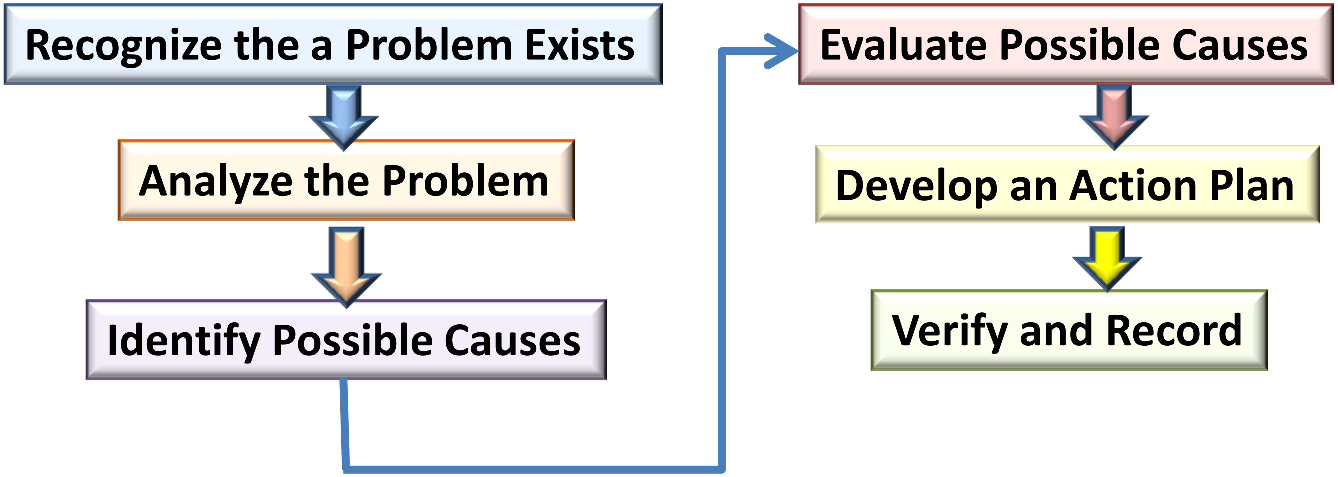
Too thick?

Yes

Put DOWN the Machine and TS the problem

No

Release the machine for production and determine the cause of the out-of-control situation



Recognize the a Problem Exists

Analyze the Problem

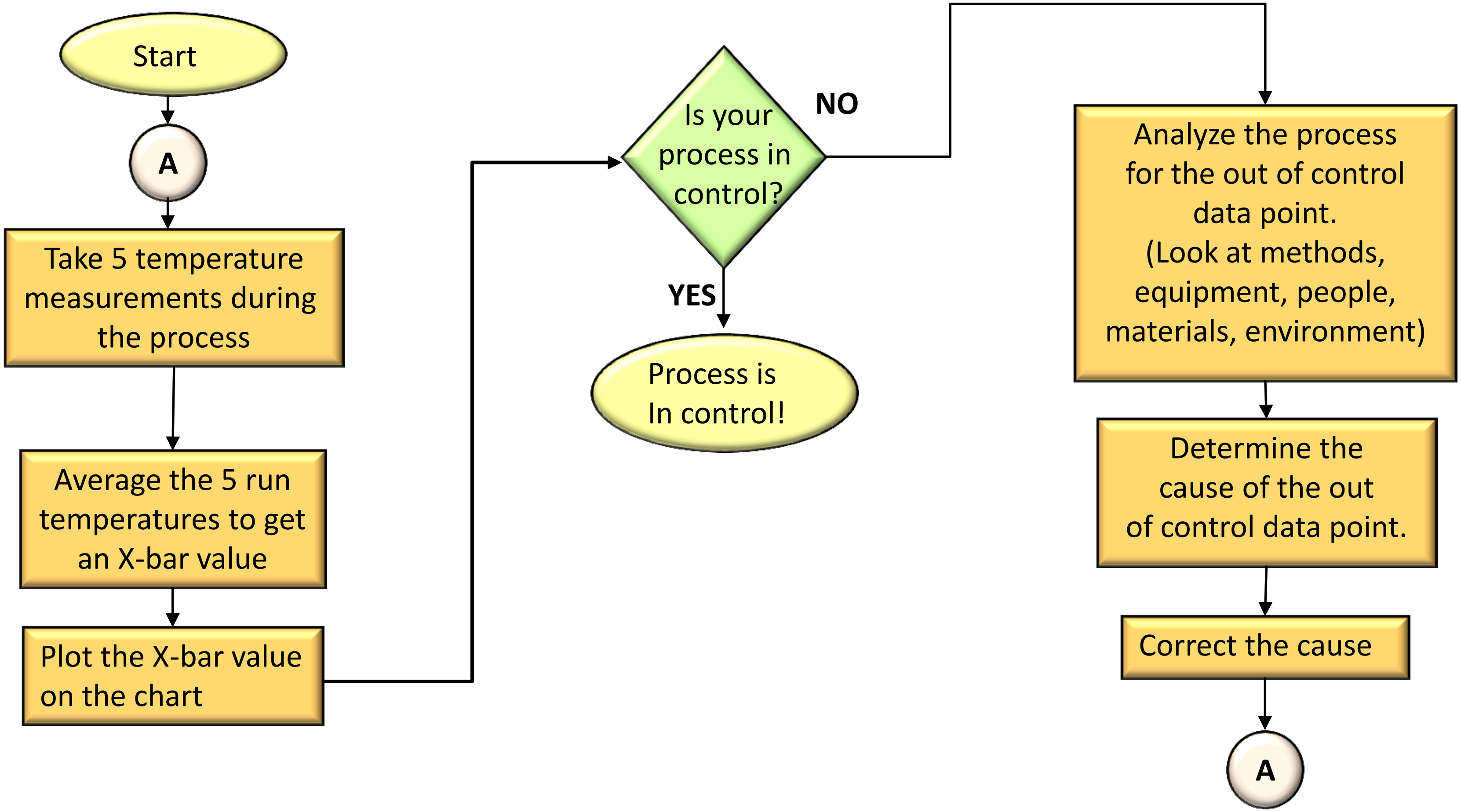
Identify Possible Causes

Evaluate Possible Causes

Develop an Action Plan

Verify and Record

Data Collection/Analysis Plan


Start

A

Take 5 temperature measurements during the process

Average the 5 run temperatures to get an X-bar value

Plot the X-bar value on the chart

Is your process in control?

