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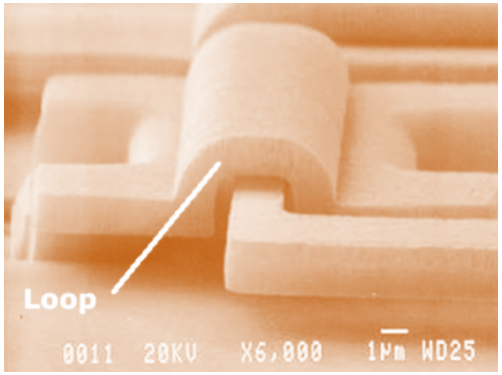

Control Chart Basics

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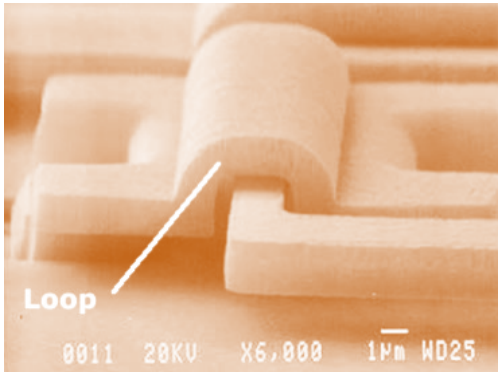

SCME is a National Science Foundation Advanced Technological Education (ATE) Support Center at the University of New Mexico.

We offer professional development and educational materials to excite and engage community college, university, and high school students and faculty in the field of Microsystems (Micro Electro Mechanical Systems, MEMS) technology.

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants #DUE 1205138 & 1700678 .

SEM of Loop and Hinge System Courtesy of Sandia National Laboratories

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Objectives

- Normal distribution and how it is significant in $\bar{X}$-charts
- $\bar{X}$-charts and how to create them
- Interpreting Control Charts by applying the Shewhart rules

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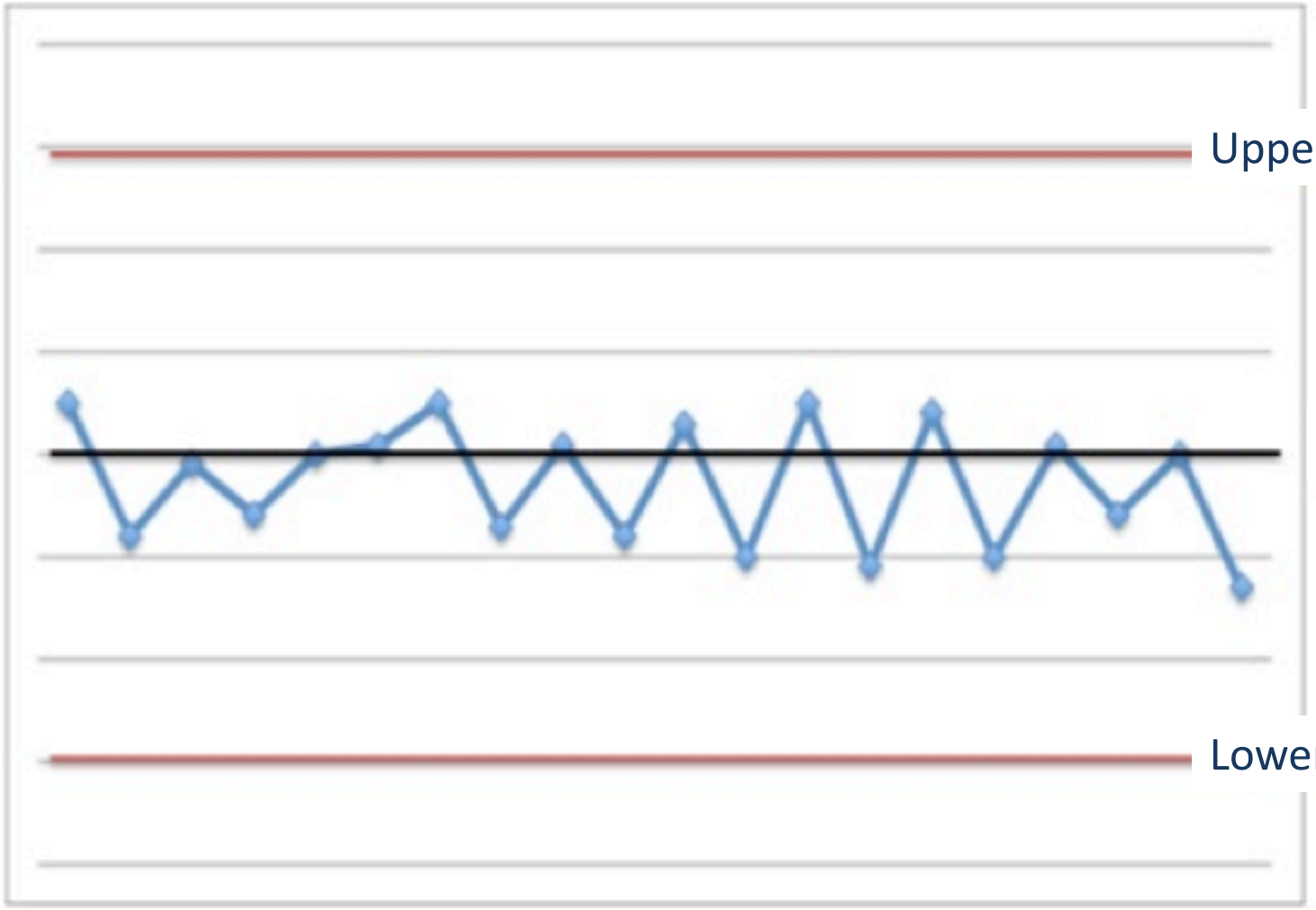
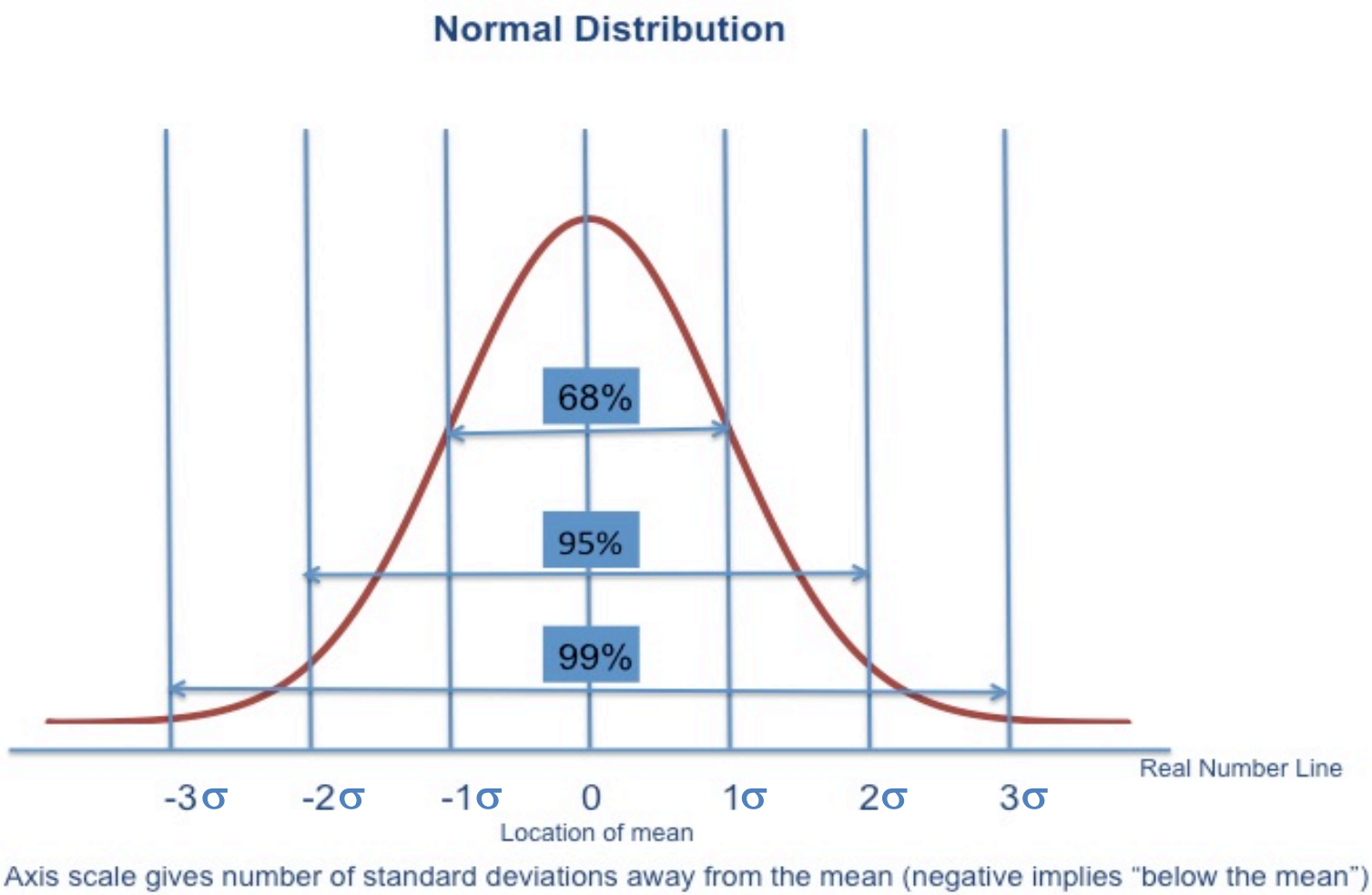
Let's Have Fun with Control Charts!

$\overline{X}$-Chart



Normal Distribution
Yes, it does matter



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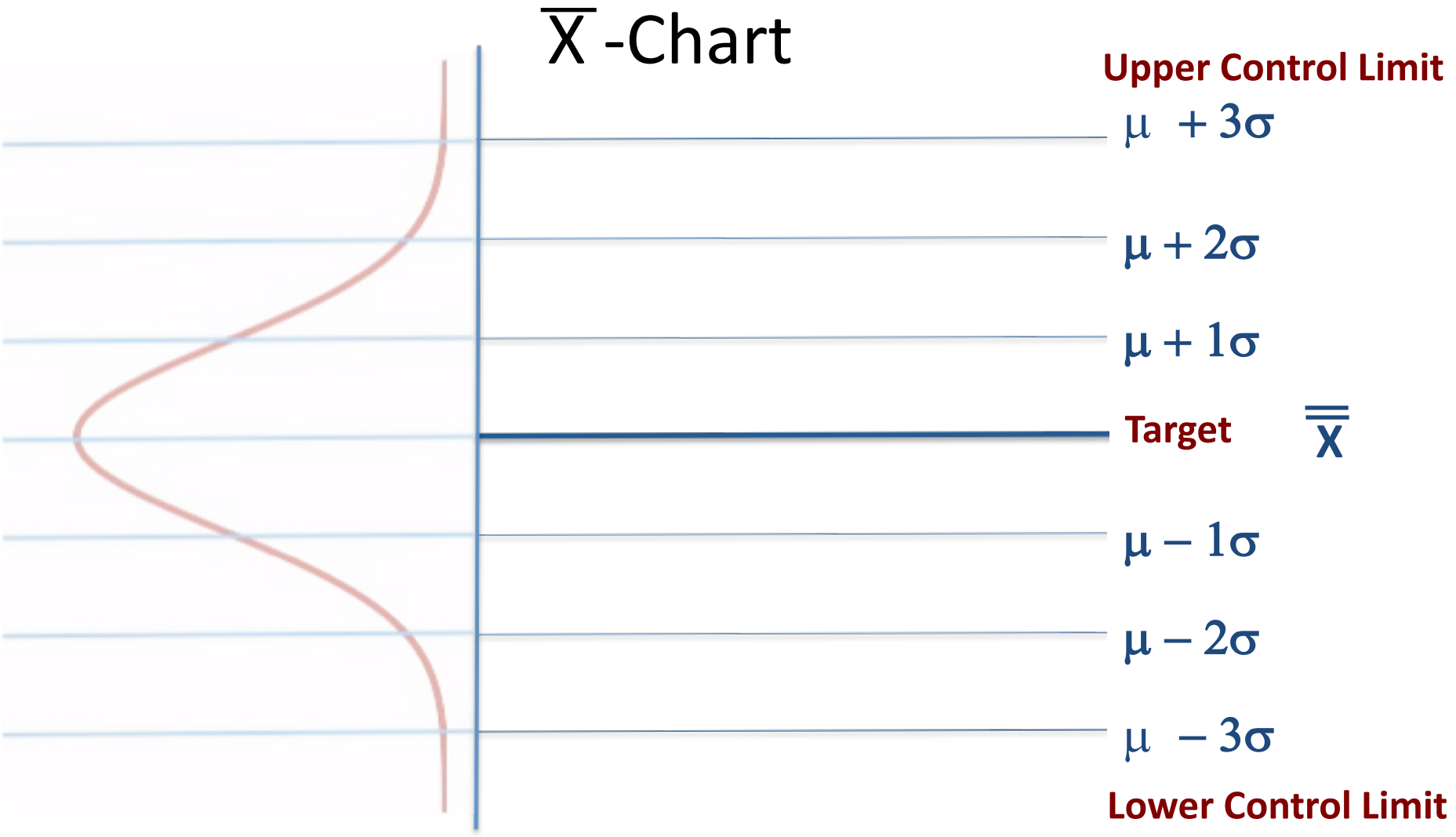
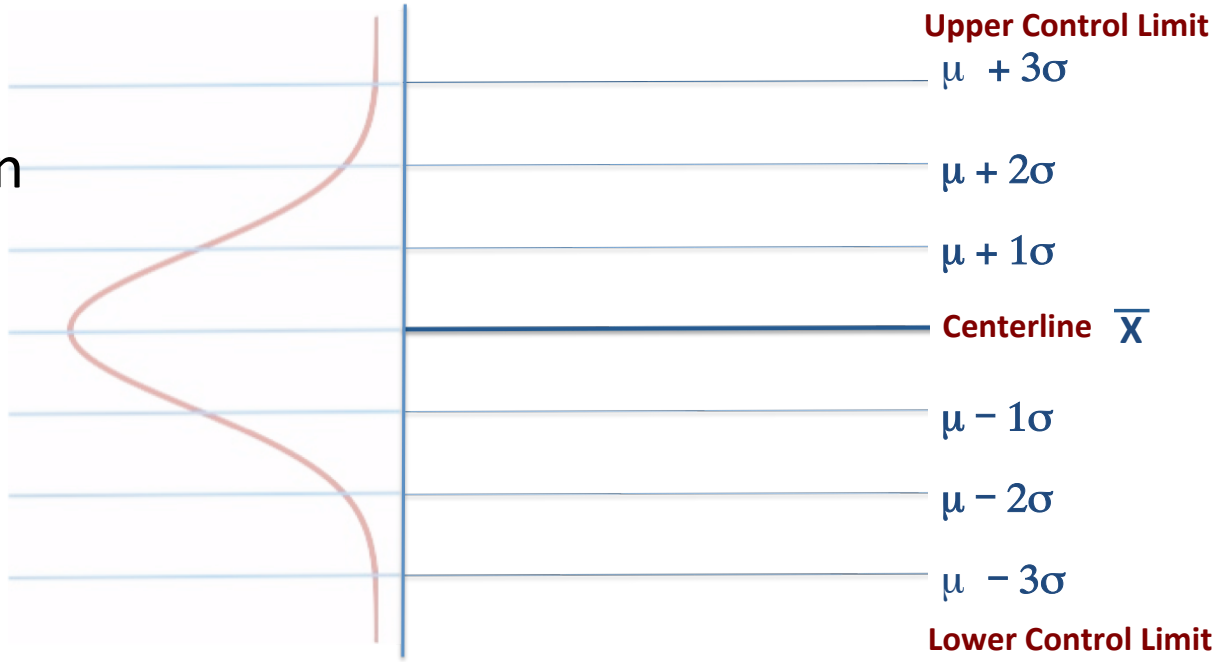
Control Chart Basics



