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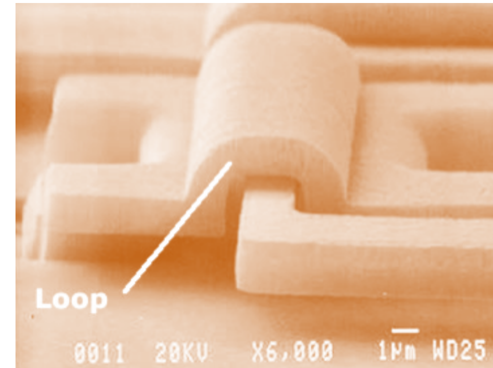

Introduction to Statistical Process Control (SPC) For Technicians

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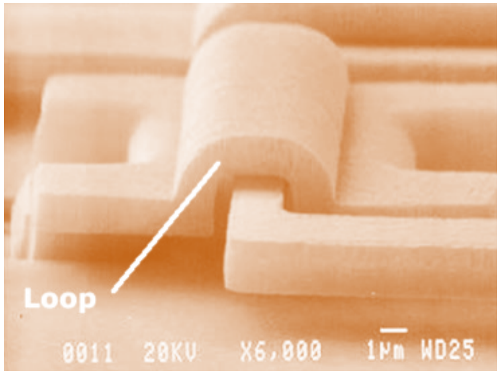

SCME is a National Science Foundation Advanced Technological Education (ATE) Support Center at the University of New Mexico.

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

- Process variation and the need to identify special cause variation
- Statistical Process Control (SPC)
- Statistical tools necessary to employ SPC

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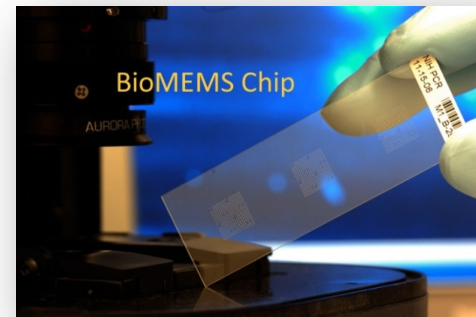
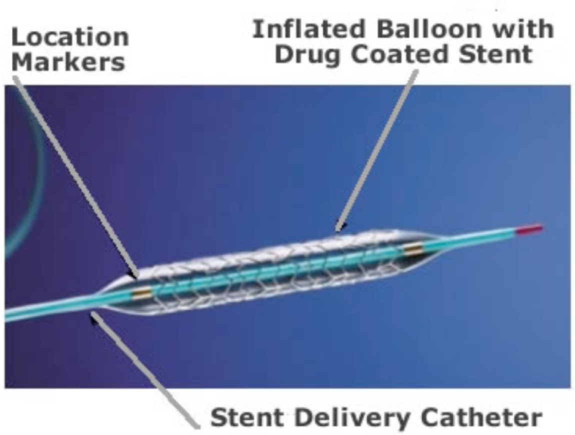
Why do we need (SPC) Statistical Process Control?

Quality Product



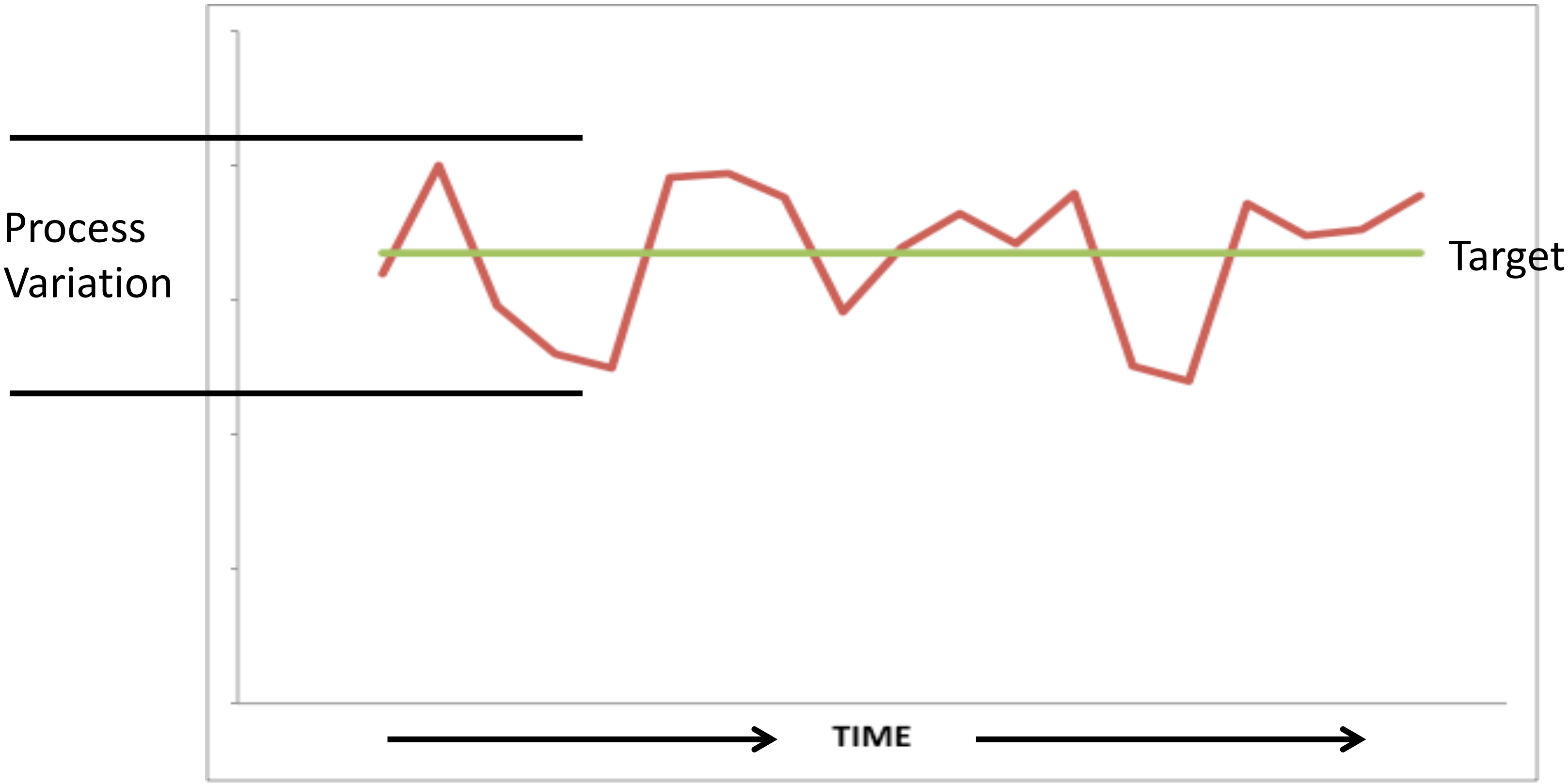
Biochip slide for testing protein arrays [Image courtesy of Argonne National Laboratories]