YES

Process is In control!

NO

Analyze the process for the out of control data point.
(Look at methods, equipment, people, materials, environment)

Determine the cause of the out of control data point.

Correct the cause

A

Control Limits are NOT Specification Limits

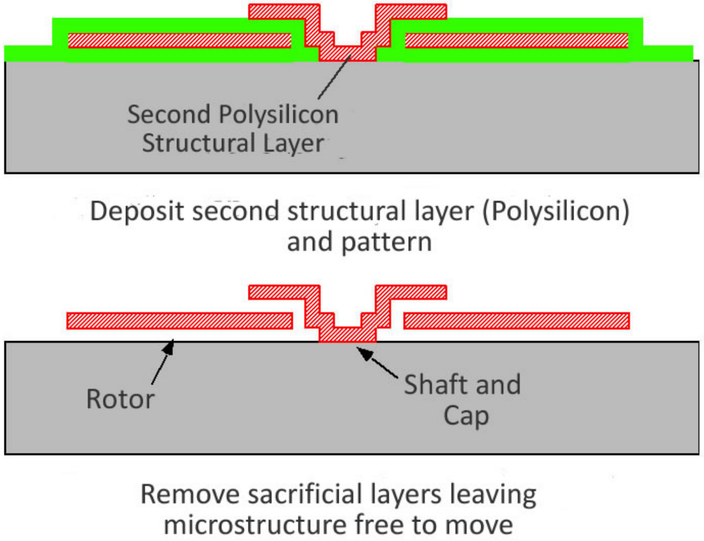
- Control Chart Centerline
  - Derived from real-time process data
- Control Limits
  - Derived from real-time process data

- Specification Limits (Spec Limits)
  - Boundaries that a product is acceptable or *not* acceptable

- Just because a process is in statistical control does not mean it is always within spec and vise versa
- SPC has to do with process predictability
- Process Specification Limits have to do with the process capability
- General Rule: Do not put Specification Limits in a control chart!

EXAMPLE – SiO_2 Growth

- Silicon Dioxide Growth for a Sacrificial Layer on a MEMS device
- Specification states that the Average Run Temperature ($\bar{X}$) should be 1000°C ± 10°C