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



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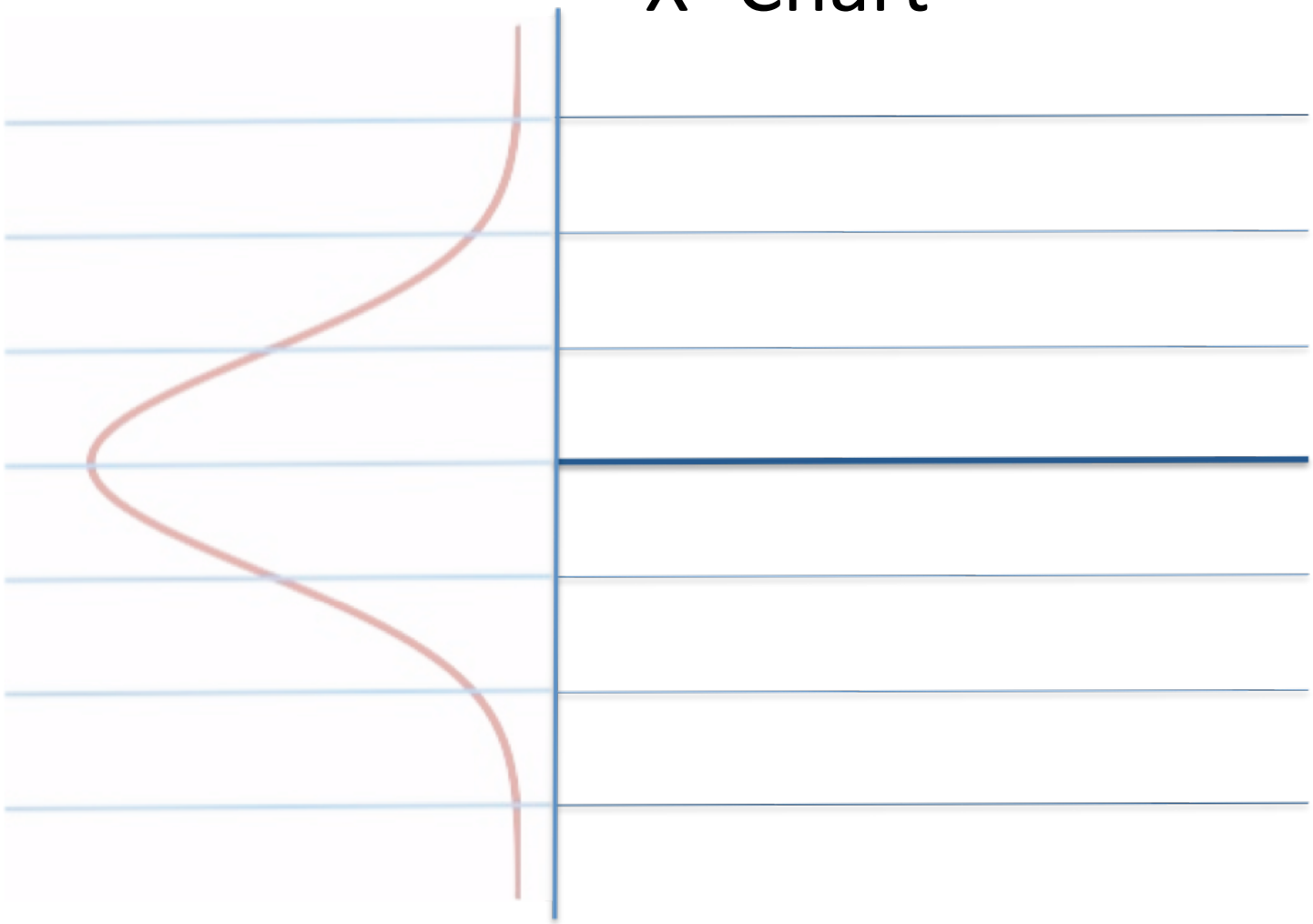
Control Chart Basics

$\overline{X}$-Chart



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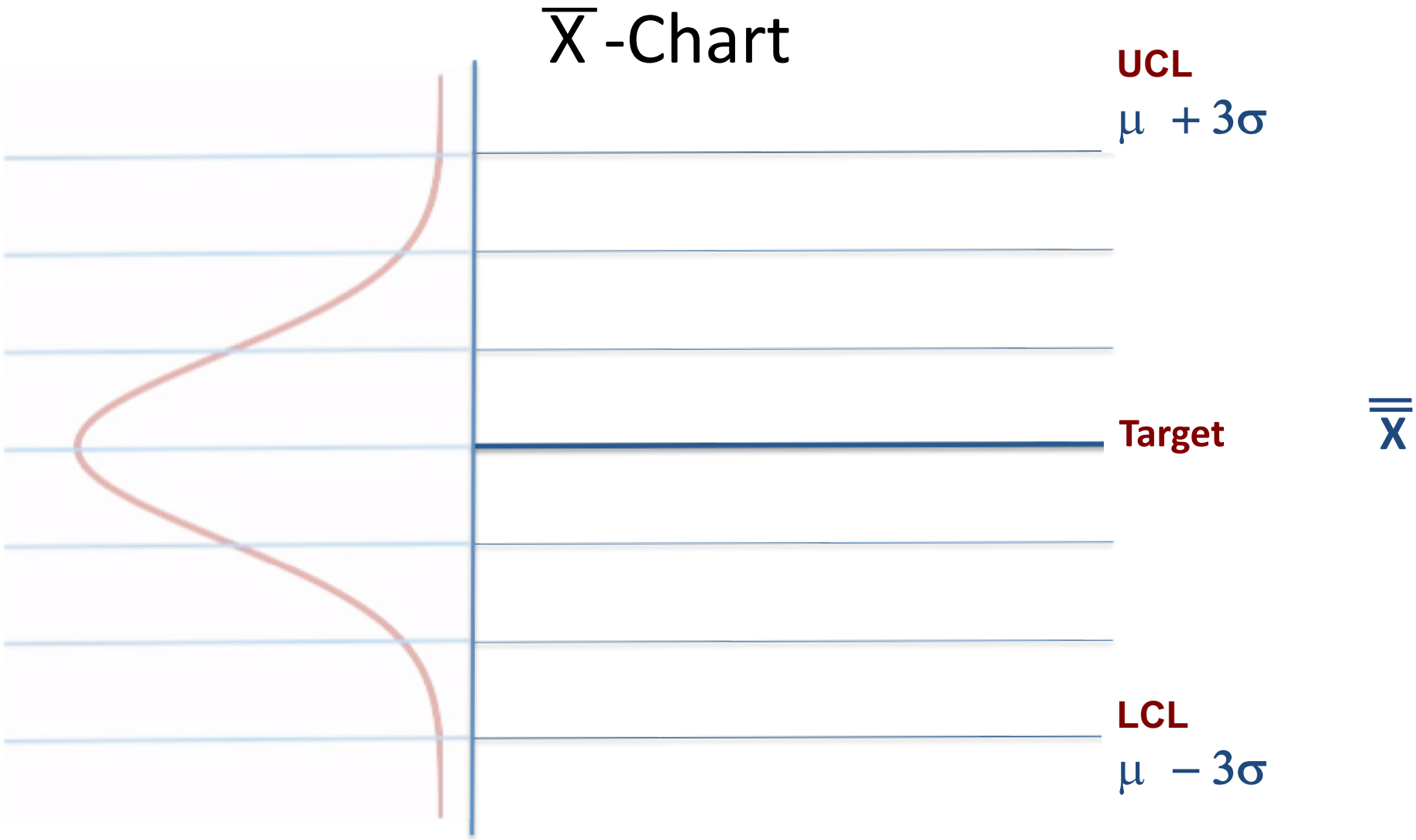

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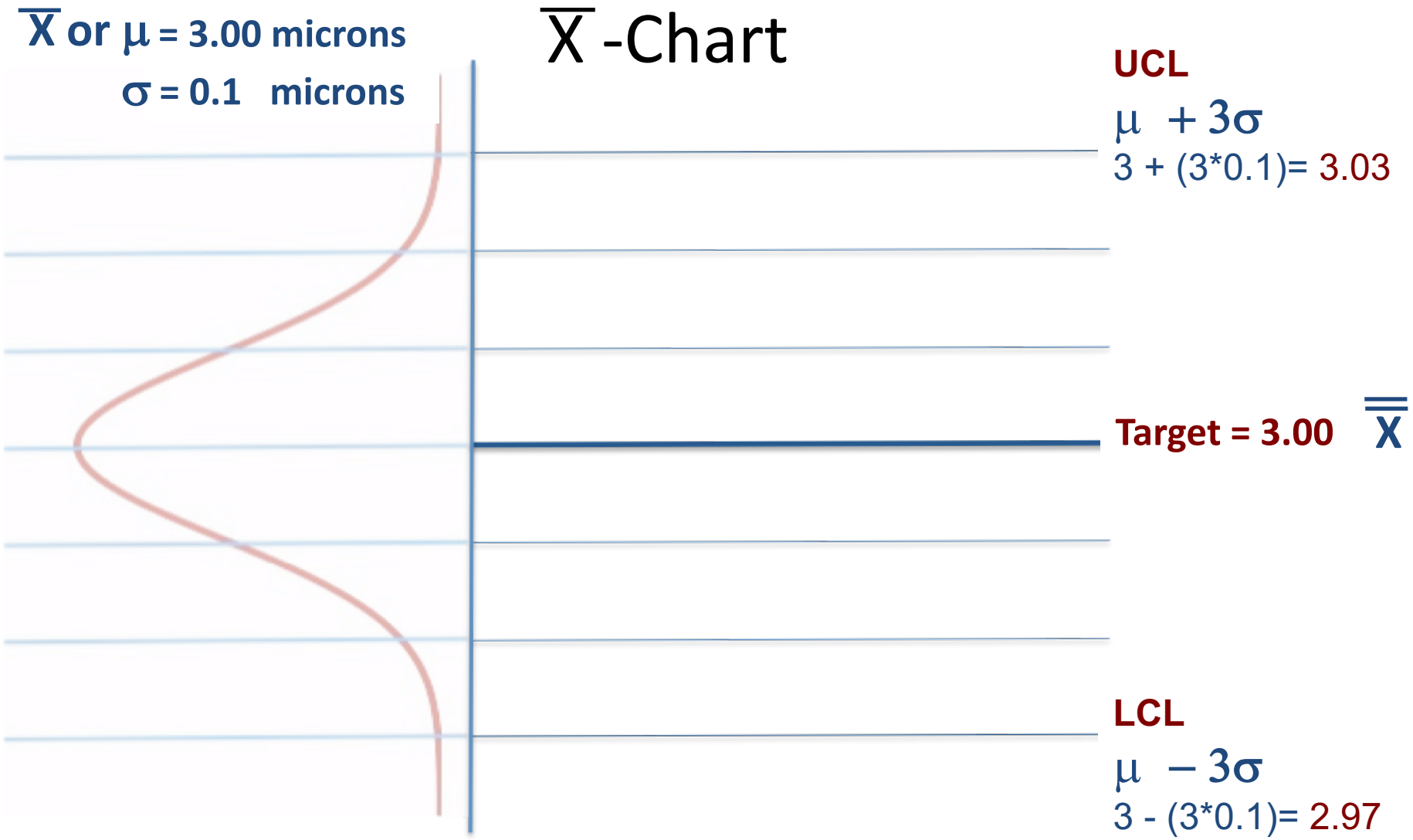

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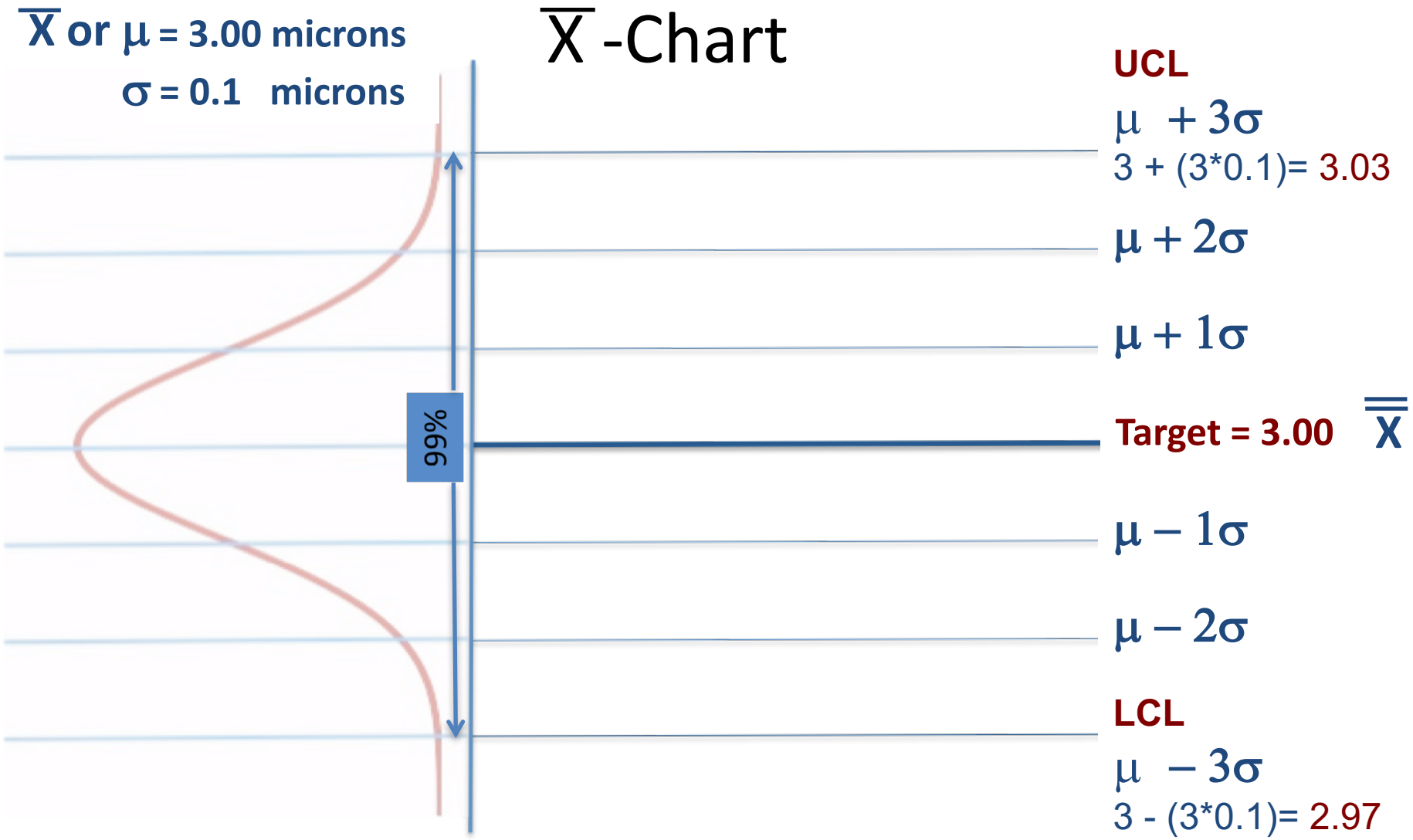

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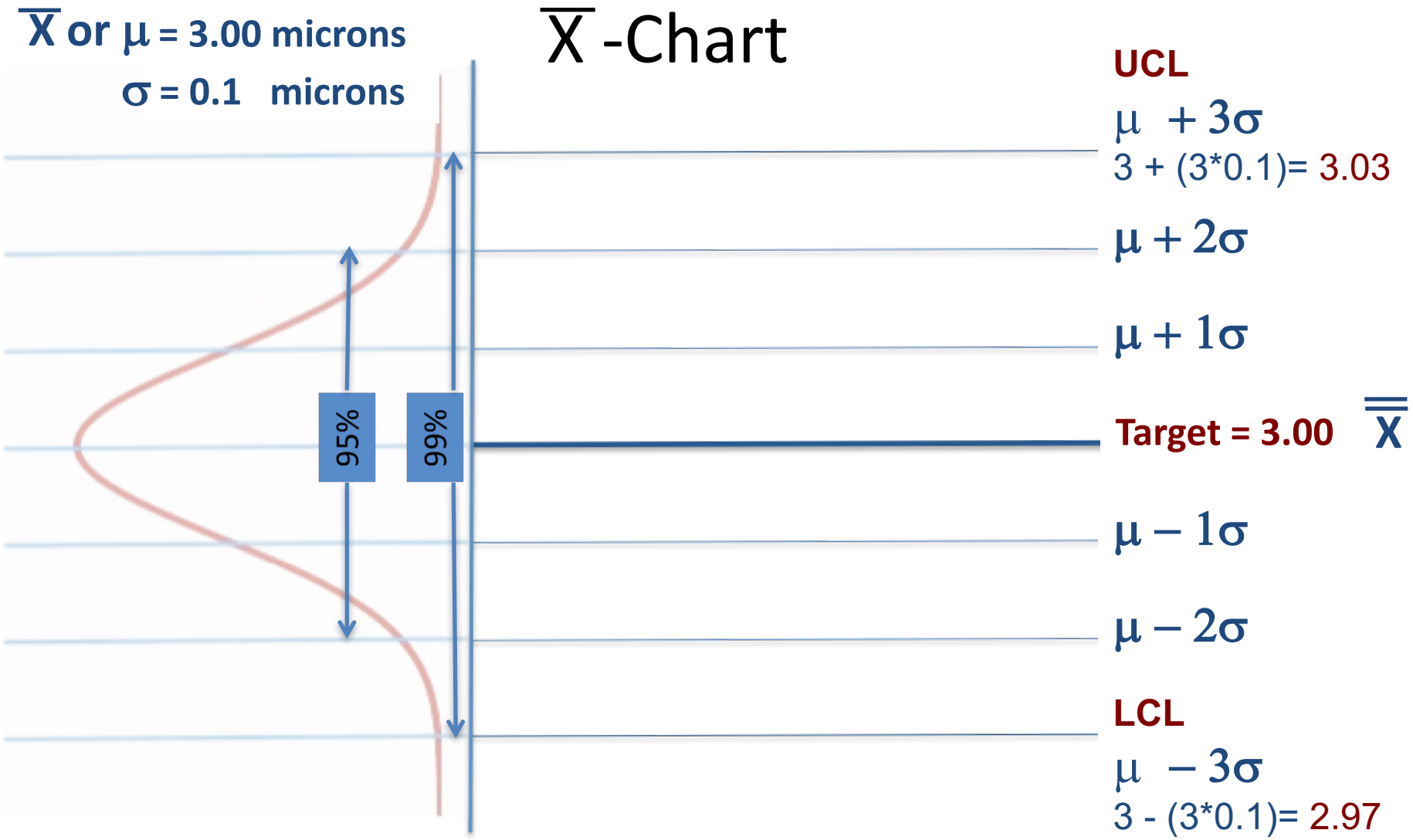