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

Statistical Process Control (SPC)

SPC is about "control".



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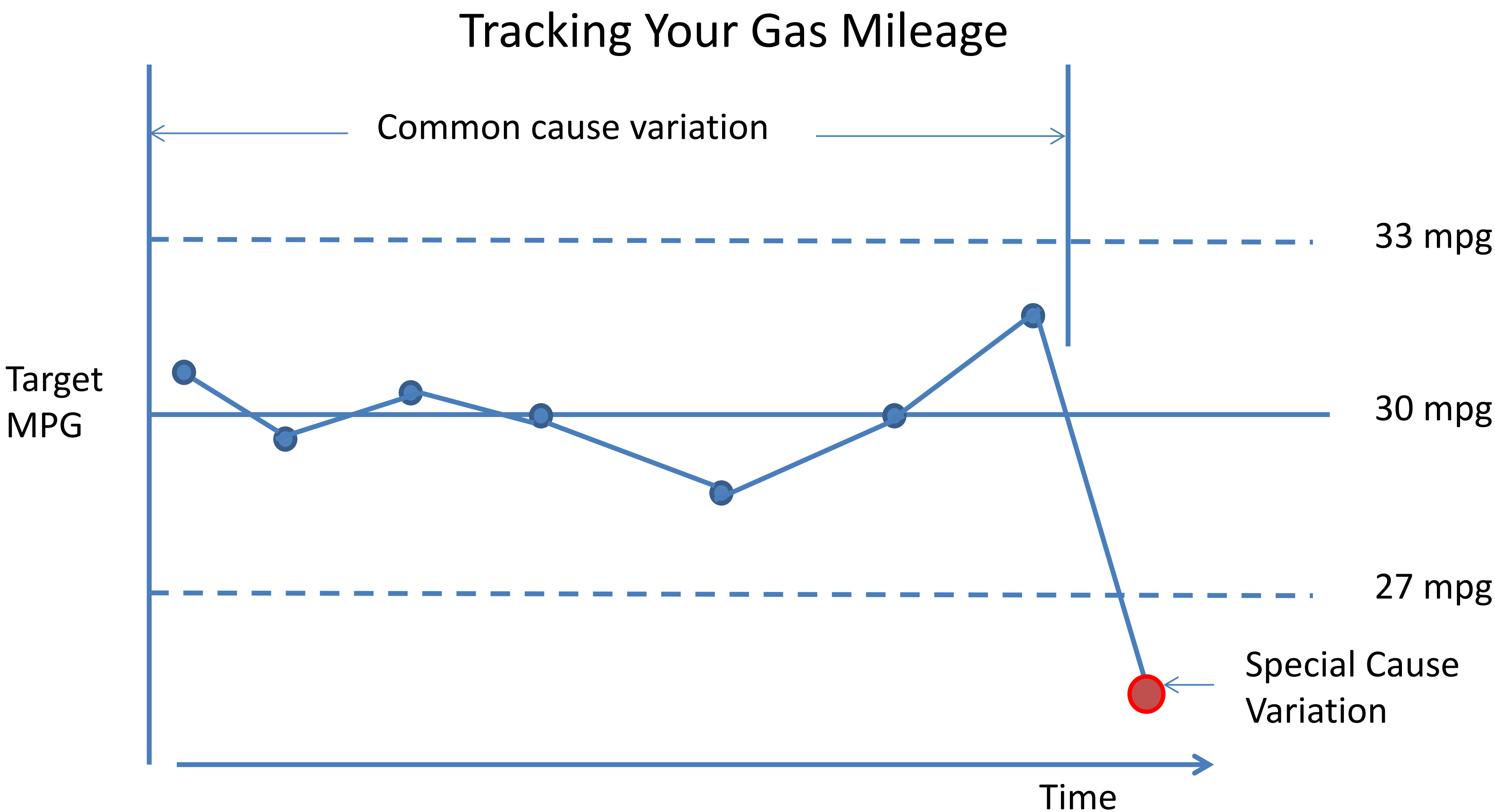
Inherent or Common Cause Variation