Deposit second structural layer (Polysilicon) and pattern

Remove sacrificial layers leaving microstructure free to move

Image courtesy of UNM MTTC

$\bar{X}$ -Chart for SiO_2 Growth

σ = 3.77 °C

$\mu + 3\sigma = 1004 + (3*3.77) = 1015°C$

$\mu - 3\sigma = 1004 + (3*3.77) = 993°C$

UCL

$\mu + 3\sigma = 1015°C$

Target = 1004°C

LCL

$\mu - 3\sigma = 993°C$

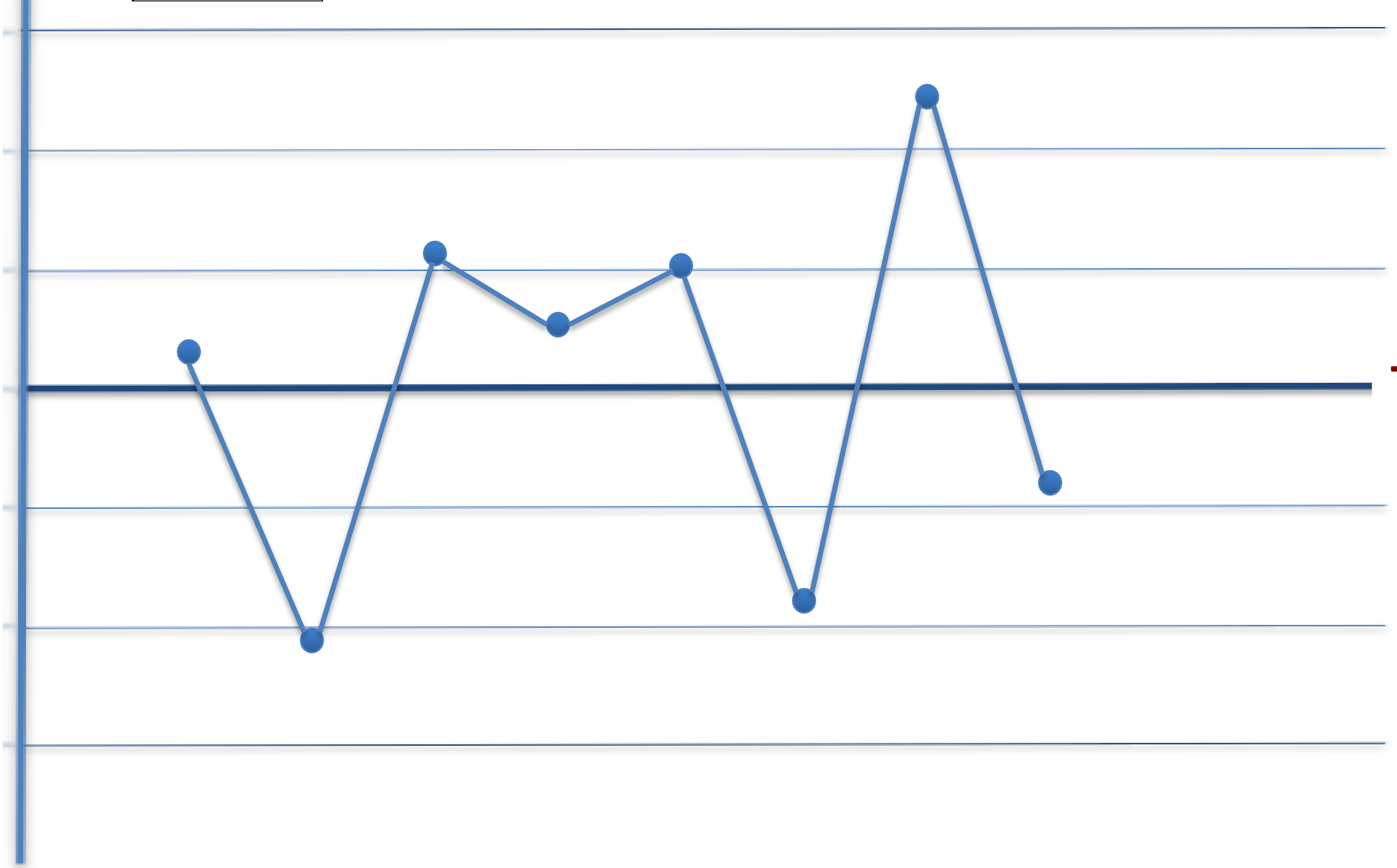
$\bar{X}$ -Chart for SiO_2 Growth

Management has determined that this process should be monitored for only the following 4 Shewhart Rules:

Rule 1: A single point outside the $\mu \pm 3\sigma$ zone.
Rule 2: Two out of three successive points outside $\mu \pm 2\sigma$ zone.
Rule 4: 8 or more successive numbers either strictly above or strictly below the mean.
Rule 5: 6 or more successive numbers showing a continuous increase or continuous decrease.

$\bar{X}$ -Chart for SiO_2 Growth

Run #9
992
989
987
994
990



UCL

$\mu + 3\sigma =$ 1015°C

Target = 1004°C

LCL

$\mu - 3\sigma =$ 993°C

$\bar{X}$ -Chart for SiO_2 Growth

Rule 1: A single point outside the *μ±3σ* zone.
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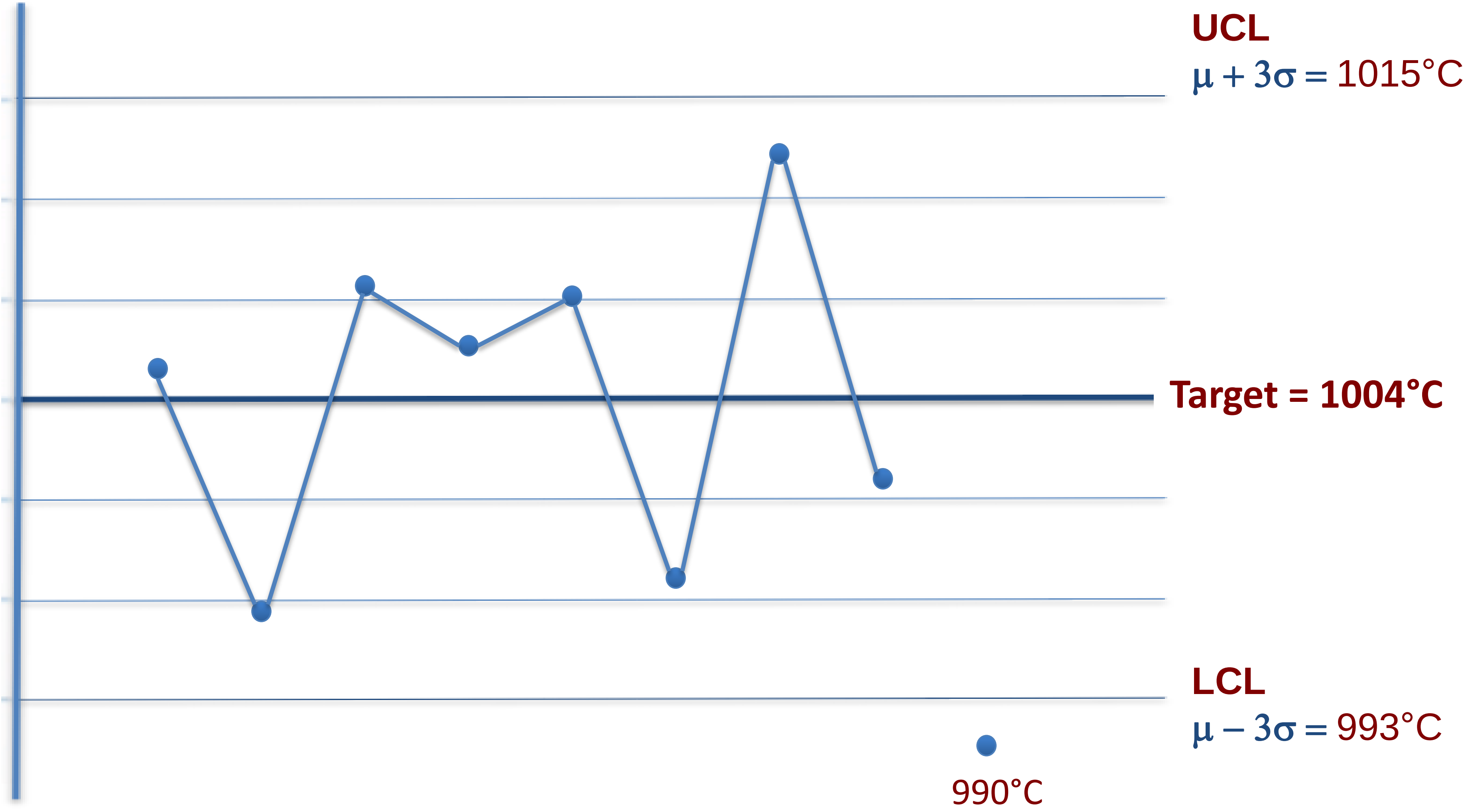