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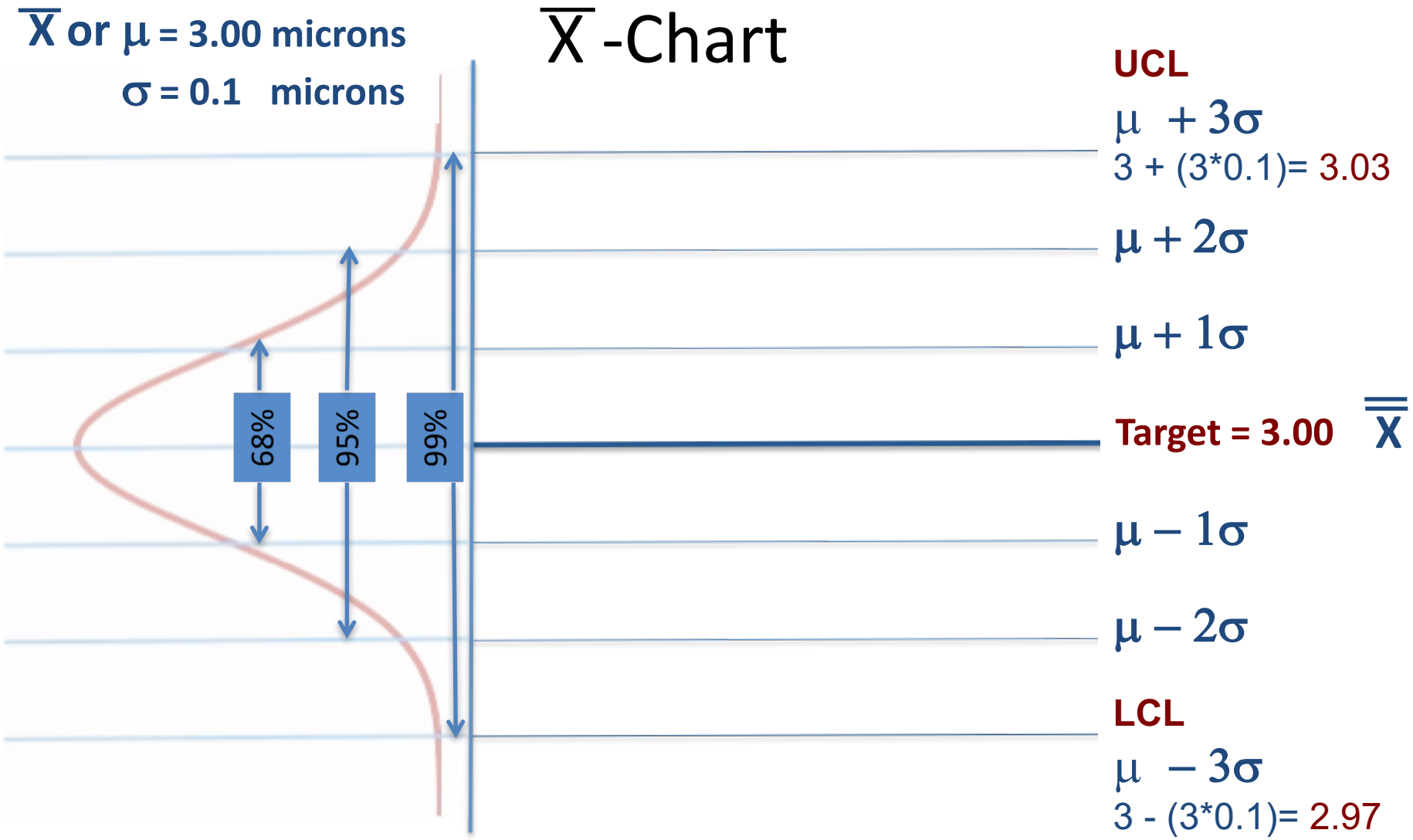

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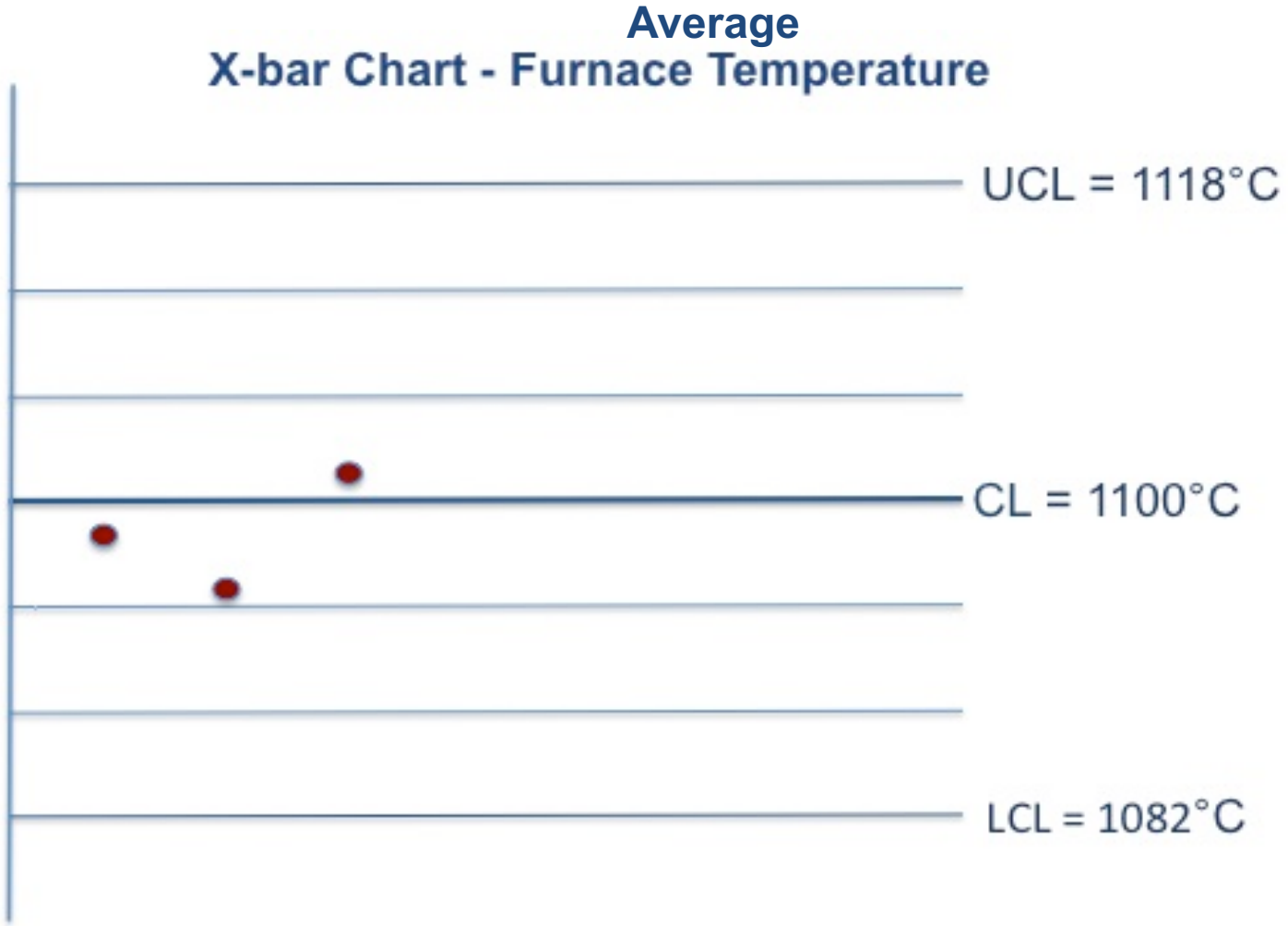


Shewhart Rules
aka Western Electric Rules (WECO)

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).

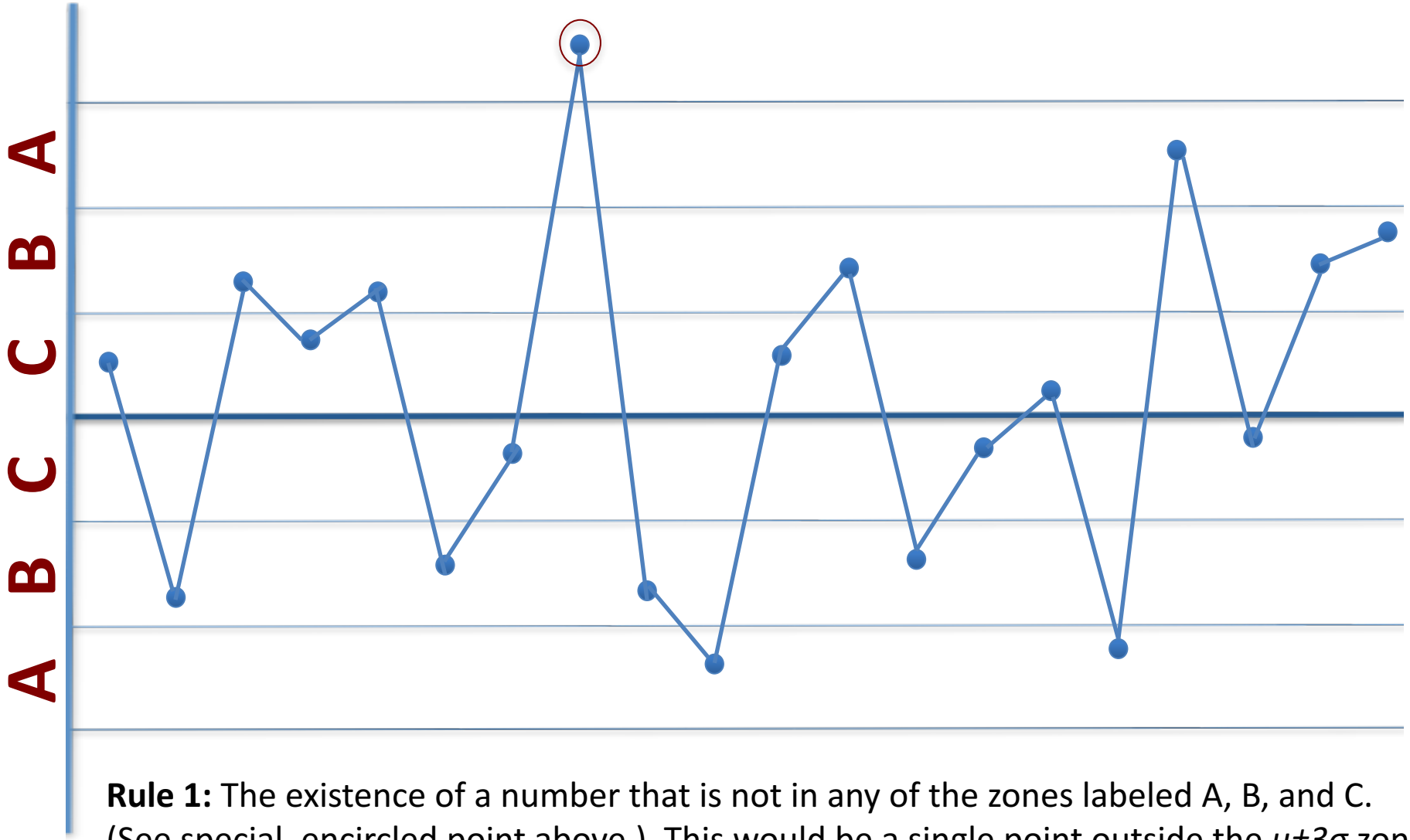
Rule 5: Six or more successive numbers showing a continuous increase or continuous decrease.

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.

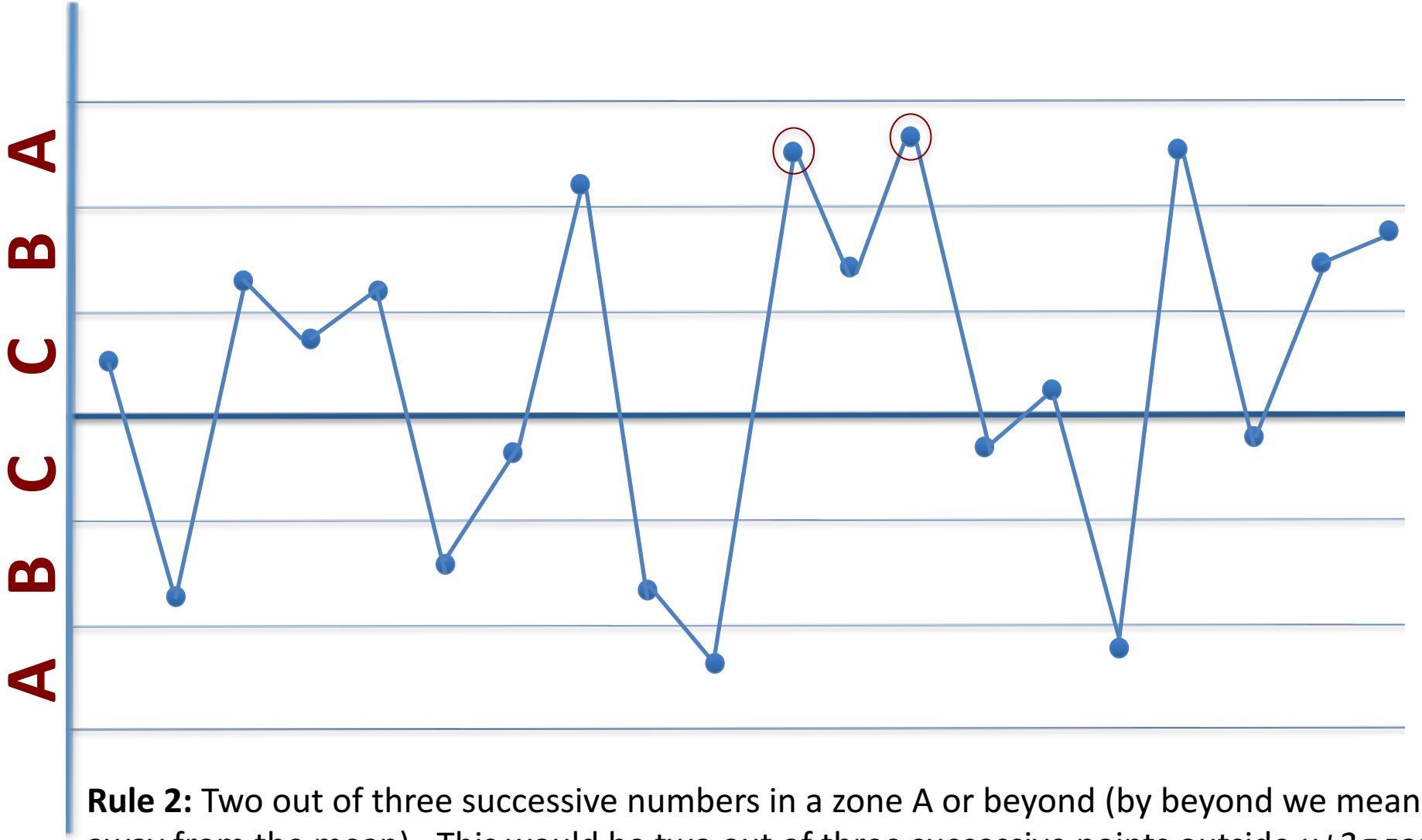
Rule 8: Fifteen successive points fall into $\mu \pm 1\sigma$ zone only, to either side of the centerline.