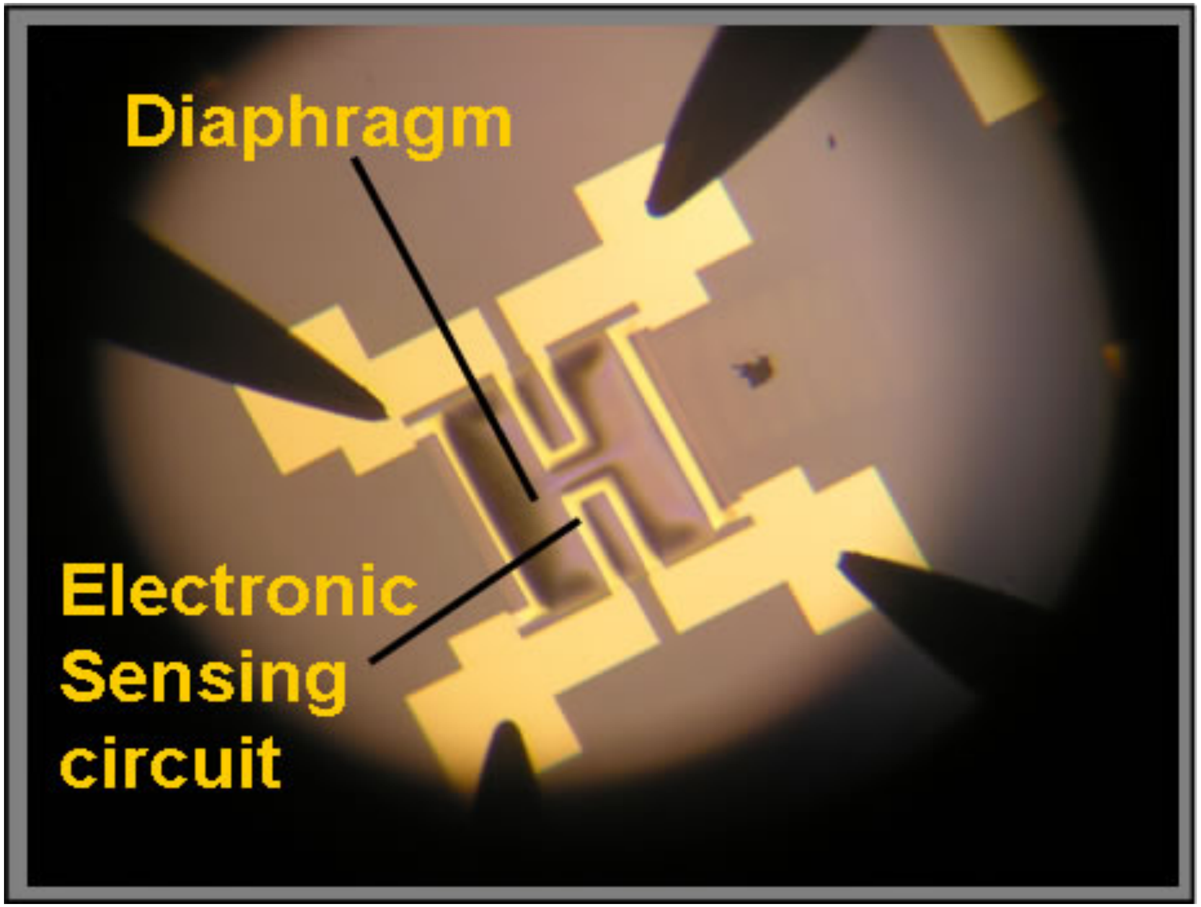




Special Cause Variation



Special Cause Variability

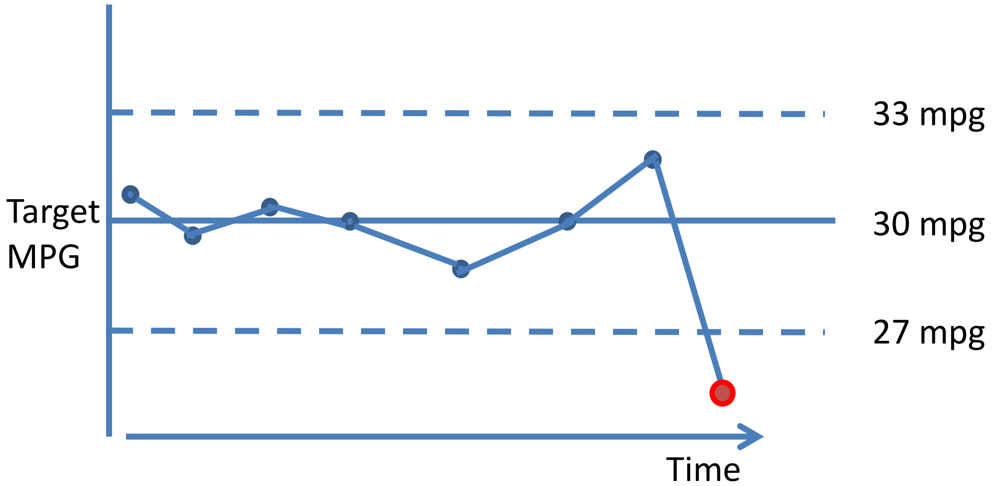


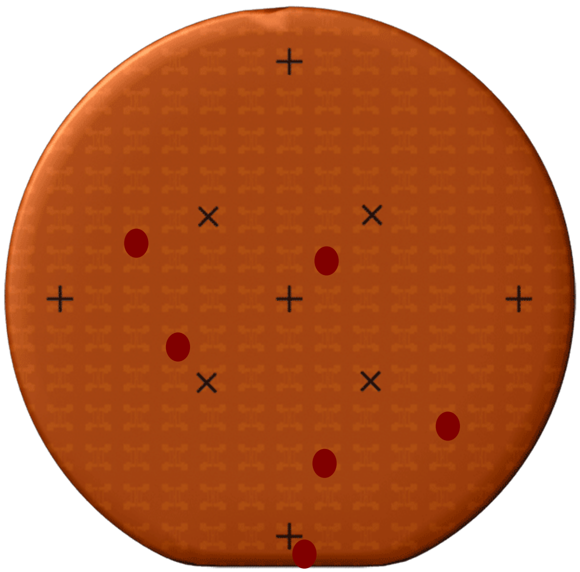
Process Steps:

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

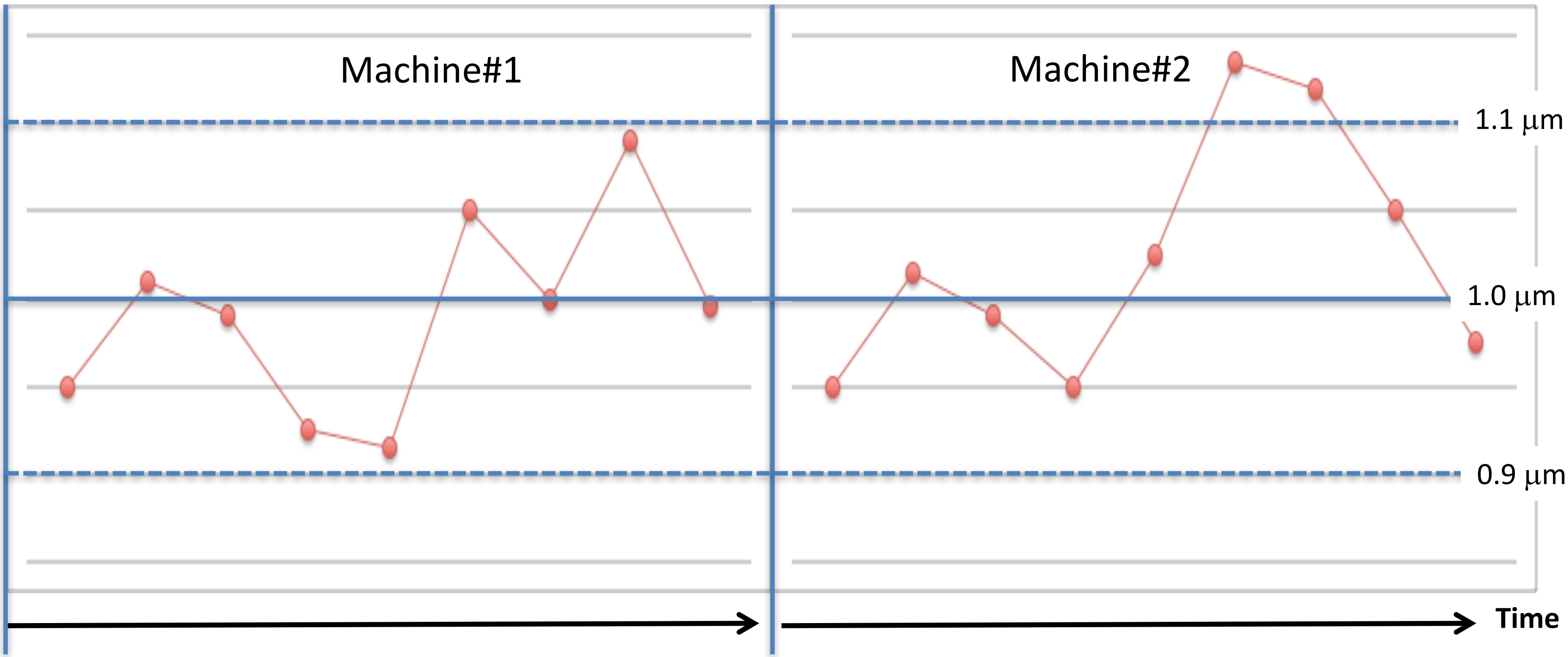
- Variable Data
  - Data Based upon measurements
  - Length, time, weight, temperature, pressure, film thickness
- Attribute Data
  - Data based upon counts (discrete)
  - Either there or not
  - Number of defects, acceptable or unacceptable