$\bar{X}$ -Chart for SiO_2 Growth

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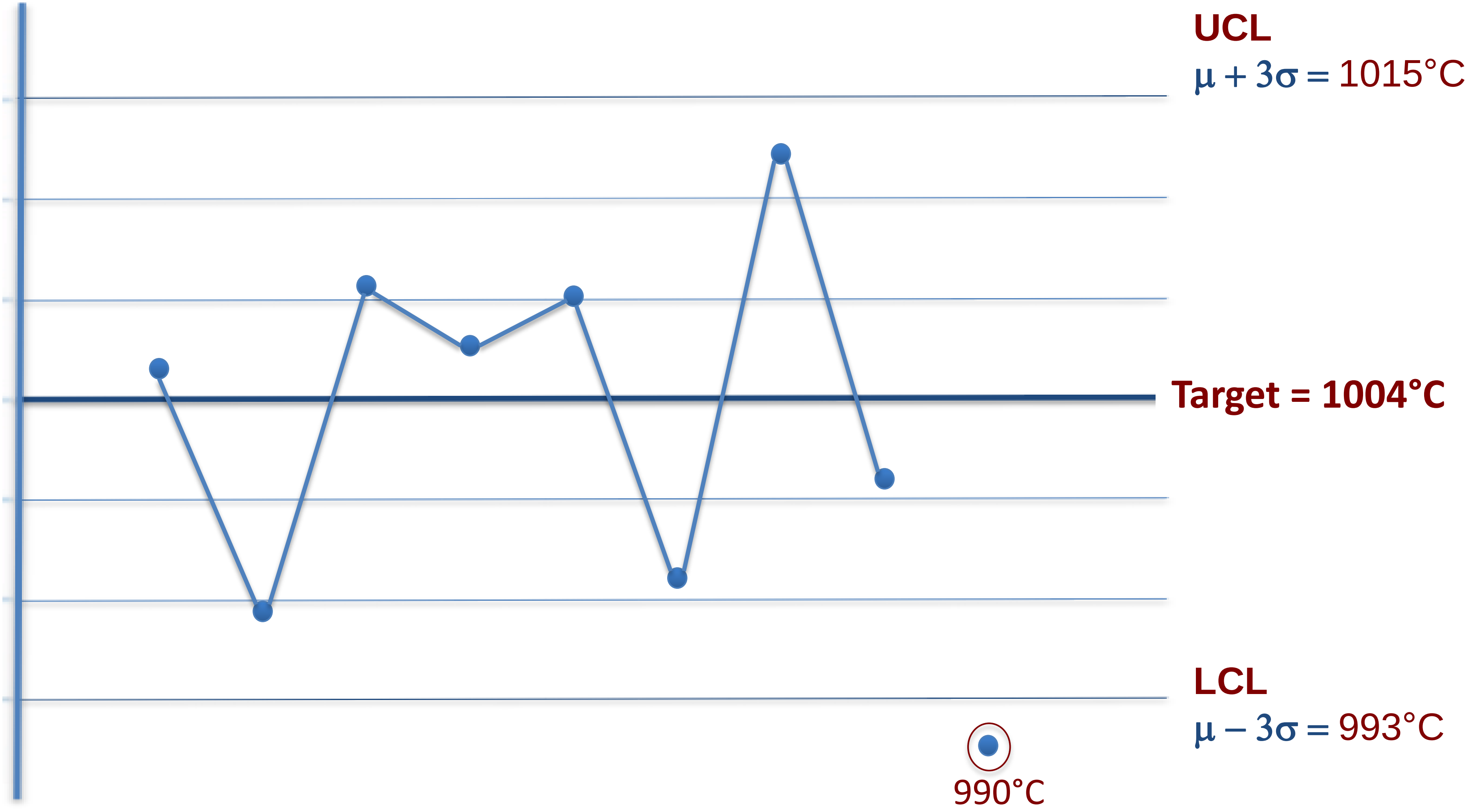

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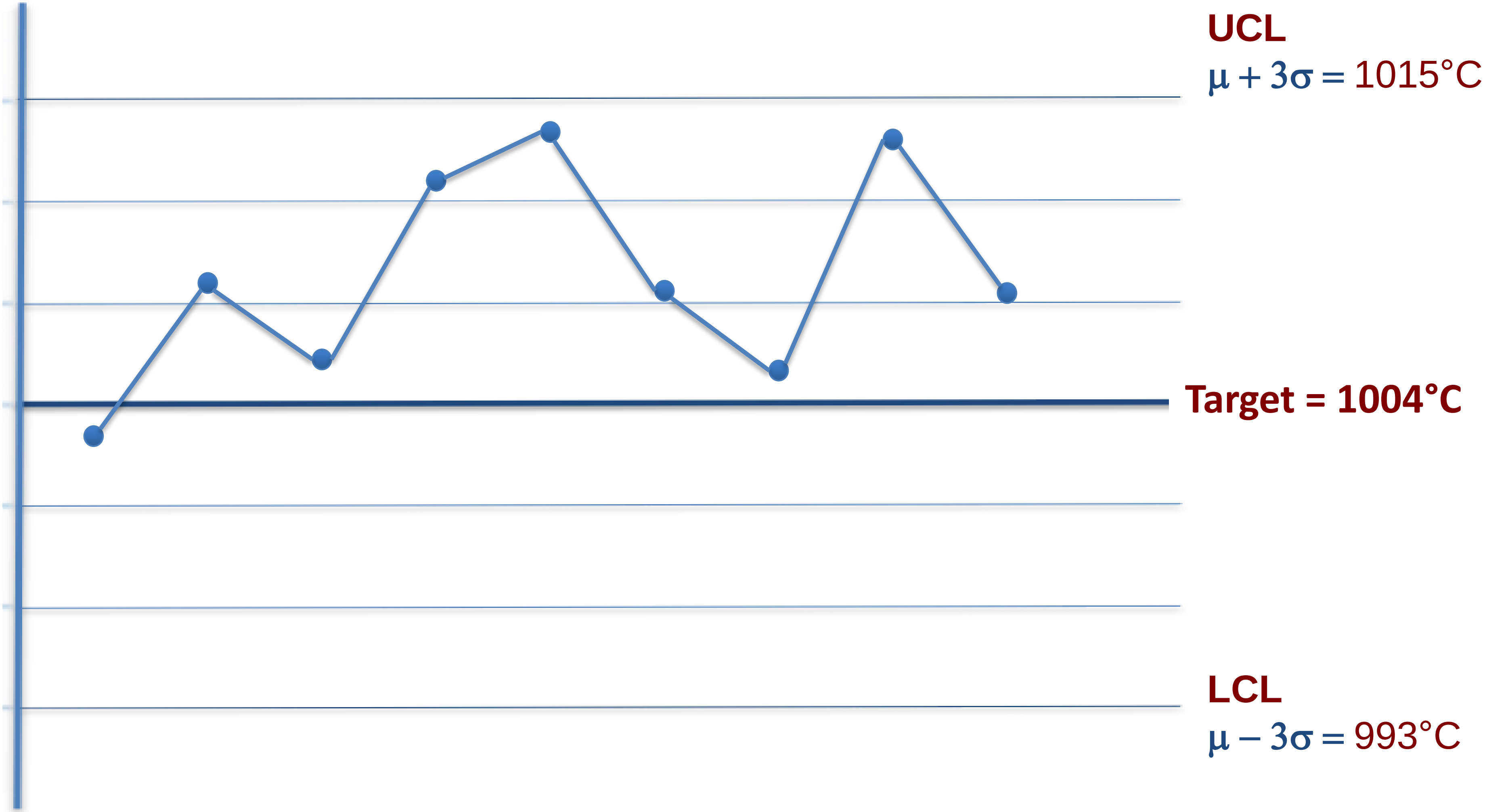