Shewhart Rules – Rule #1



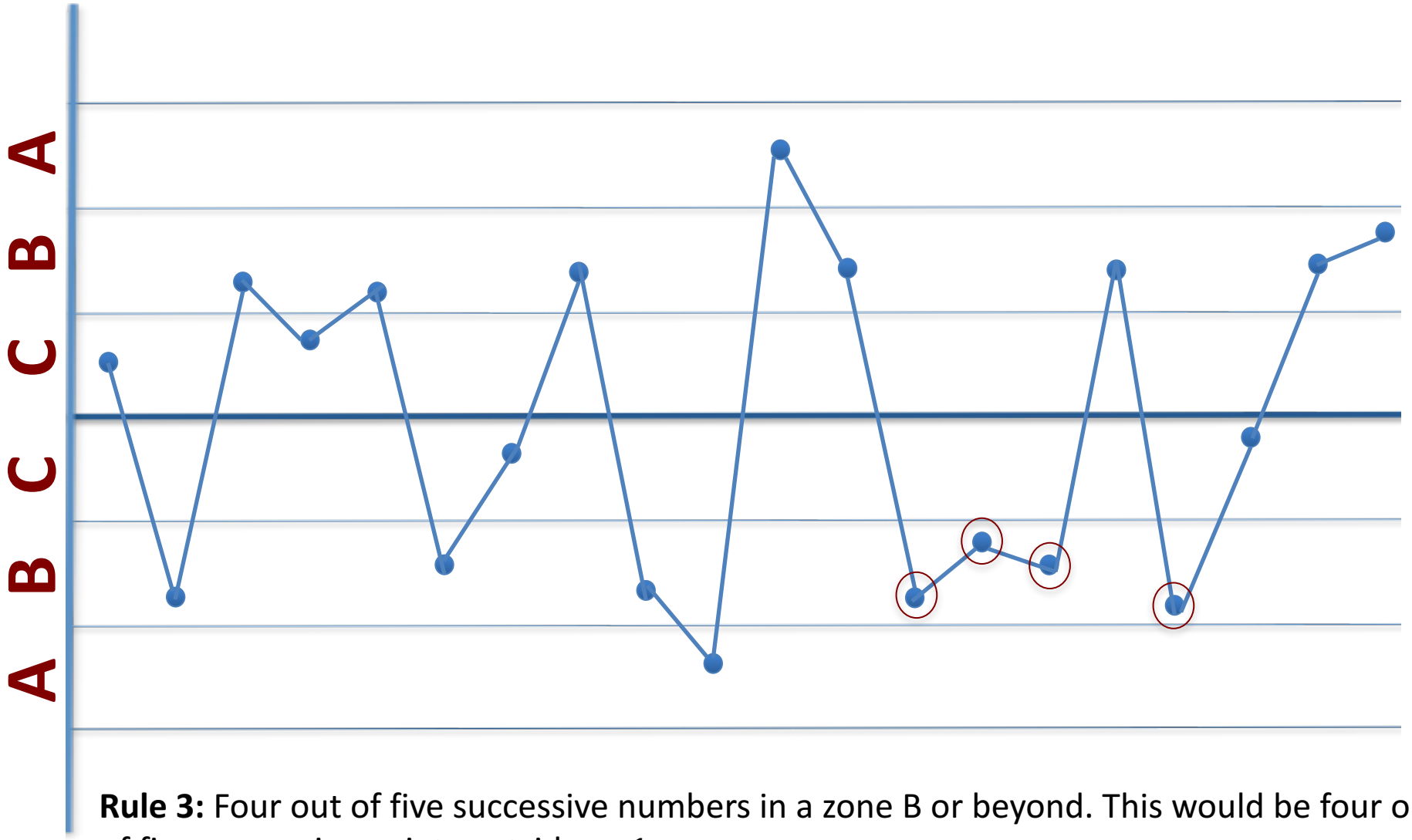
Rule 1: The existence of a number that is not in any of the zones labeled A, B, and C. (See special, encircled point above.) This would be a single point outside the $\mu \pm 3\sigma$ zone.

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.

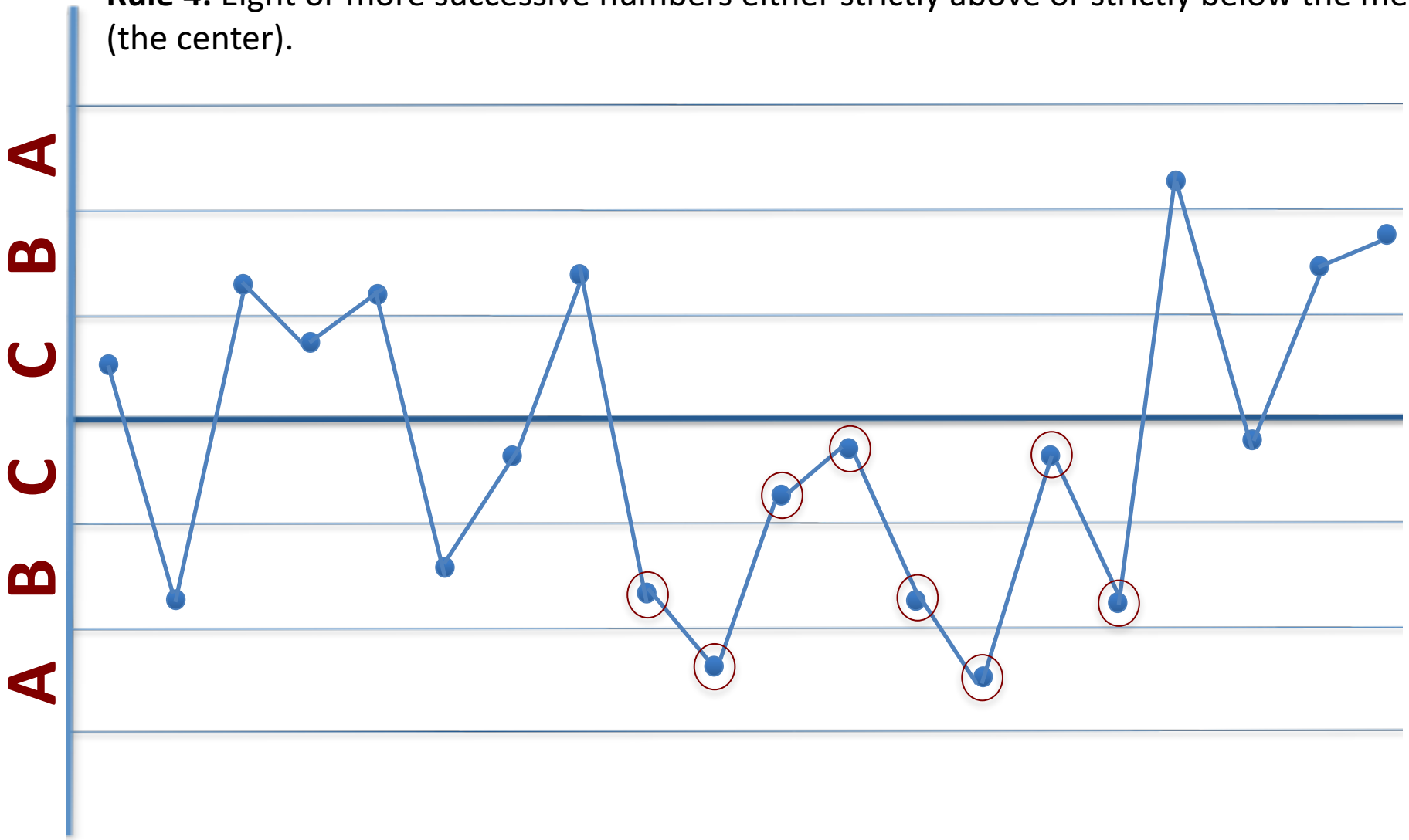
Shewhart Rules – Rule #3



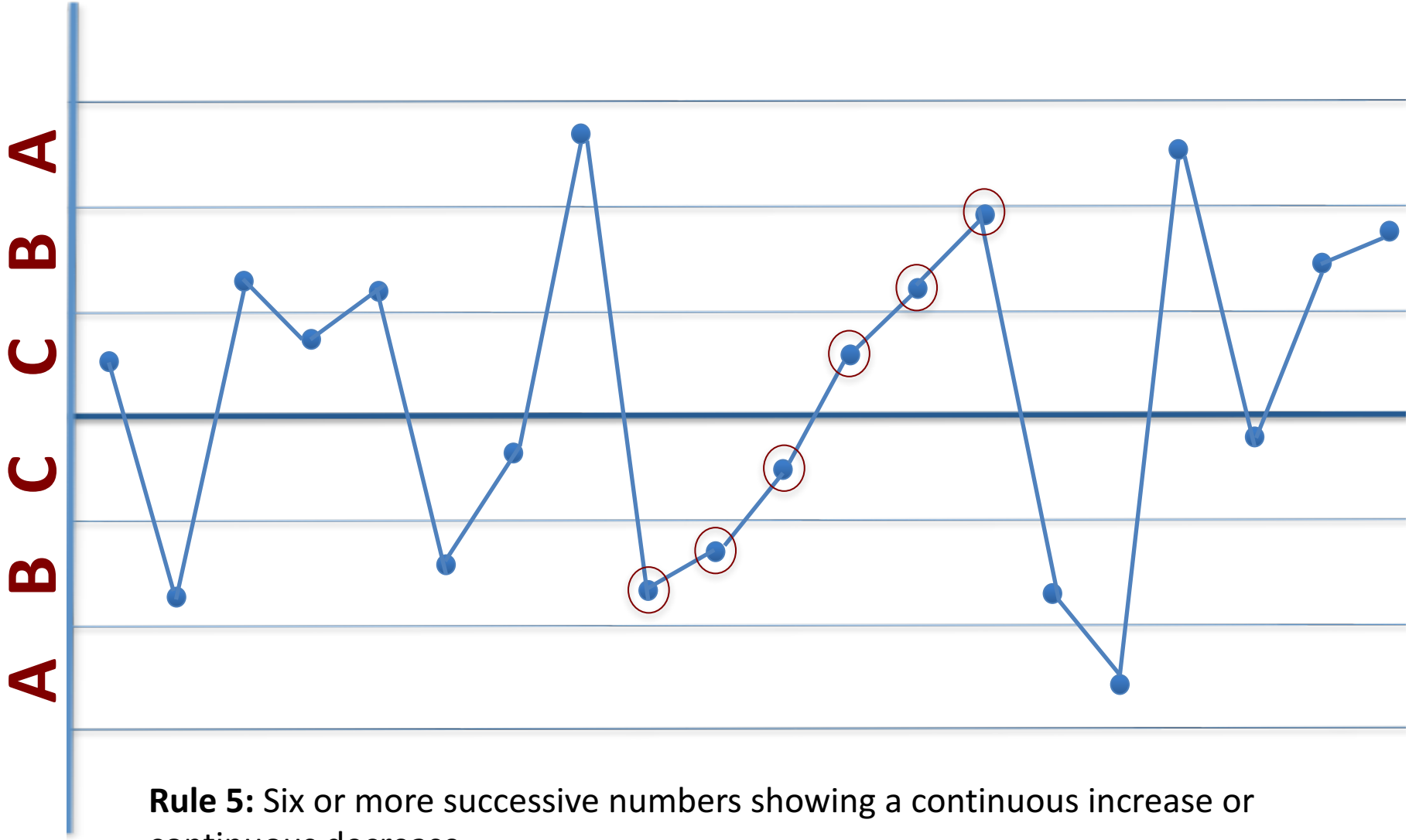
Rule 3: Four out of five successive numbers in a zone B or beyond. This would be four out of five successive points outside $\mu \pm 1\sigma$ zone.

Shewhart Rules – Rule #4

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



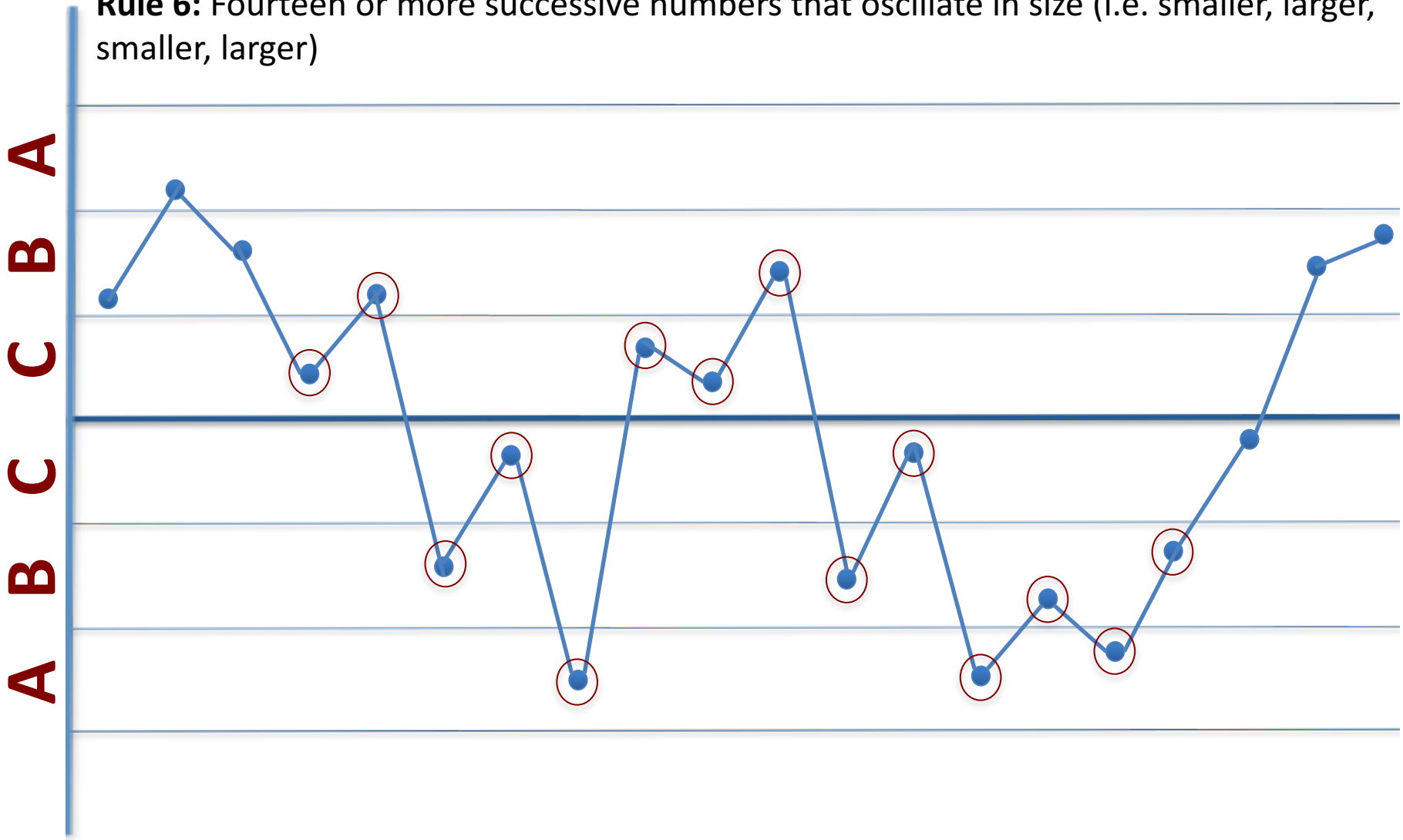
Shewhart Rules – Rule #5



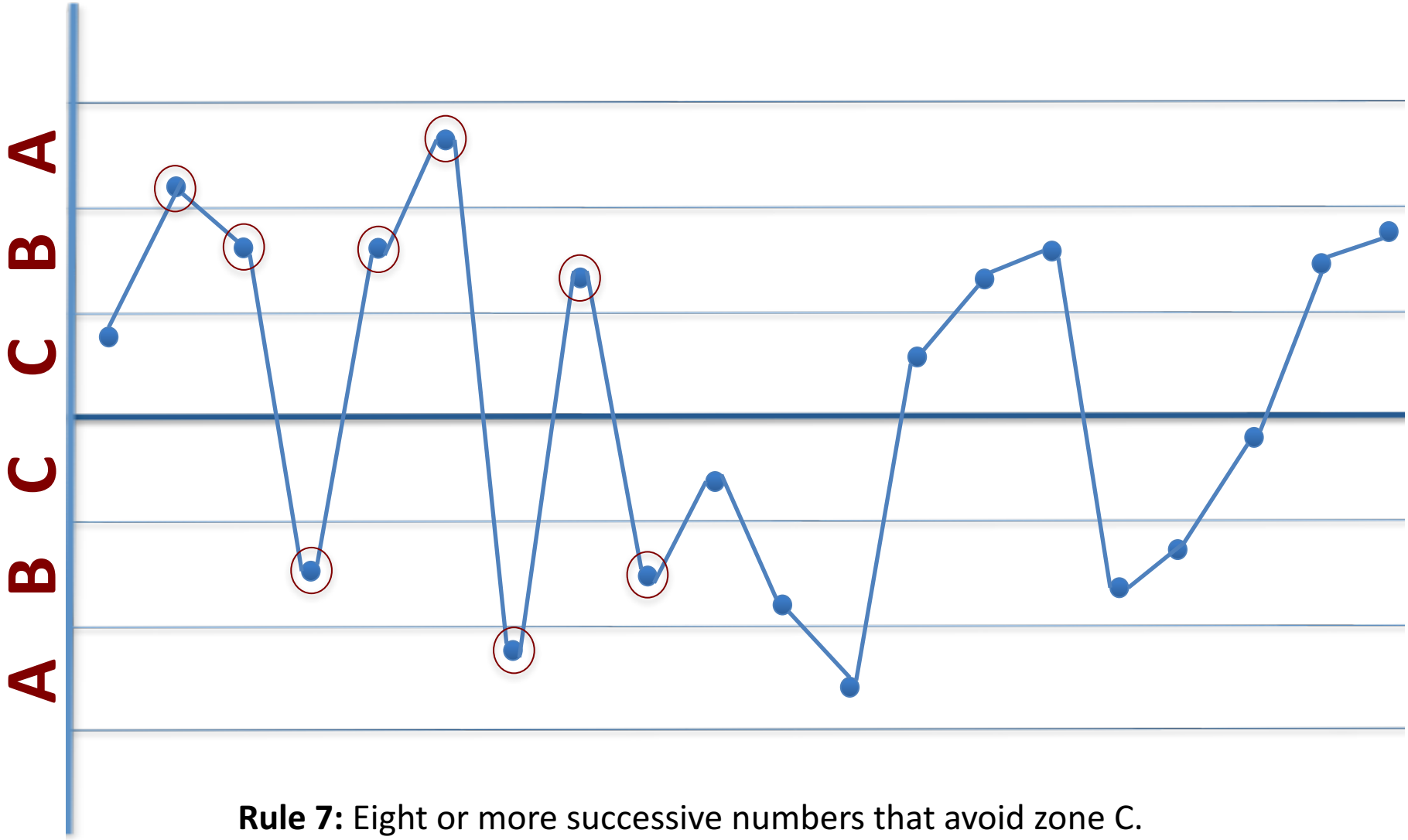
Rule 5: Six or more successive numbers showing a continuous increase or continuous decrease.