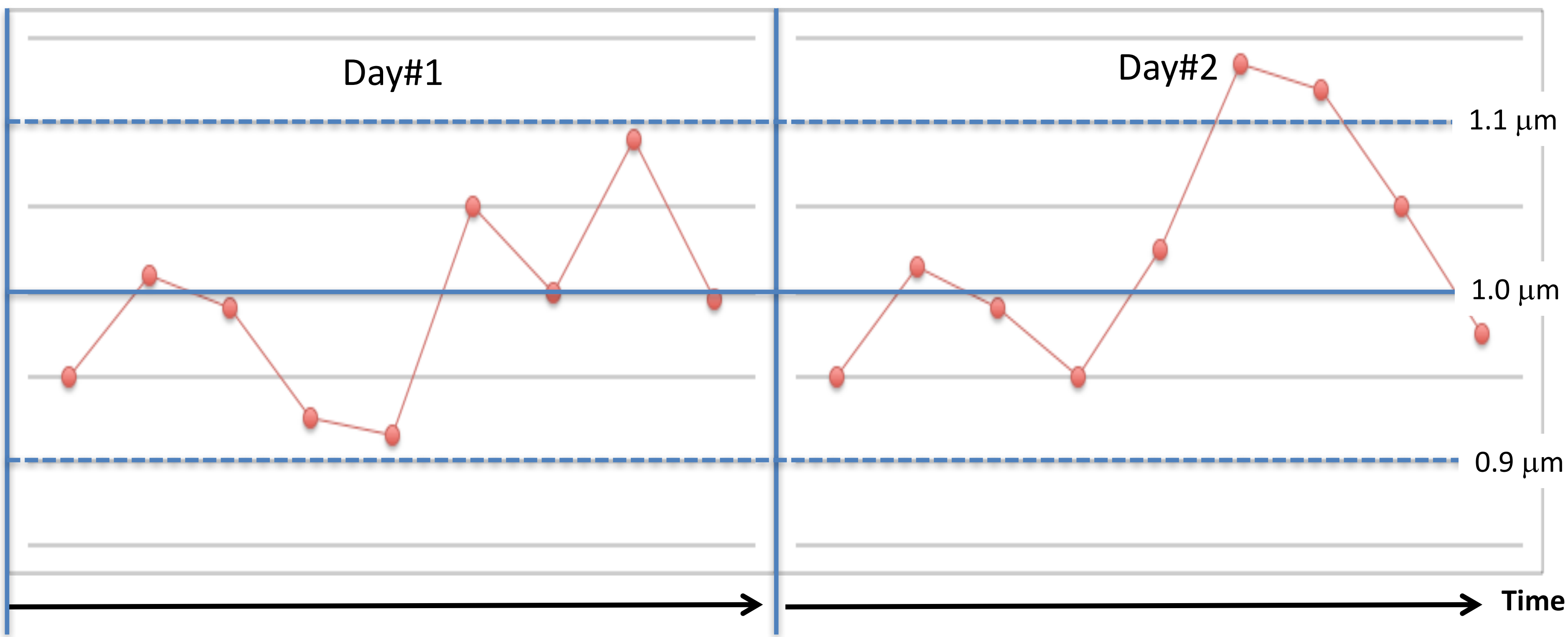
Variability

Photoresist Thickness

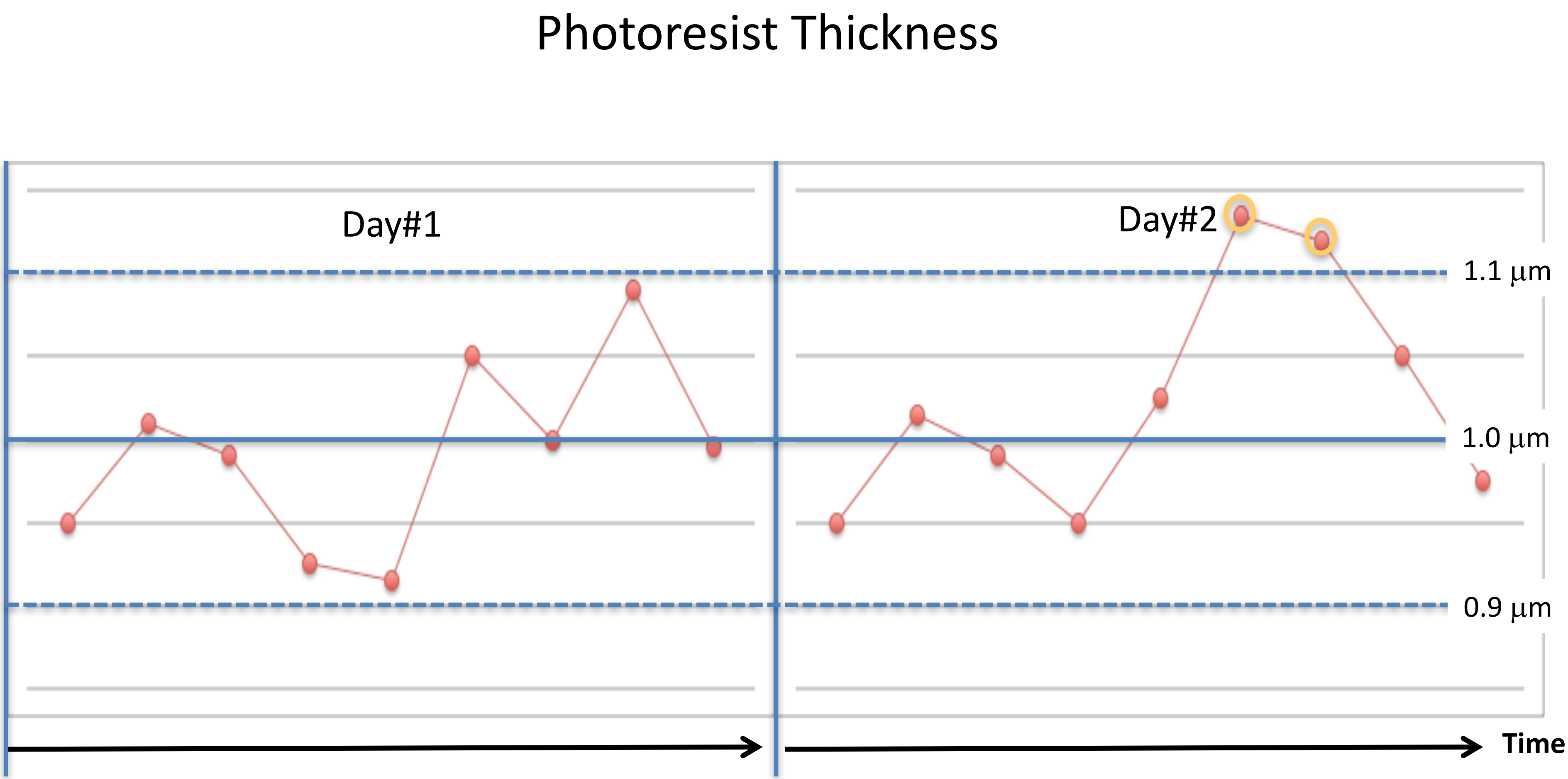


Variability

Photoresist Thickness



Variability

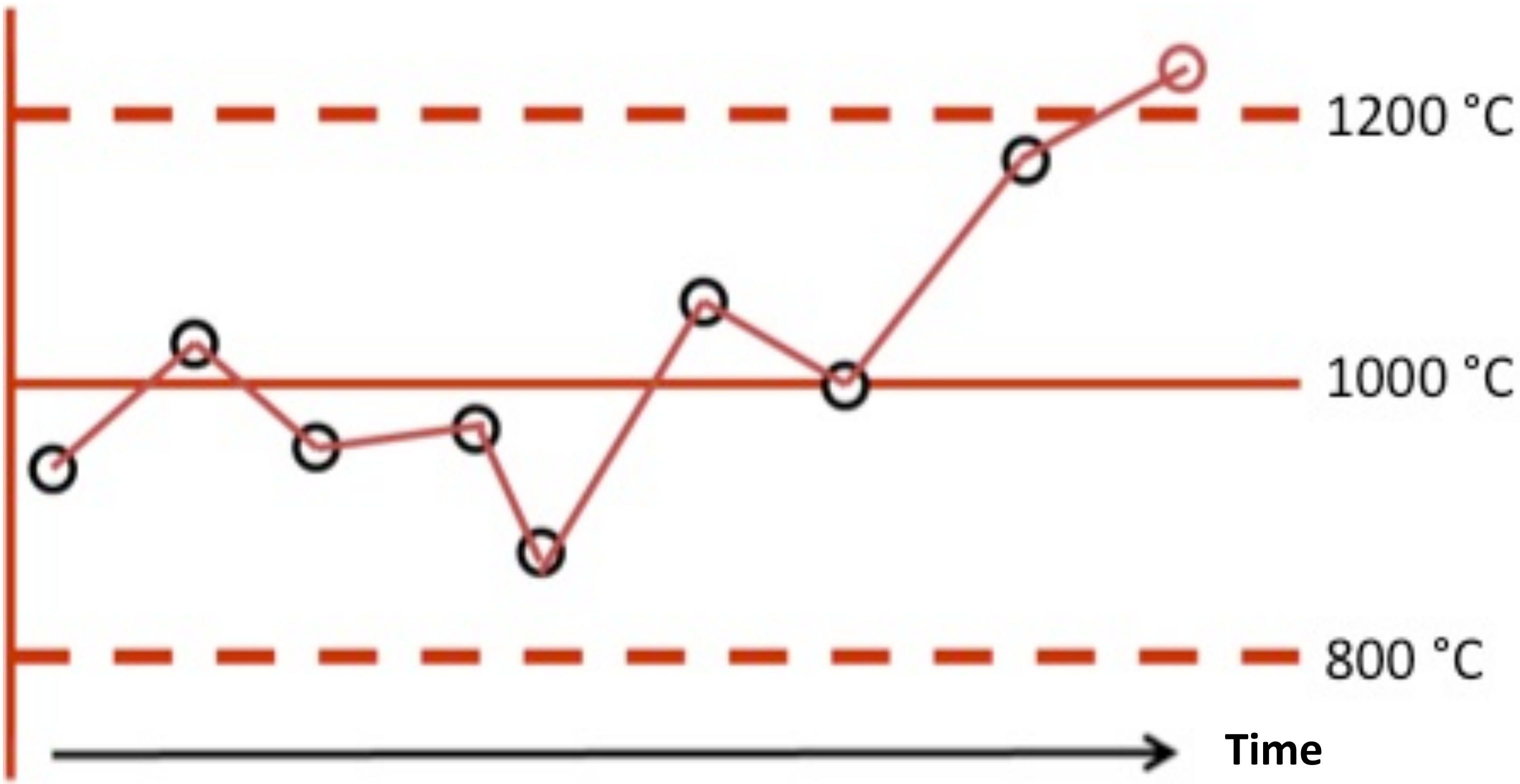