$\bar{X}$ -Chart for SiO_2 Growth

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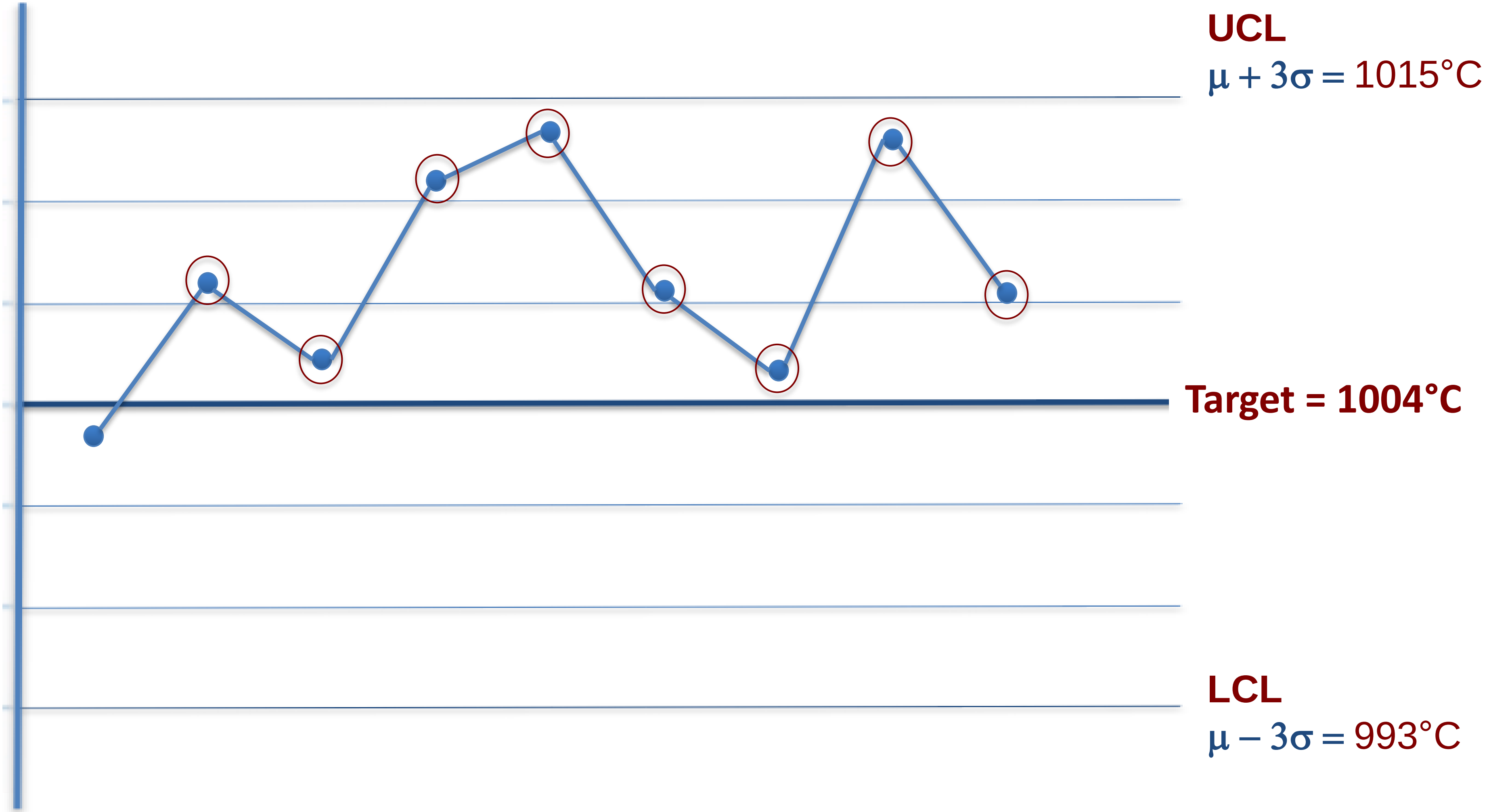