Shewhart Rules – Rule #6

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



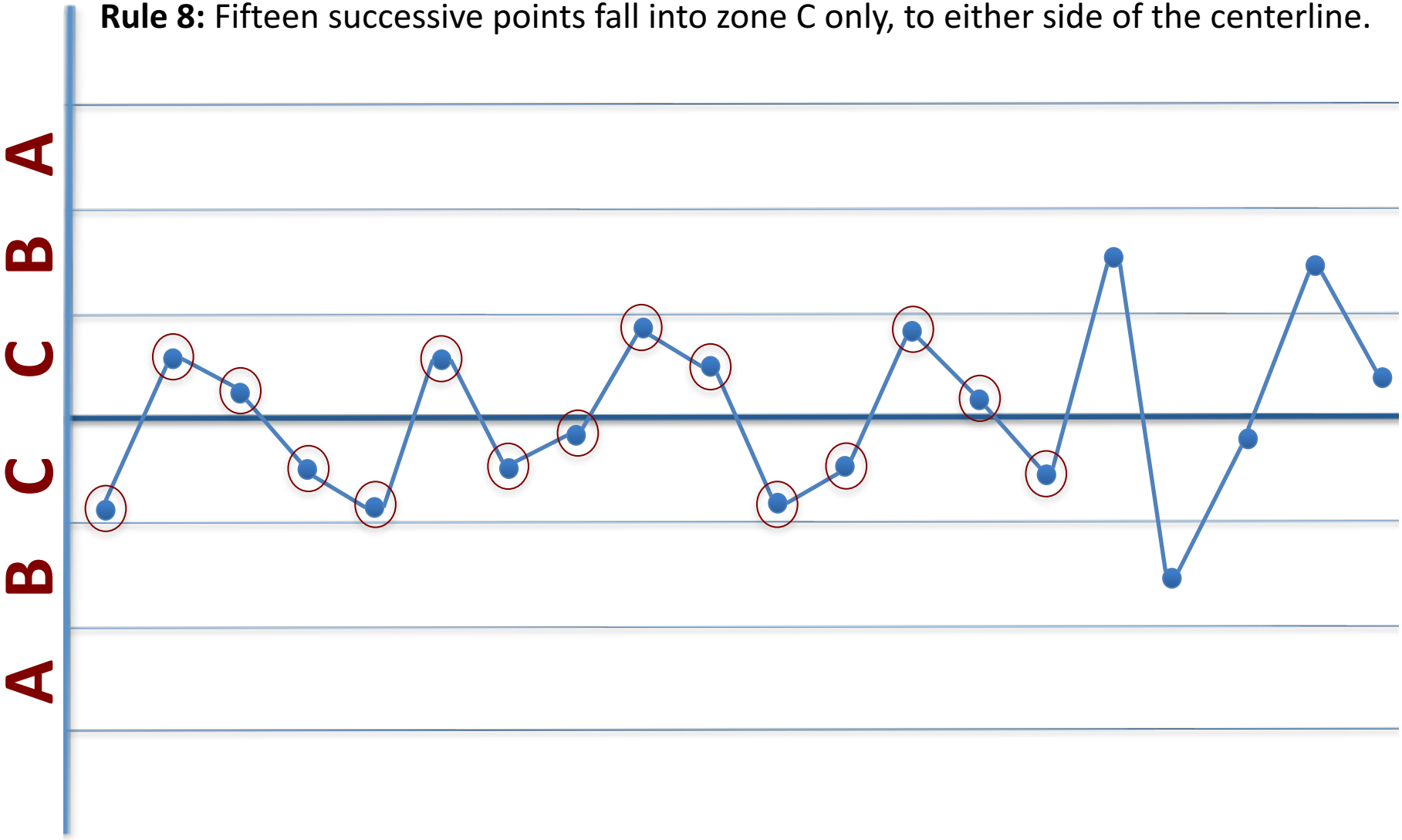
Shewhart Rules – Rule #7



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.



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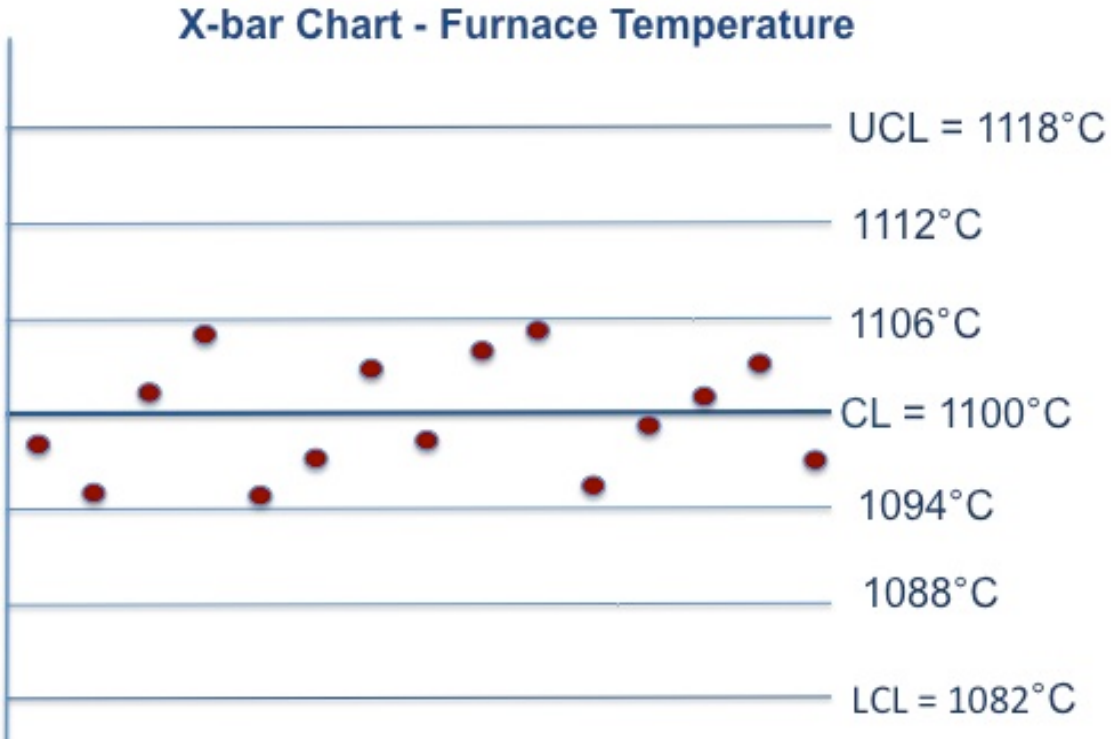
Type I and Type II Errors

- 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 $\mu \pm 3\sigma$ 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: 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 $\mu \pm 1\sigma$ zone.
Rule 8: 15 successive points fall into $\mu \pm 1\sigma$ zone only, to either side of the centerline or target.



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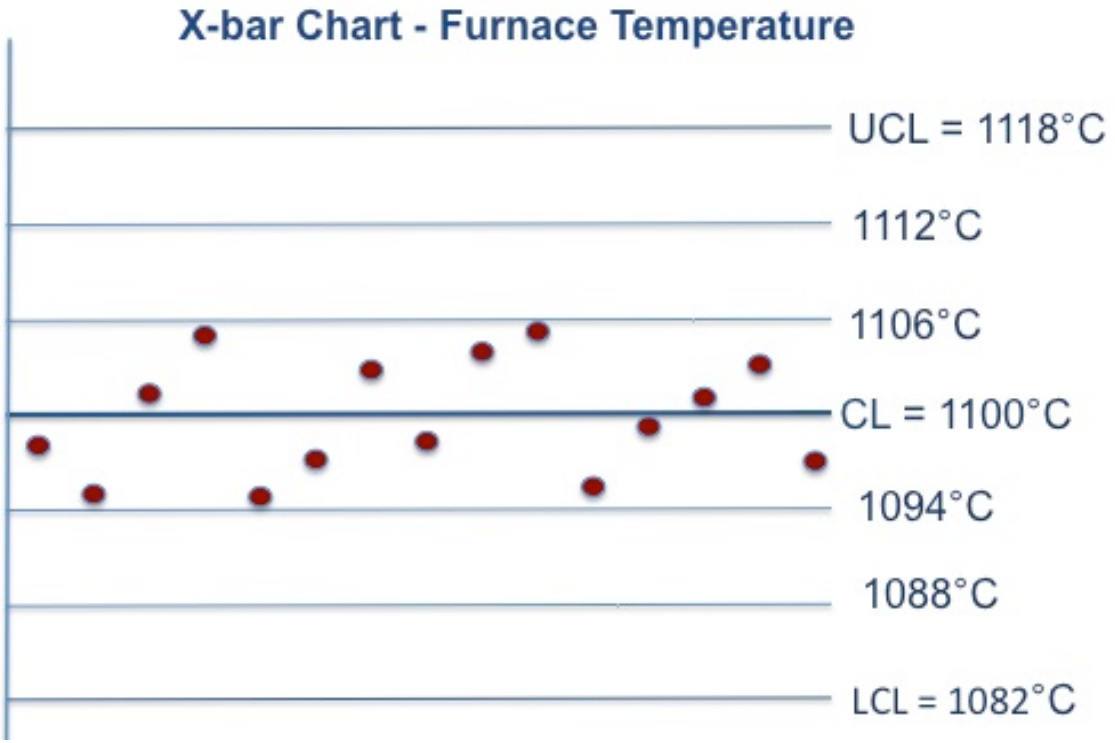
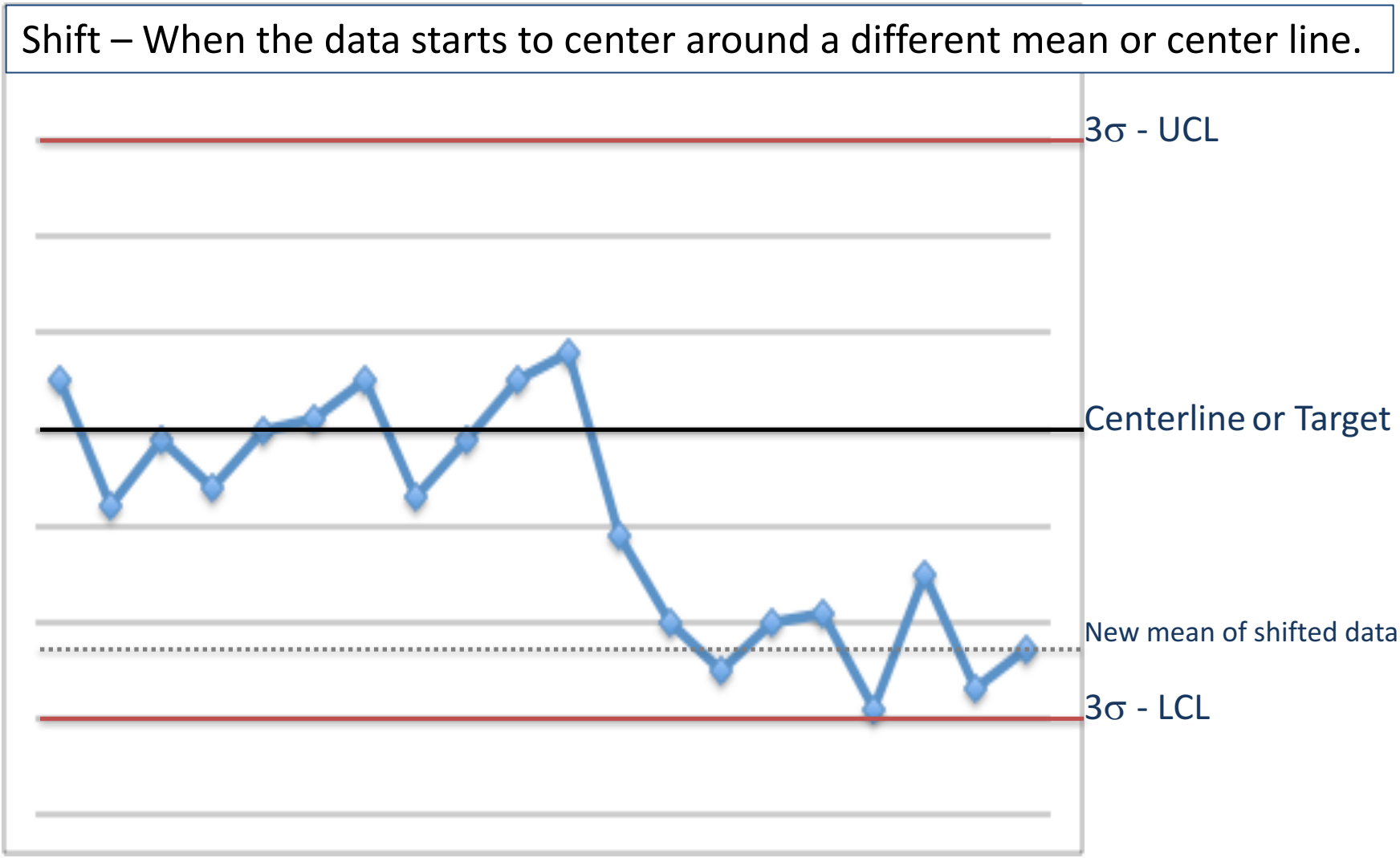