Common Cause Variation
Controlled Variation

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?

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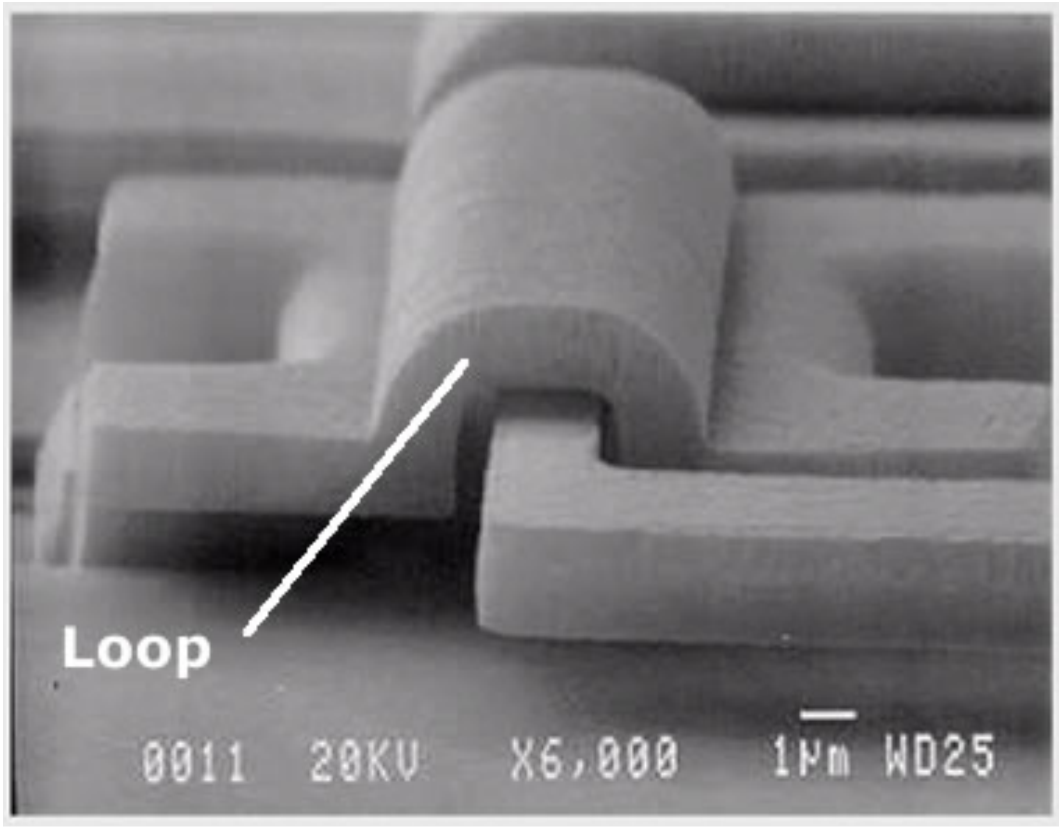
Desired Variation