$\bar{X}$ -Chart for SiO_2 Growth

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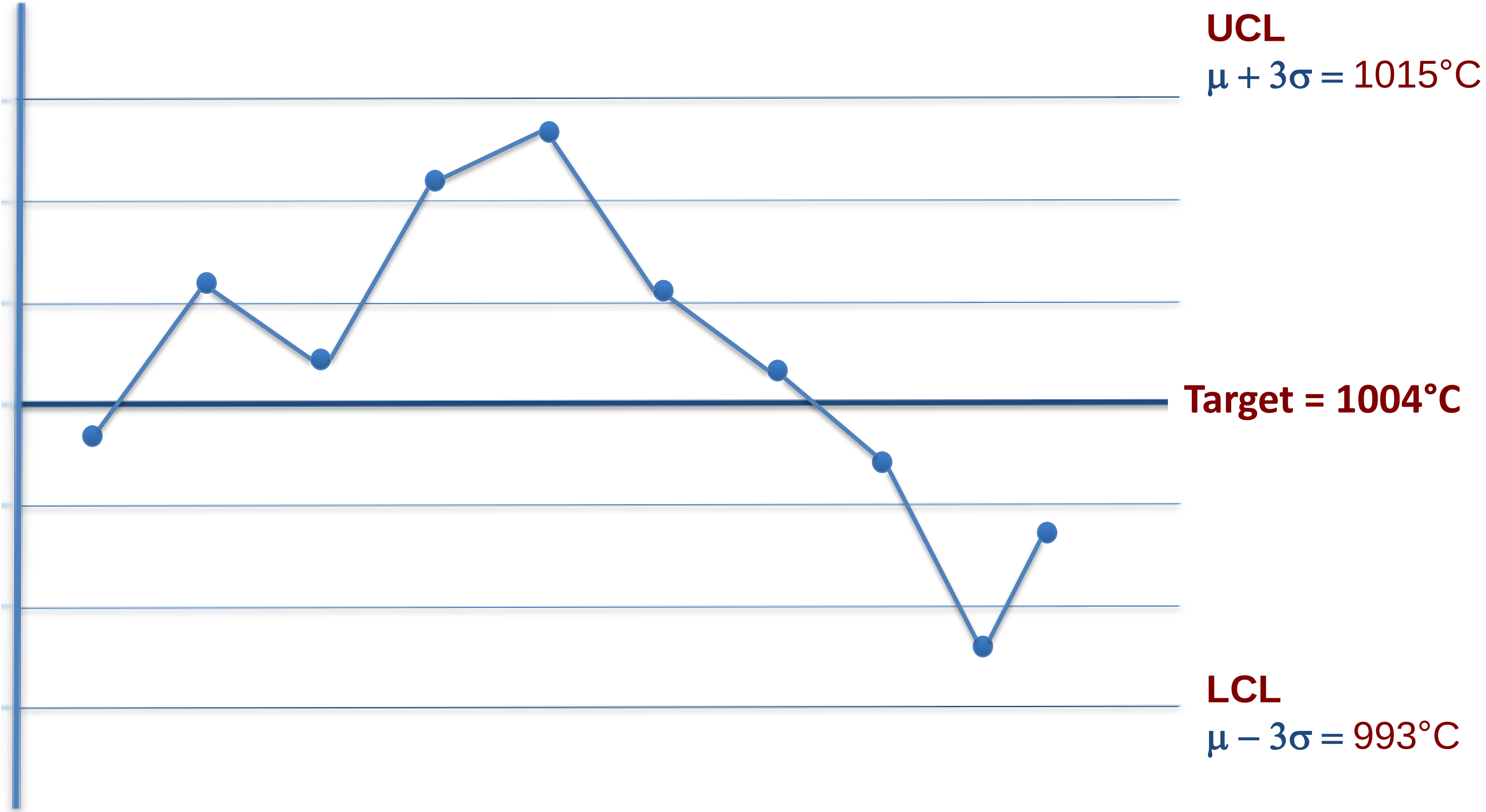