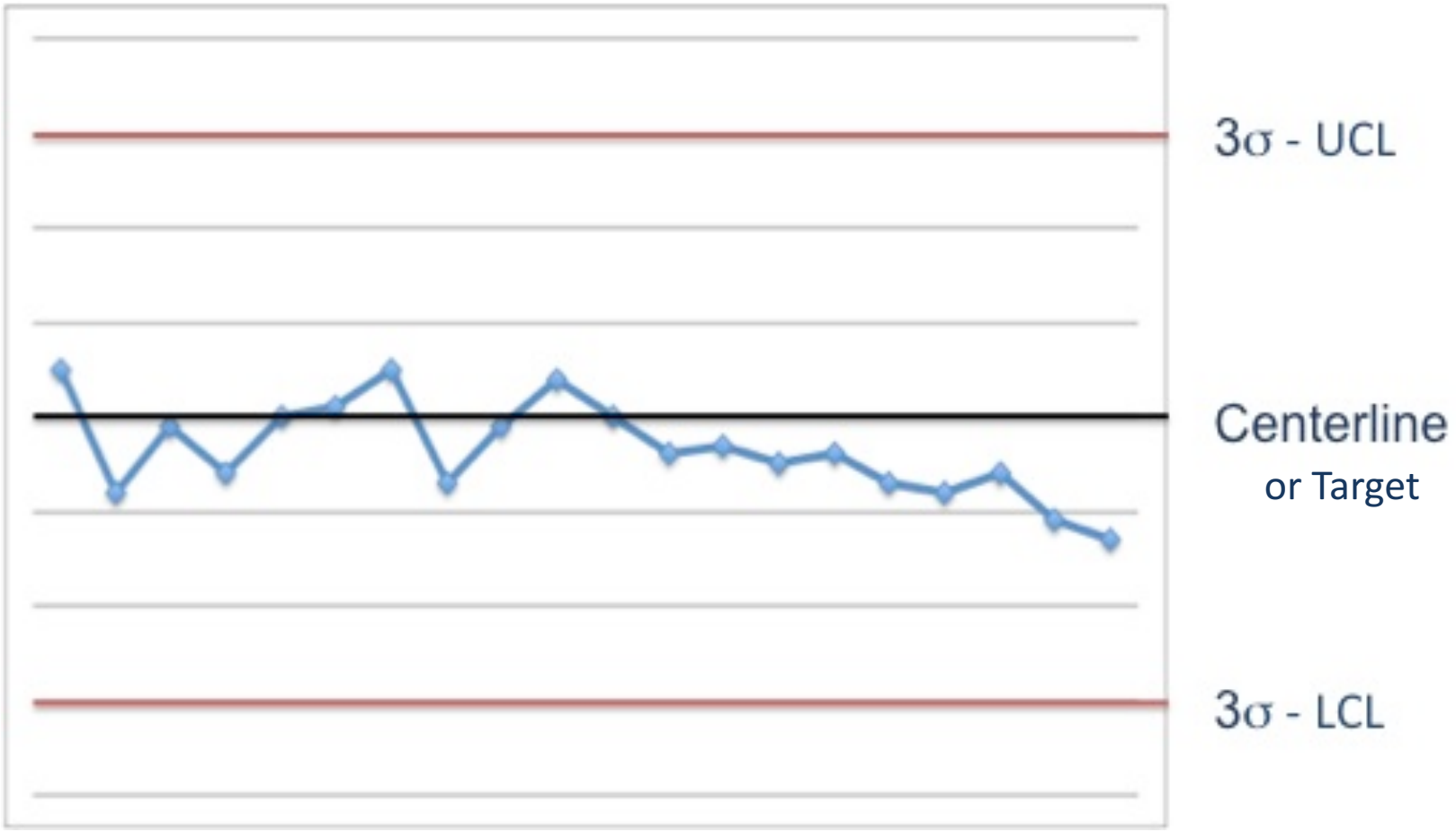
Process Changes - Shift

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



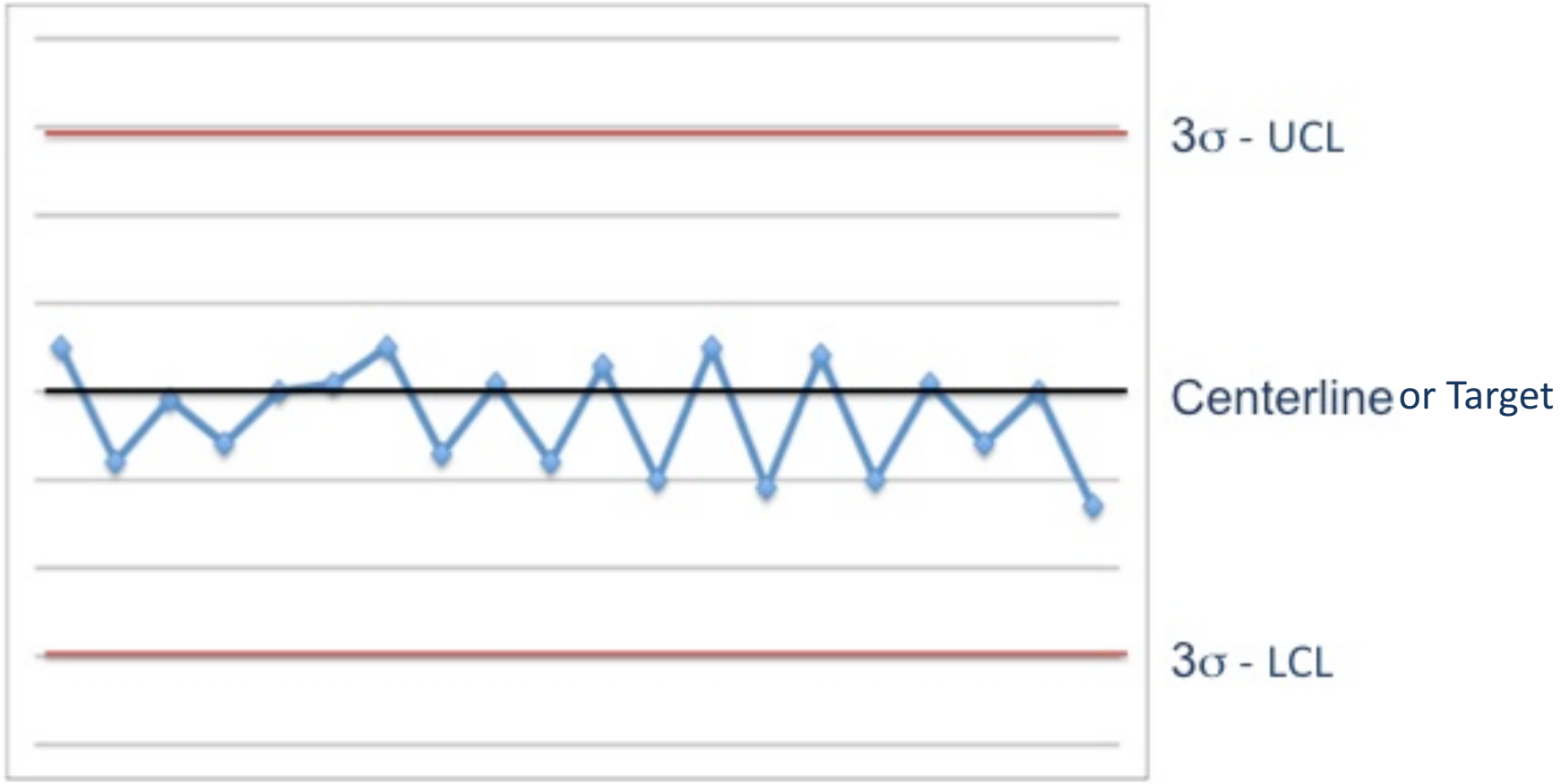
Process Changes - Trend

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



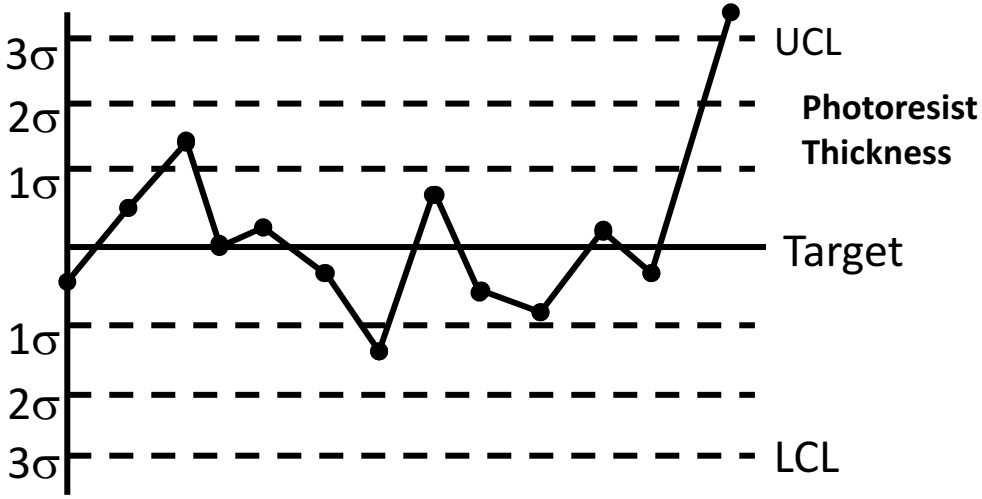
Process Changes - Cycle

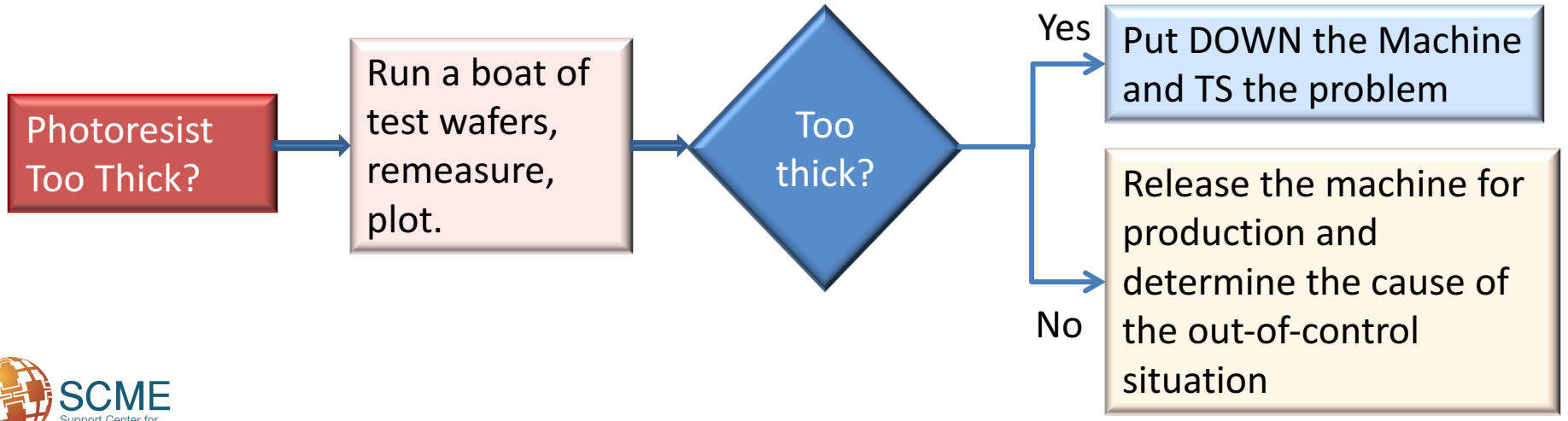
Cycle – When the data begins to increase or decrease in a cyclical or repetitive manner.



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.





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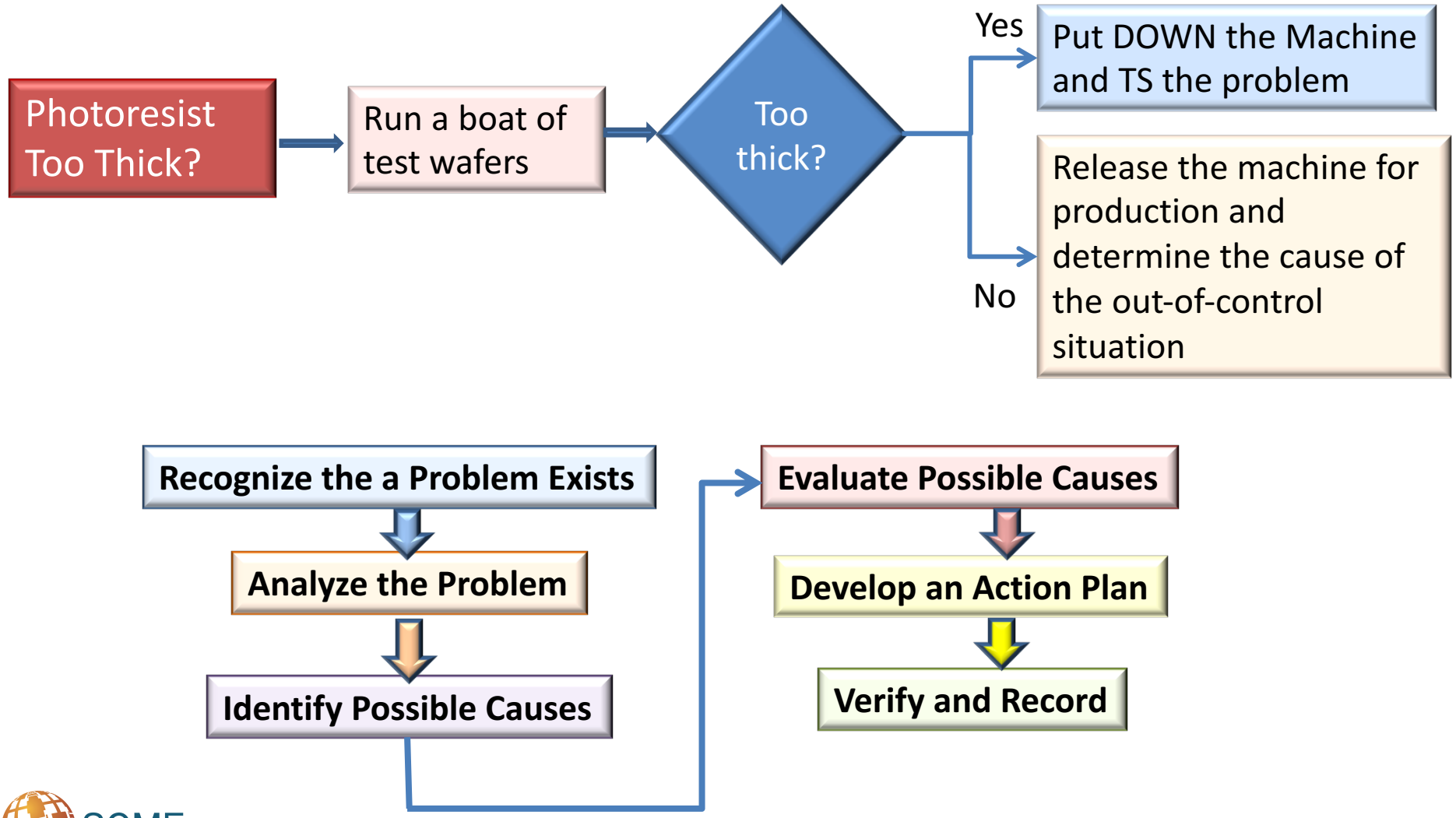
Out of Control Action Plan - OOCAP



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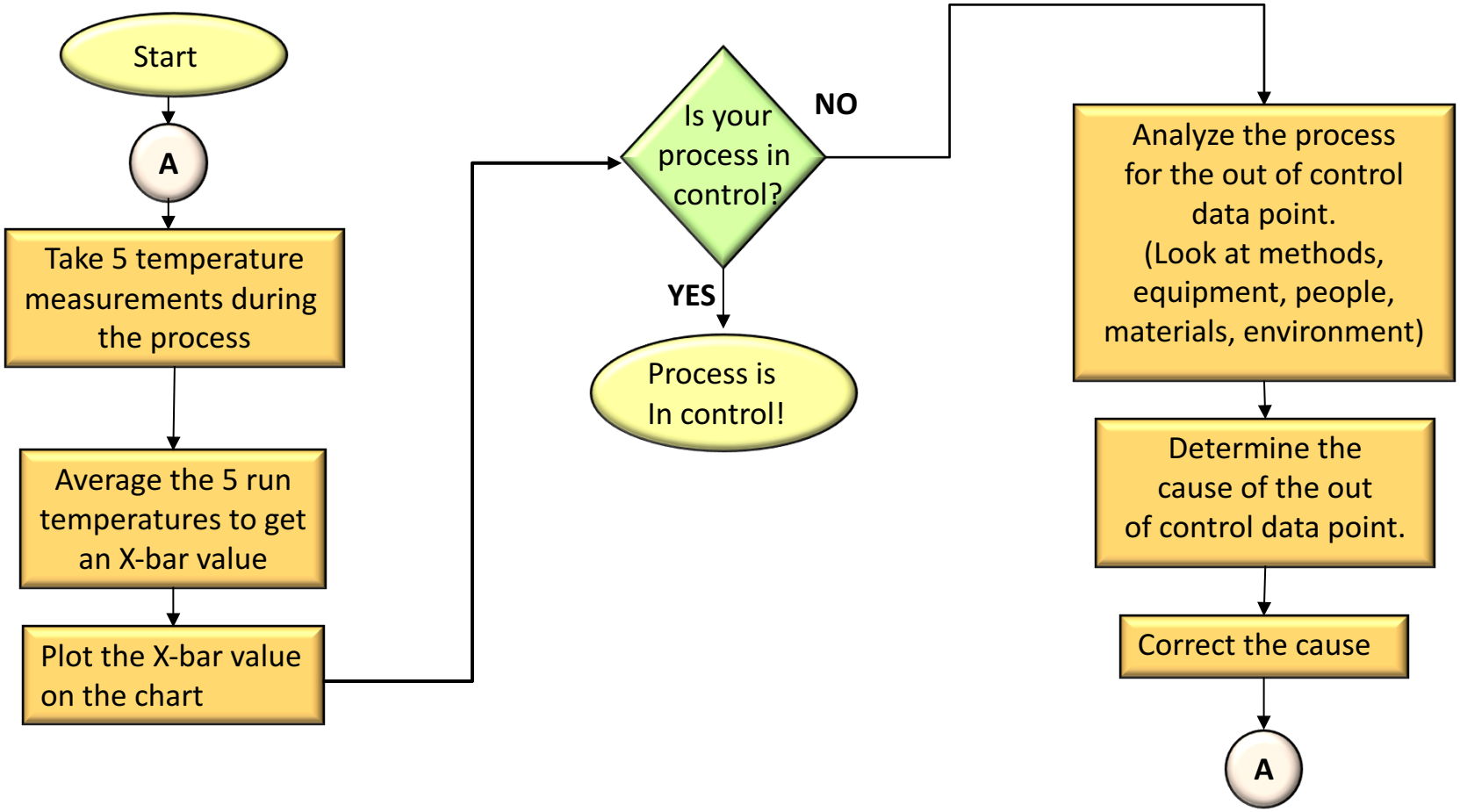
Data Collection/Analysis Plan