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

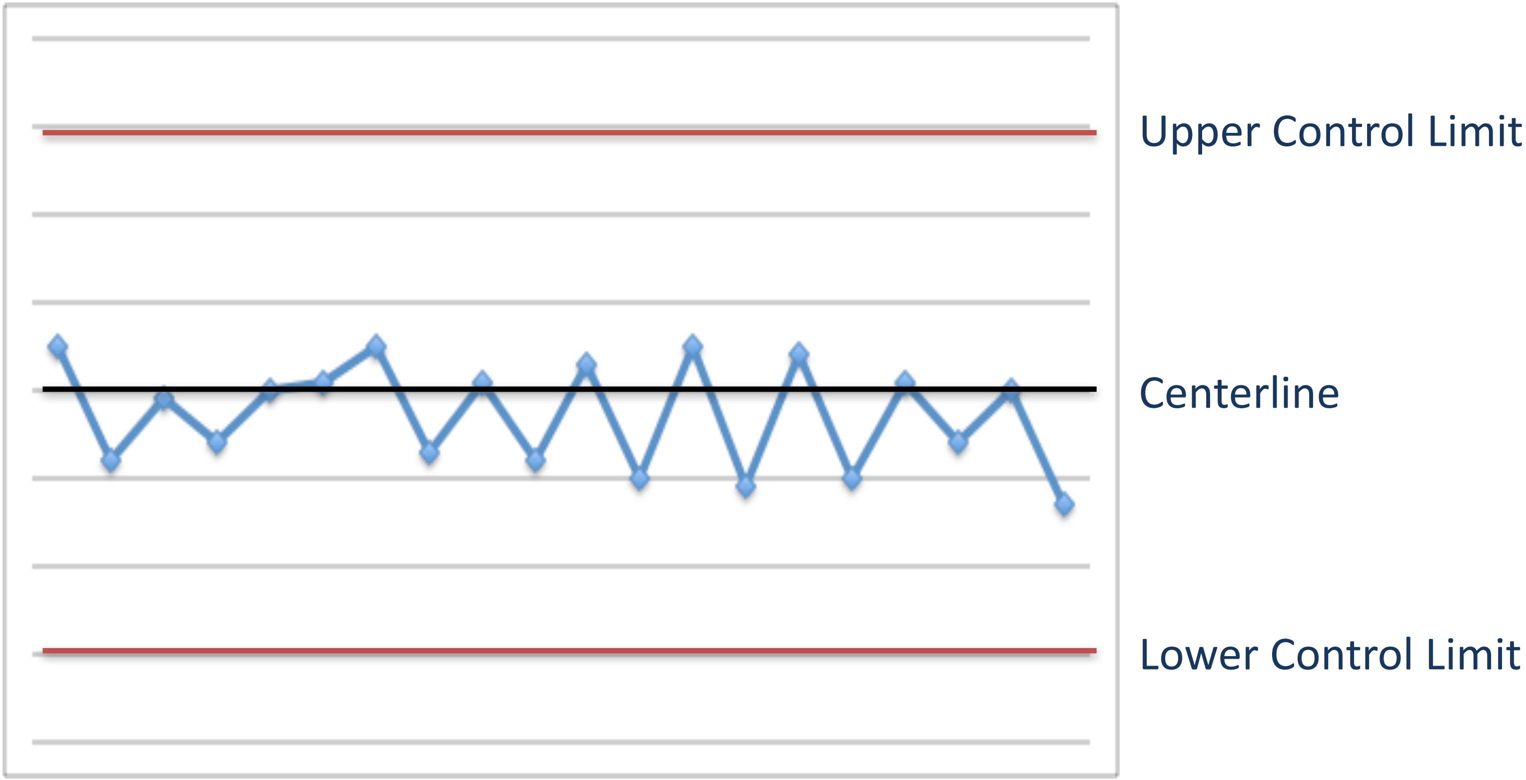
Variation in Microsystems

Hinge System

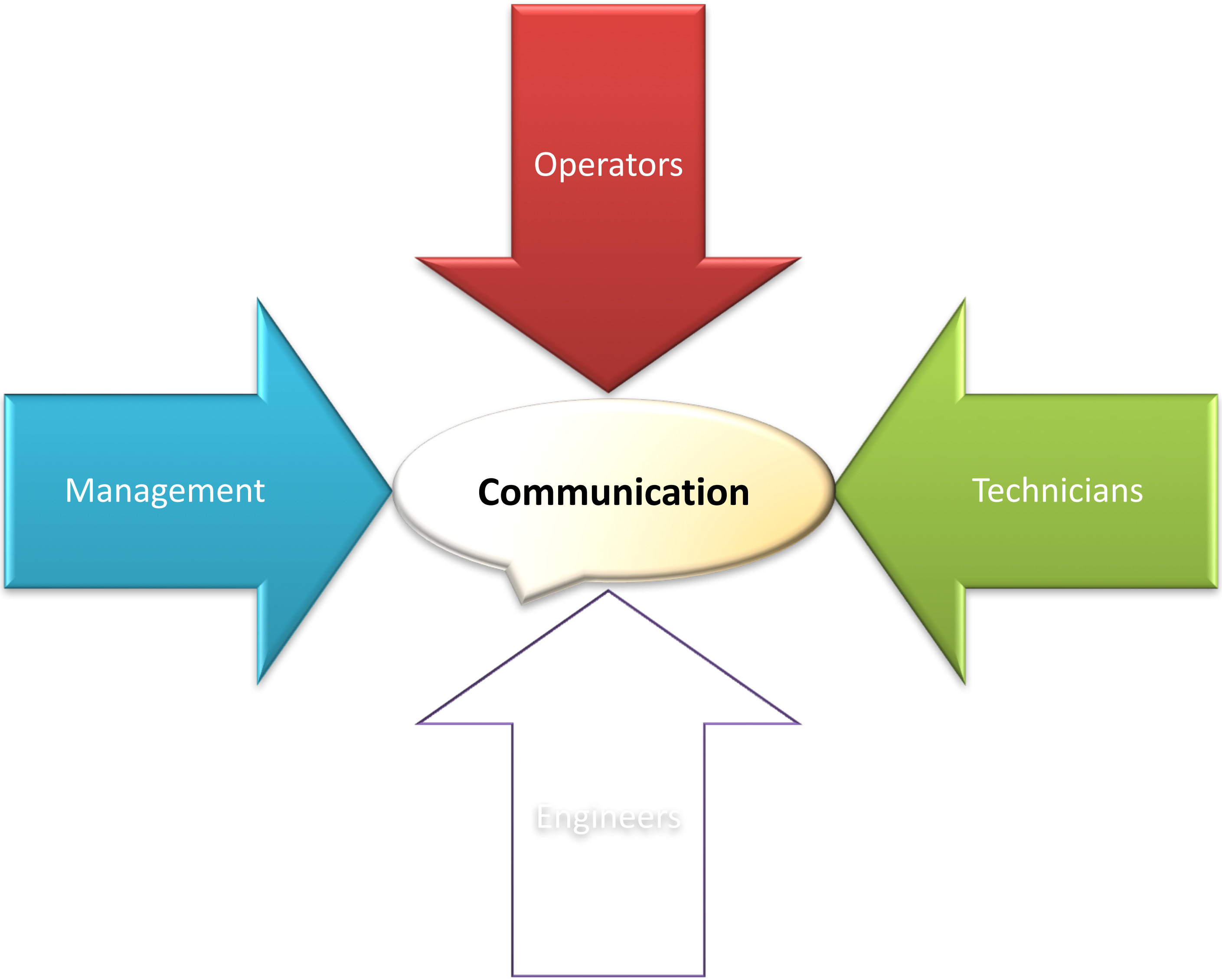


[Image courtesy of Sandia National Laboratories]

Statistical Process Control and Variation

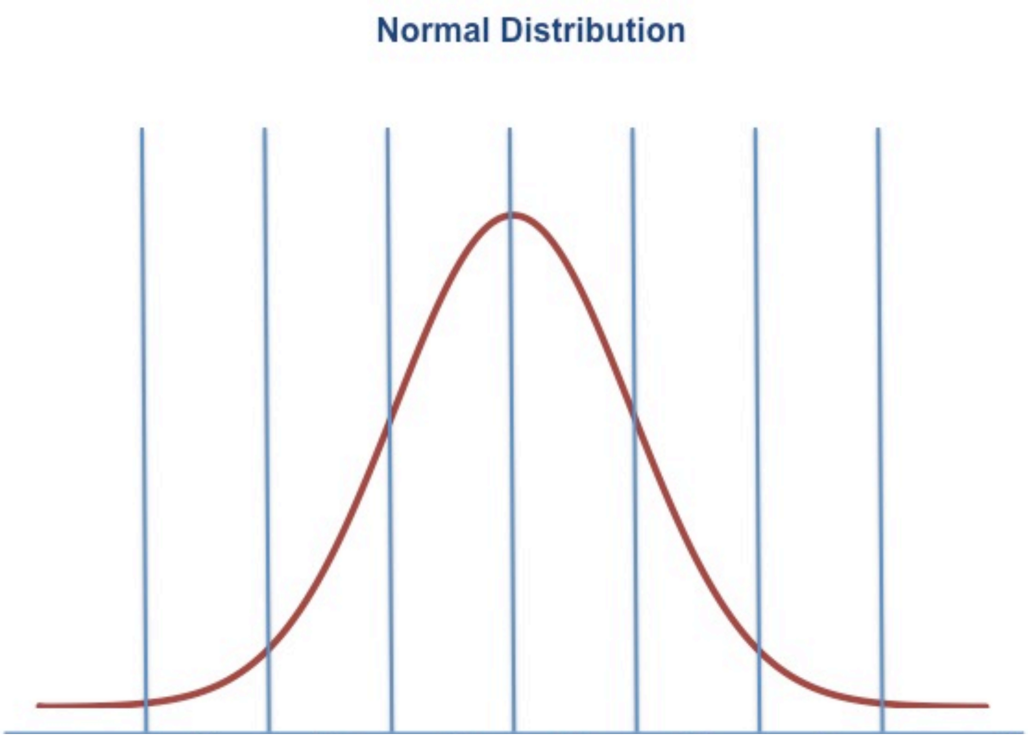


Communication is KEY!



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

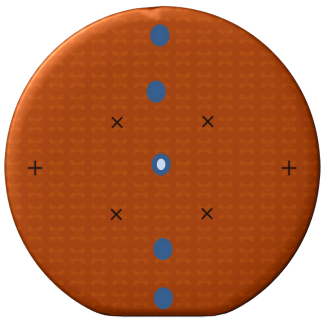
$$\mu = \frac{\Sigma x_n}{n}$$

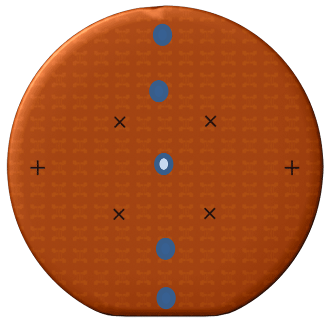
5 Resist Thickness Values: 2.87, 2.99, 3.01, 3.15, 2.98 Microns

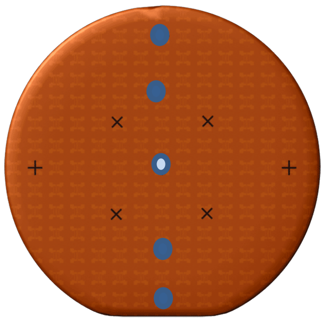
$$\mu = \overline{X} = \frac{2.87 + 2.99 + 3.01 + 3.15 + 2.98}{5} = 3.00 \text{ microns}$$

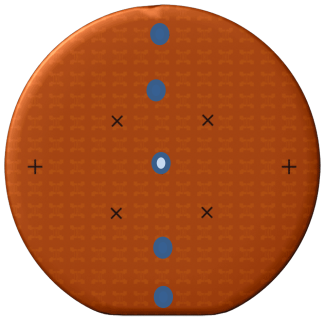
Sample Mean

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

$\bar{X}$

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

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 microns

- 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

Summary

- SPC is a statistical scientific method that provides valuable information about a process
- This type of variation (common and special cause) should be understood and controlled.
- Statistical Concepts used in SPC
  - Sample median
  - Sample mean – μ, $\bar{X}$, $\bar{\bar{X}}$
  - Sample range - R
  - Sample variance – σ^2
  - Sample standard deviation – σ