$\bar{X}$ -Chart for SiO_2 Growth

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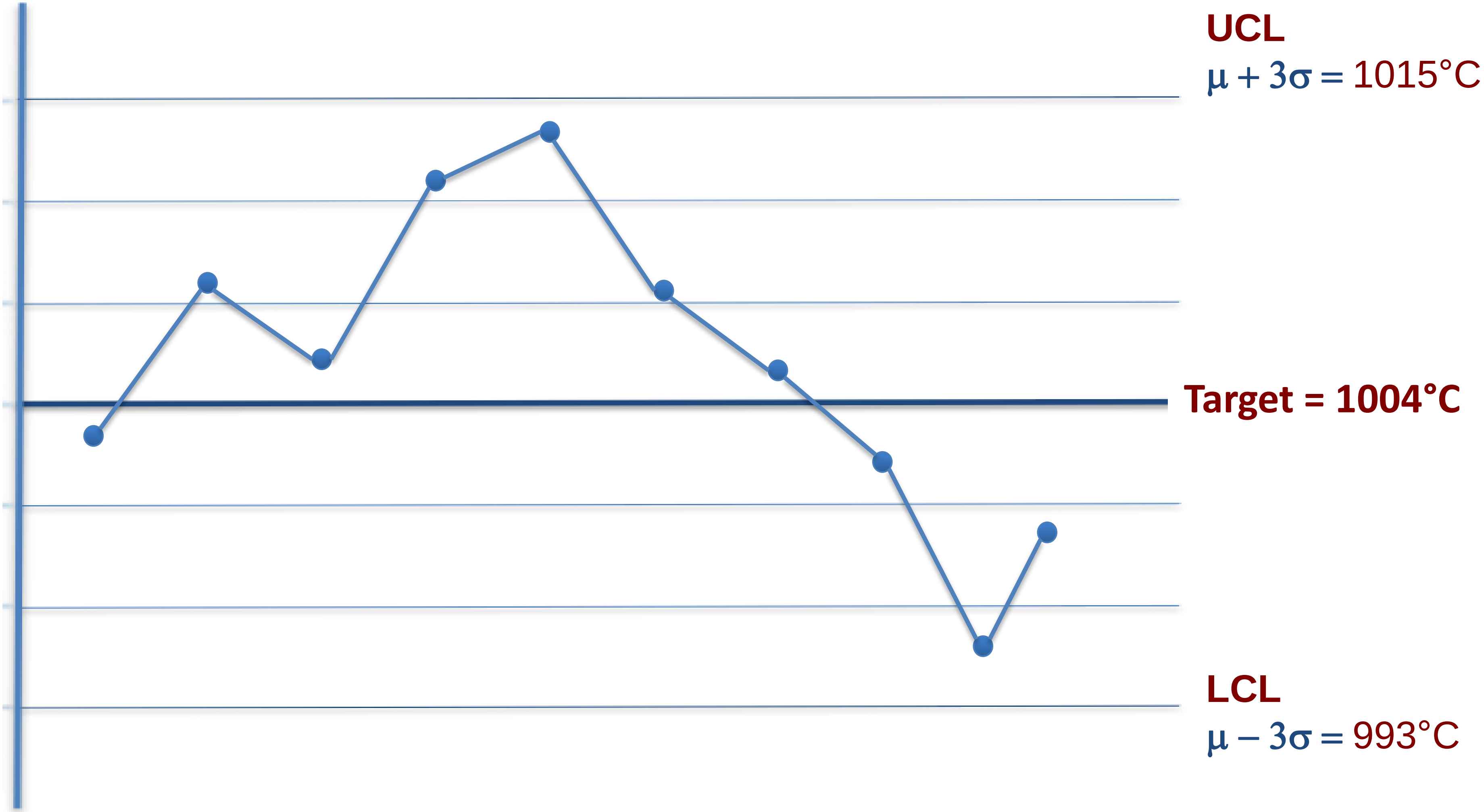
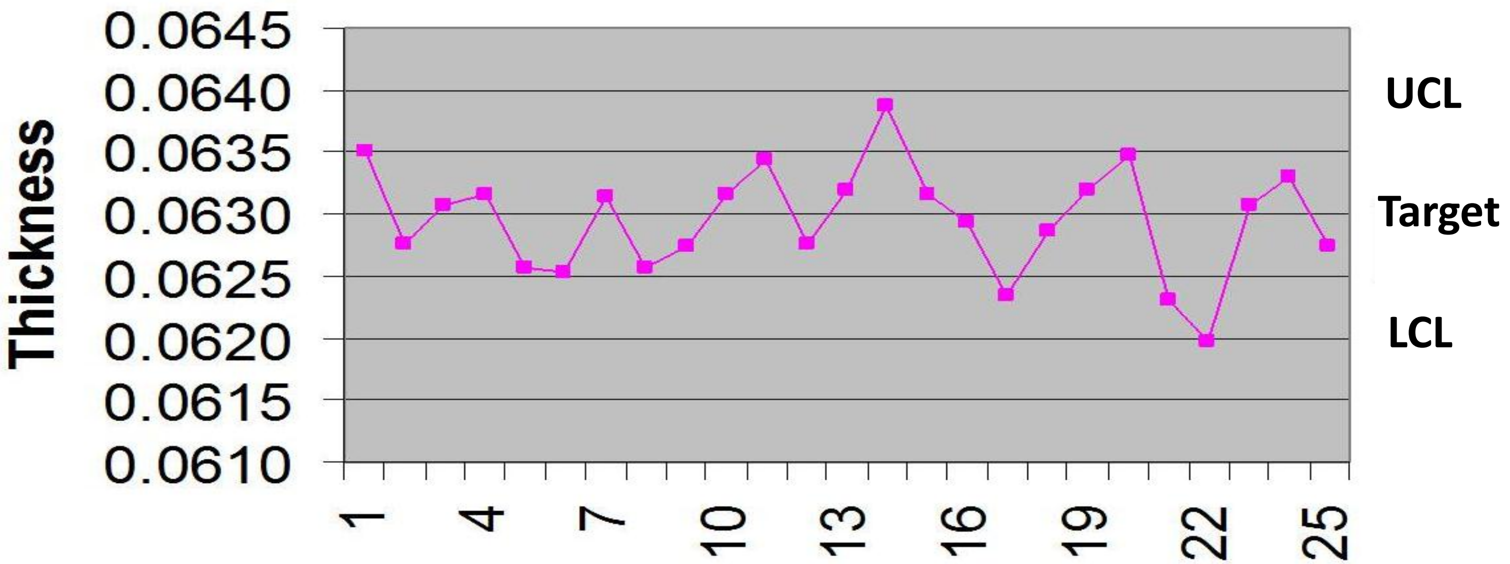
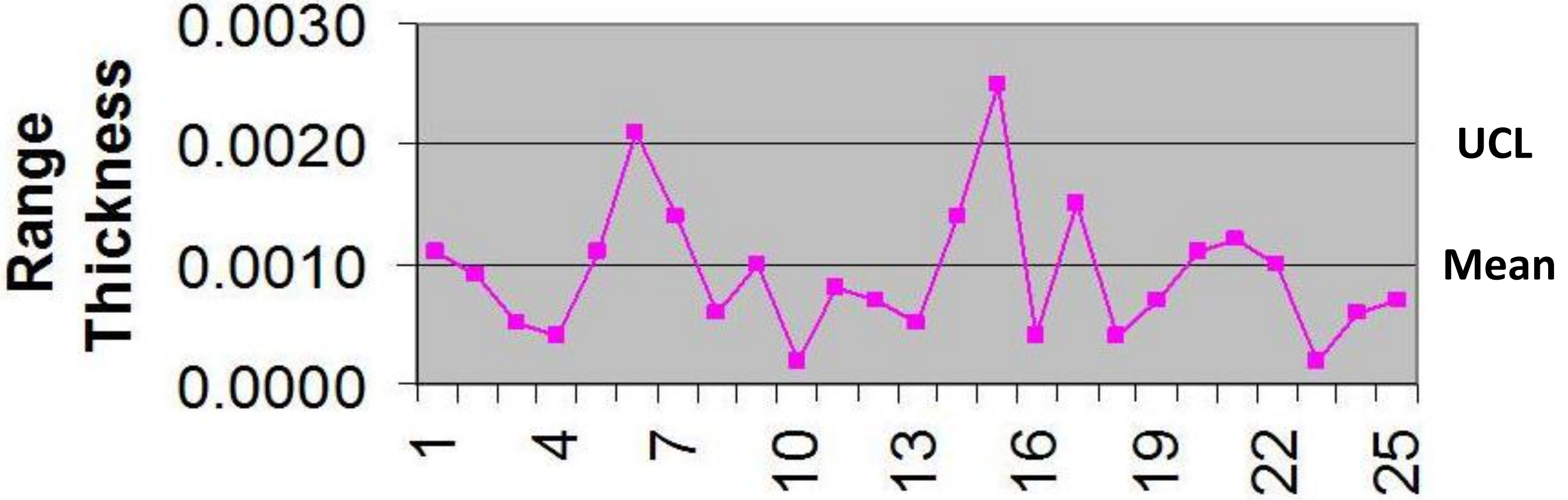