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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

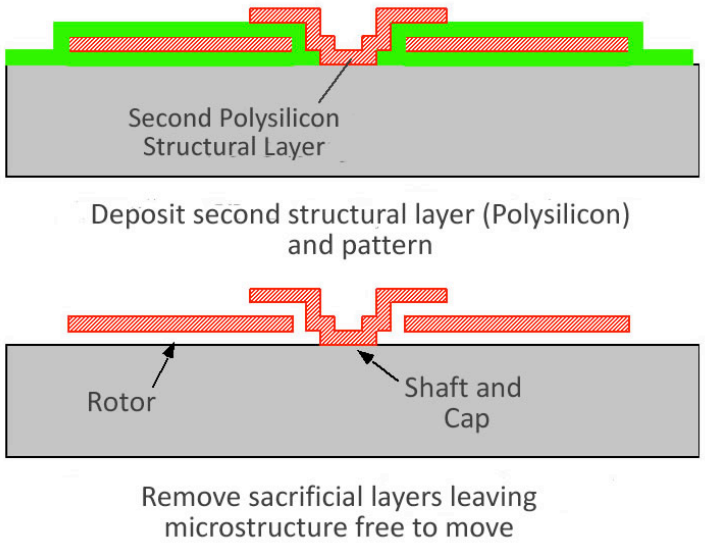


Image courtesy of UNM MTTC

$\bar{X}$ -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

$\mu - 3\sigma = 993°C$

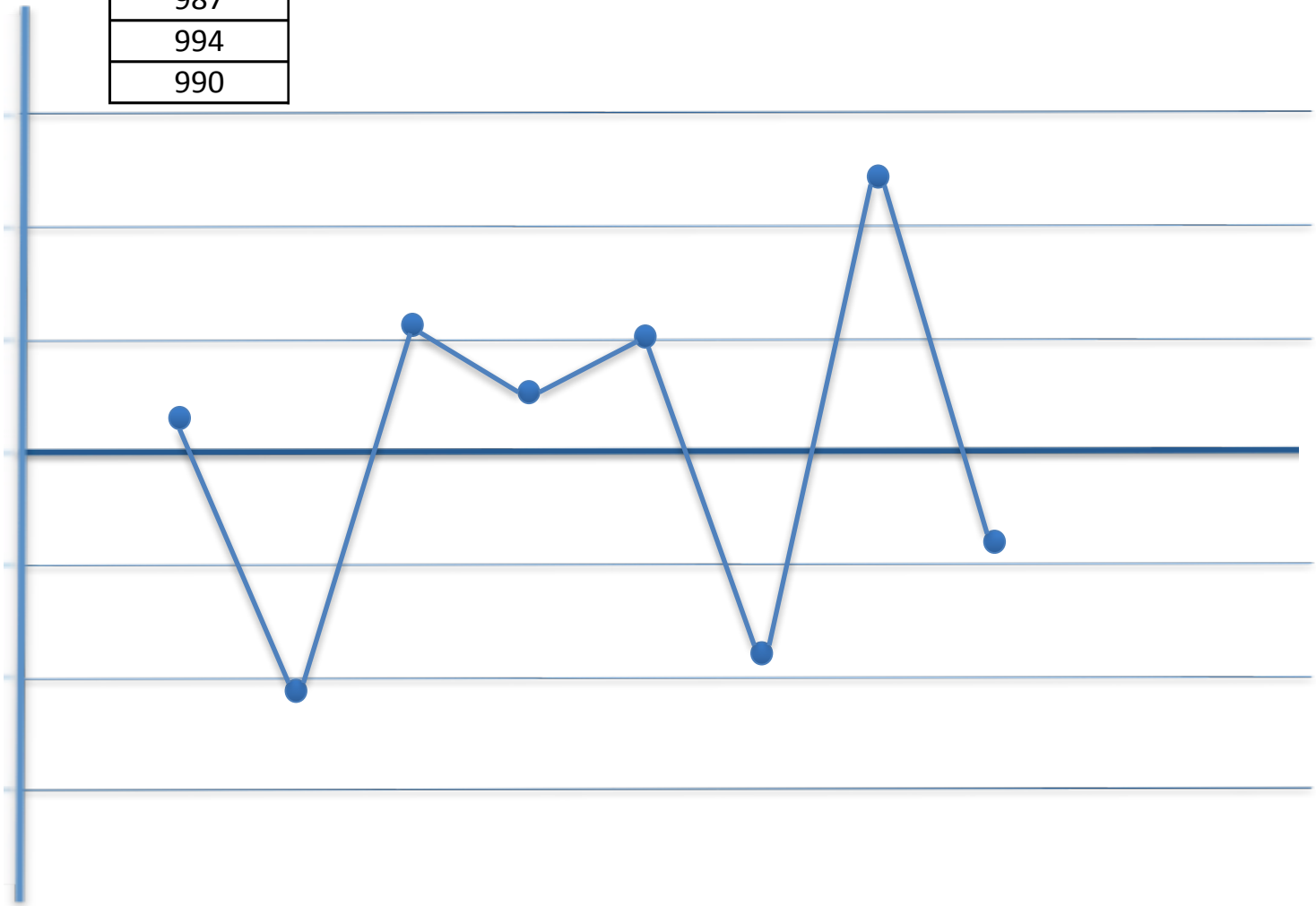
$\bar{X}$ -Chart for SiO_2 Growth

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



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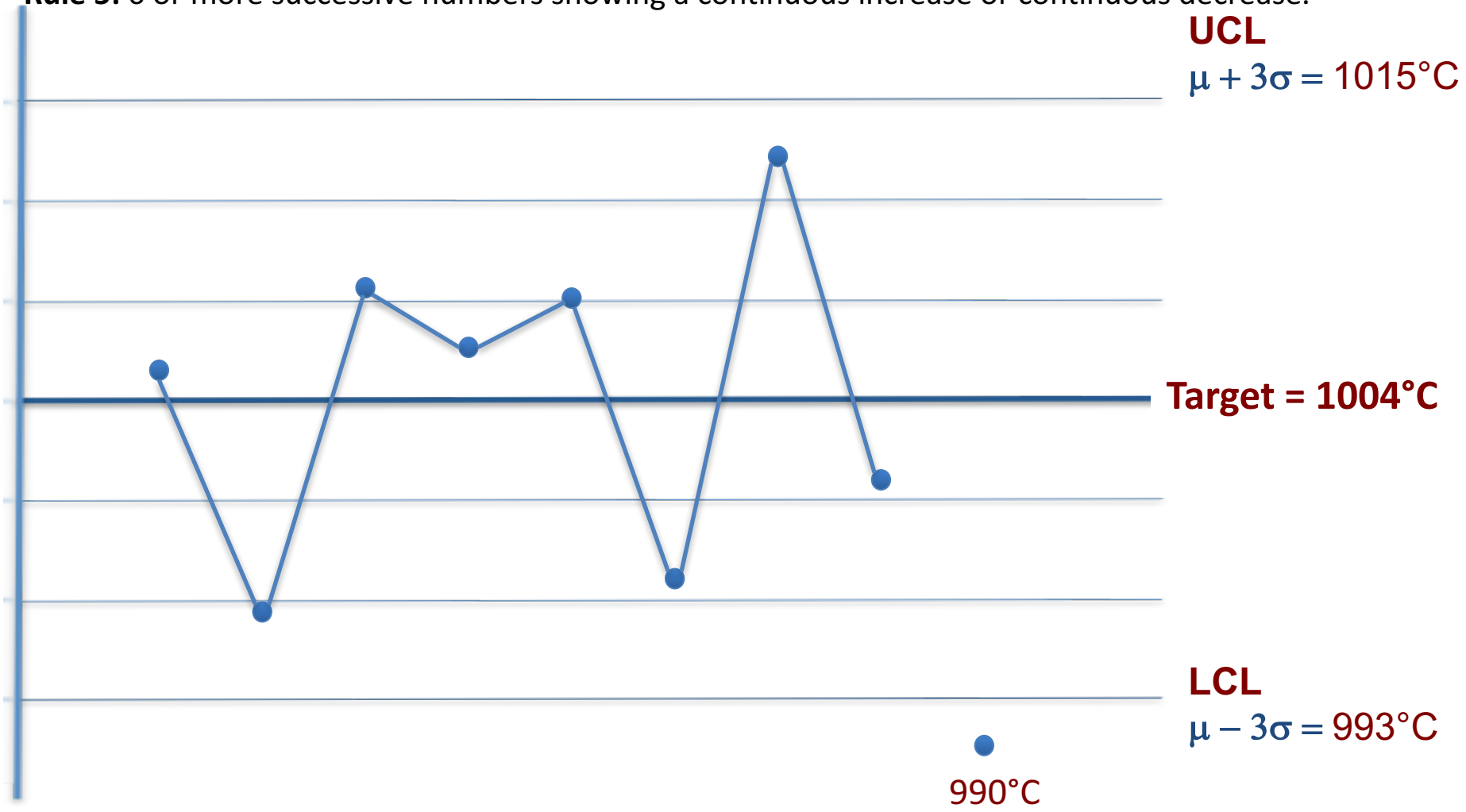

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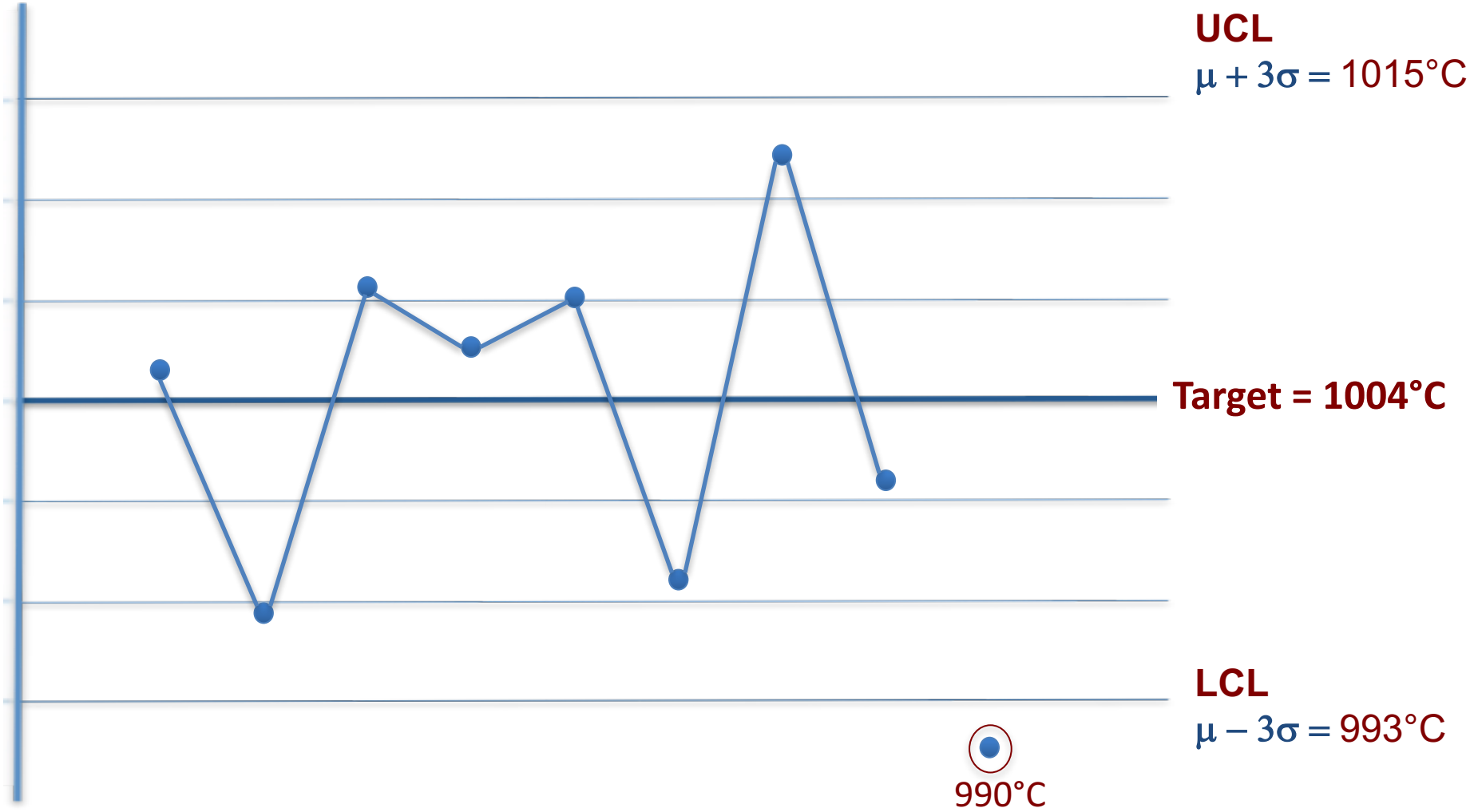

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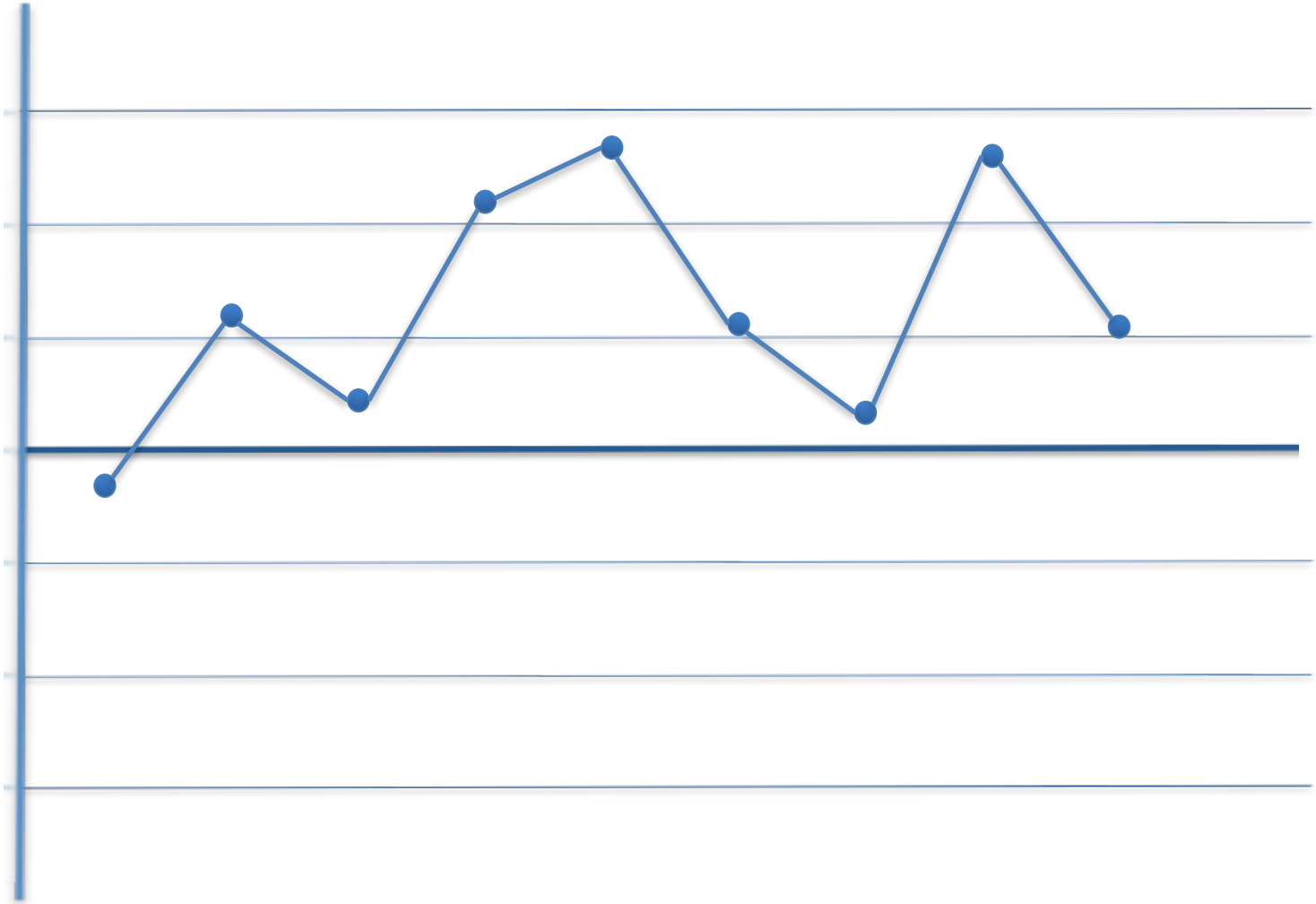

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Target = 1004°C

LCL
$\mu - 3\sigma = 993°C$

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

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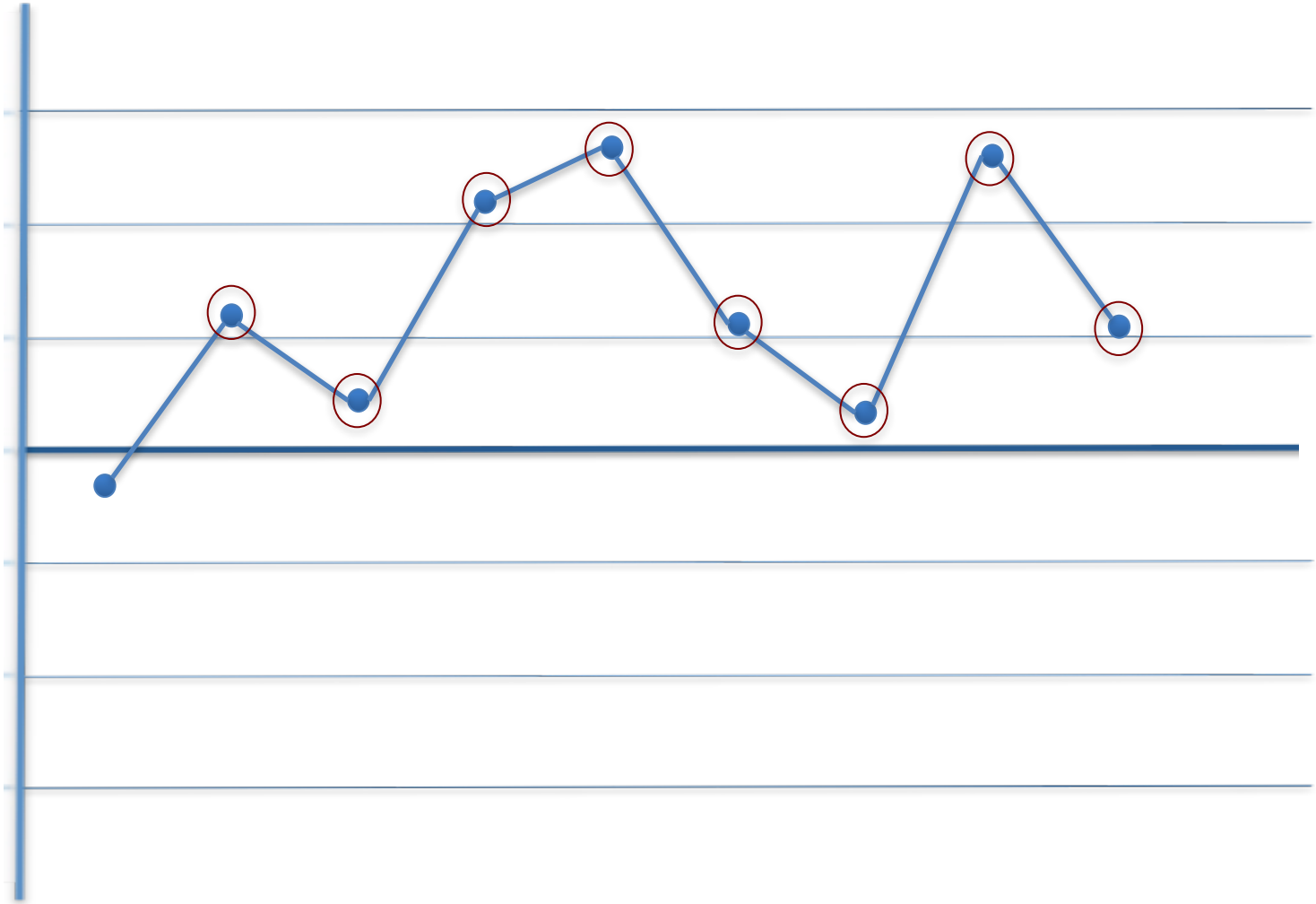

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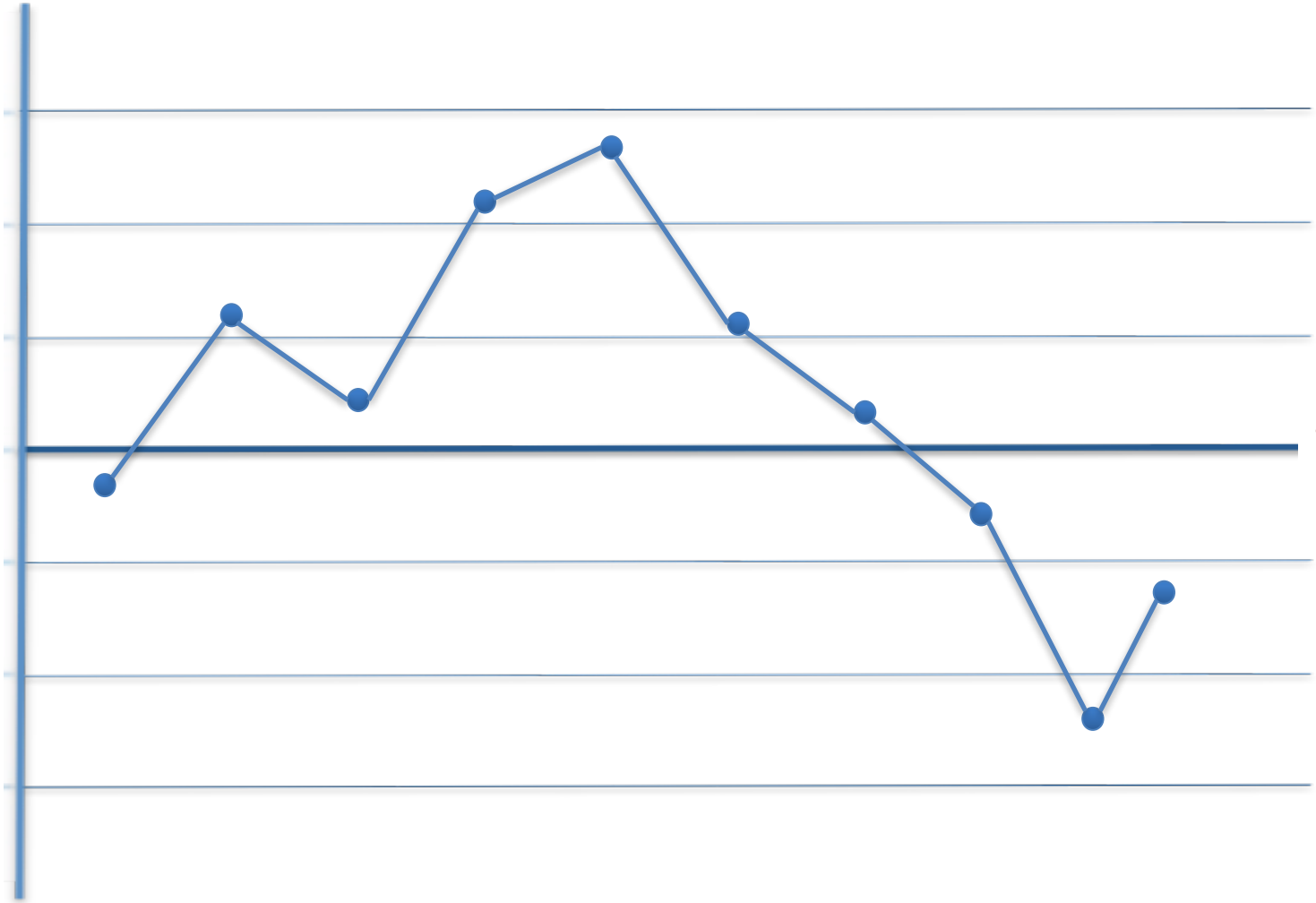

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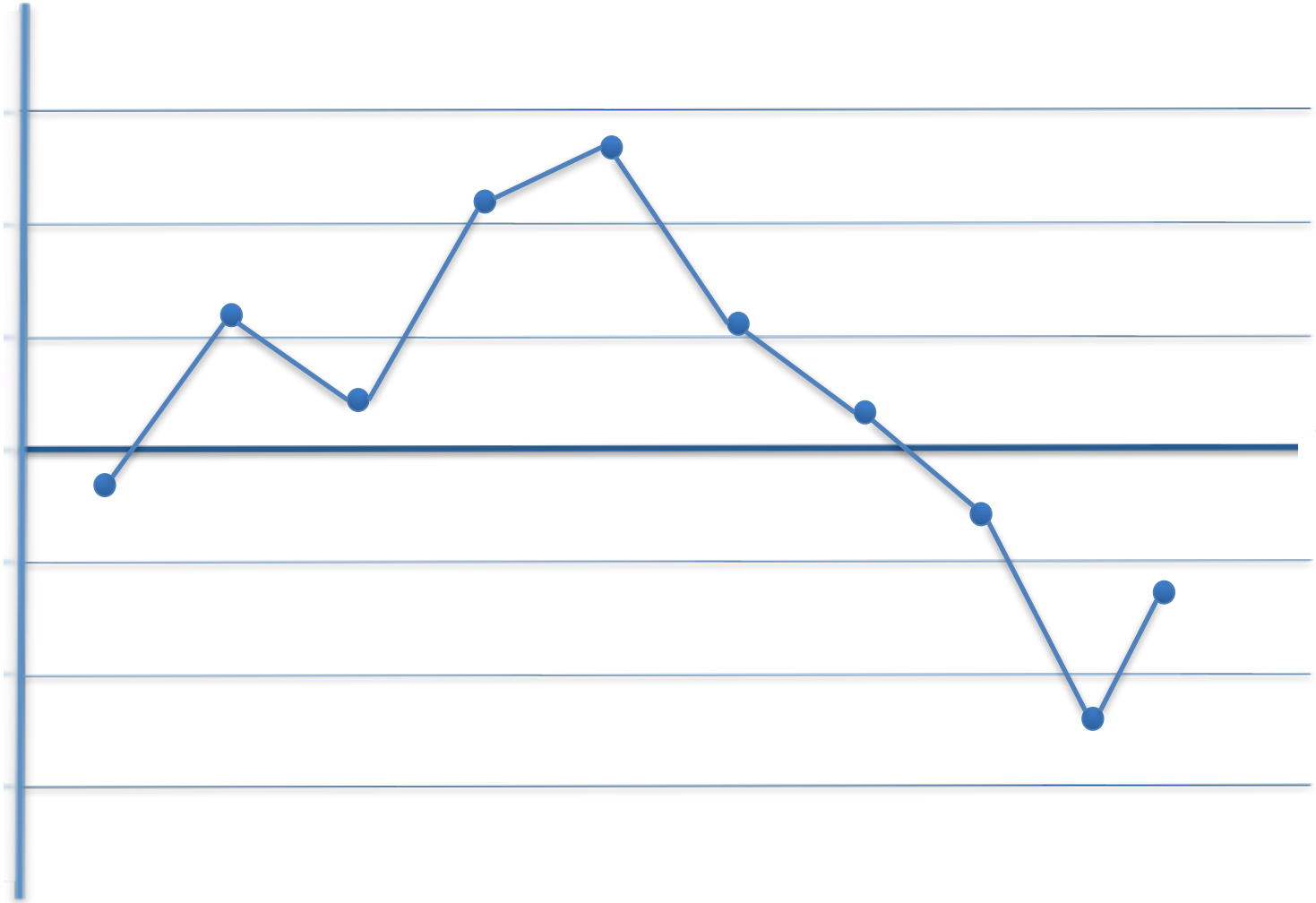

UCL
$\mu + 3\sigma = 1015°C$

Target = 1004°C

LCL
$\mu - 3\sigma = 993°C$

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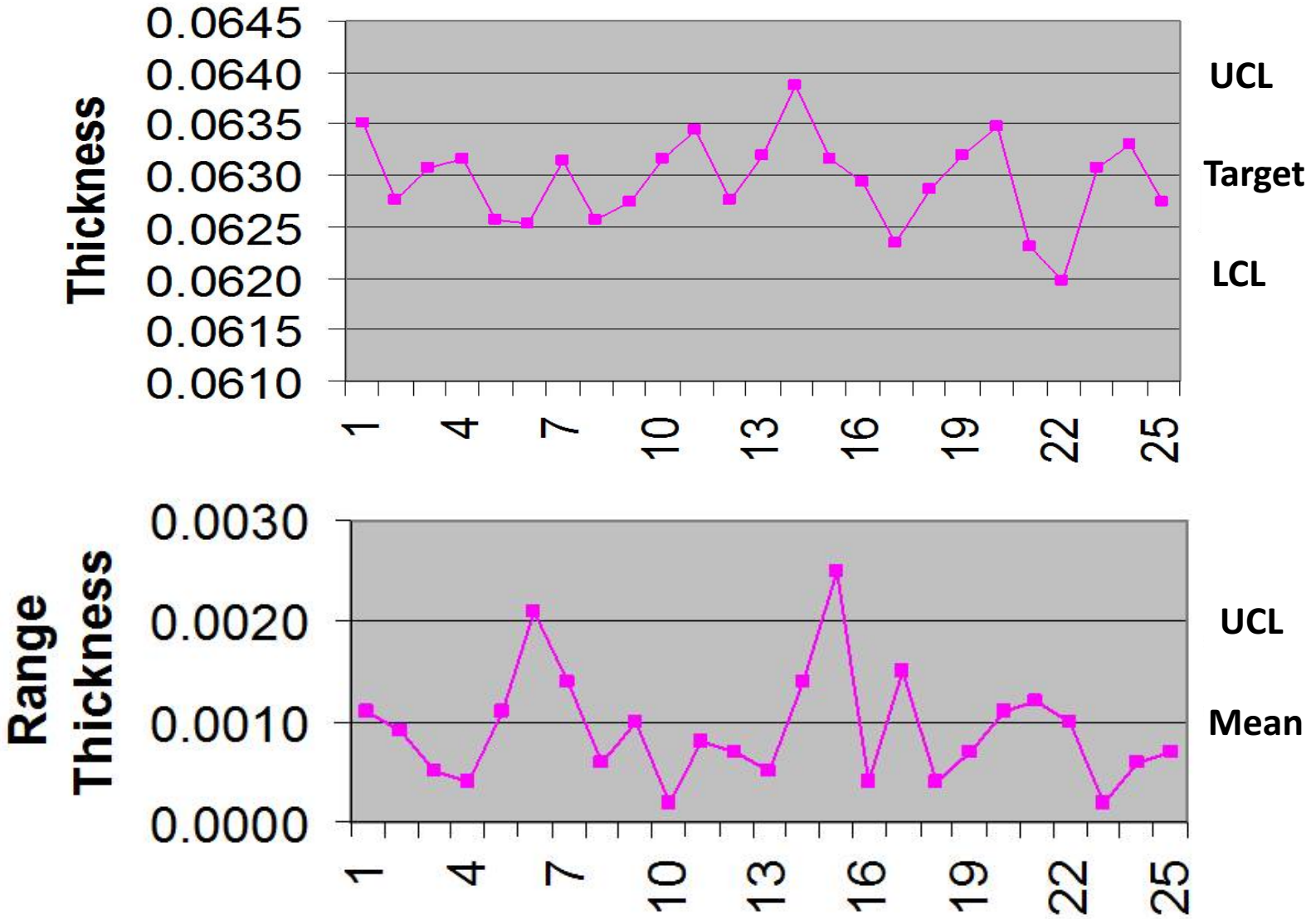
Other types of Charts

- $\overline{X}$ 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



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Summary

- Most process data follows a Normal Distribution
- Shewhart or Western Electric Rules can be used to determine if a process goes out of control