Other types of Charts

- $\overline{X}$ and R chart
- $\overline{X}$ and s chart
- p-Chart and np-chart (defectives)
- U and c charts (defects)
- Individuals Chart
- Exponentially Weighted Moving Average (EWMA) Chart

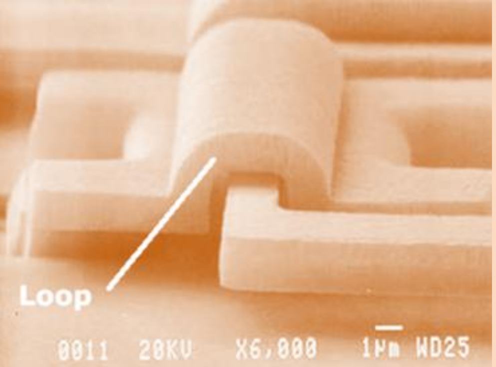
X-bar R charts for Film Thickness





Summary

- SPC is a statistical scientific method that provides valuable information about a process
- They type of variation (common and special cause) should be understood and controlled.
- Statistical Concepts used in SPC
  - Sample median
  - Sample mean – μ, $\overline{X}$, $\overline{\overline{X}}$
  - Sample range - R
  - Sample variance – σ^2
  - Sample standard deviation – σ
- Most process data follows a Normal Distribution
- Shewhart or Western Electric Rules can be used to determine if a process goes out of control



Thank You
For Joining Us

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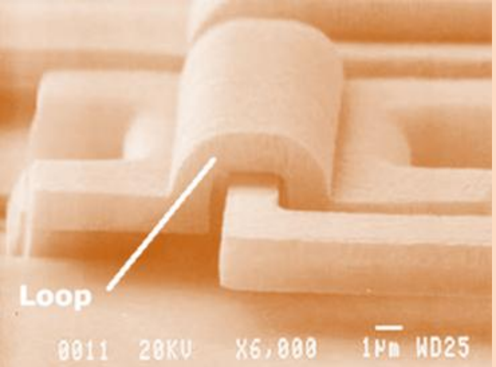
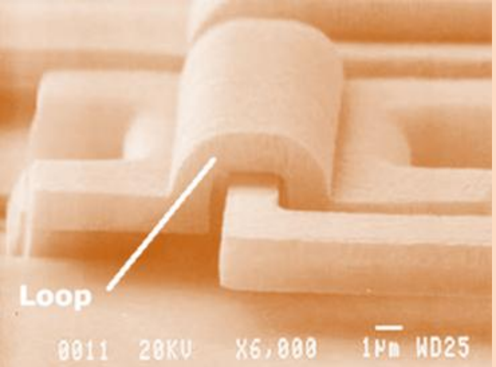


How Can We Serve You Better?

Please take 1 minute to provide your feedback and suggestions

https://www.surveymonkey.com/s/J9TVRSZ

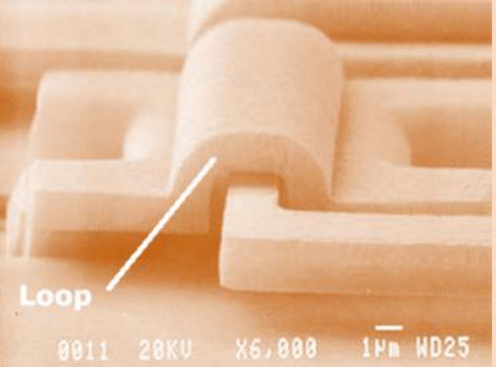


Webinar Resources

SCME
Southwest Center for Microsystems Education

To access this webinar recording, slides, and handout, please visit

www.scme-nm.org



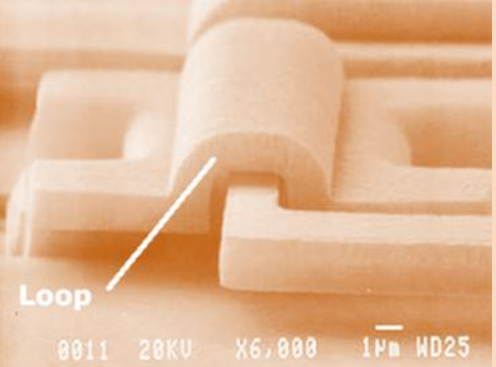
SCME Upcoming Webinars

SCME
Southwest Center for Microsystems Education

February 28, 2013: Design of Experiments for Technicians

March 28, 2013: Problem-solving Tools Applied to Microfabrication

All Webinars on Thursday @ 1 PM ET



It was Fun!

Thank you for attending this SCME Webinar

Problem Solving for Technicians