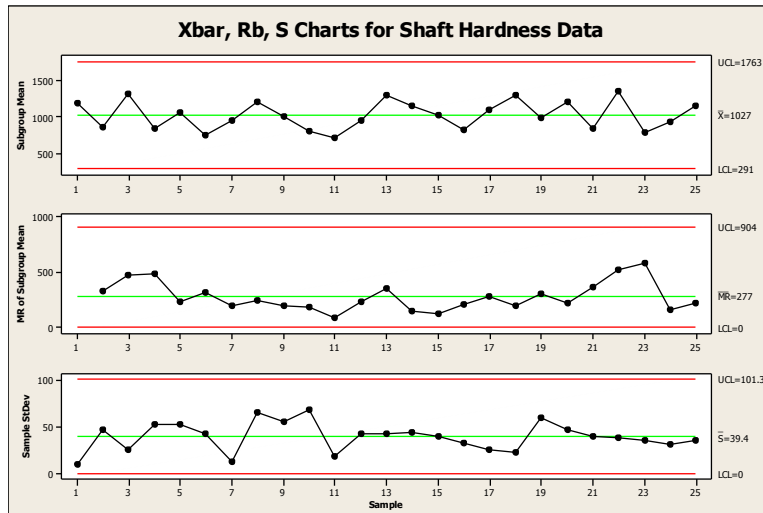


# 10 Keys for Maximizing the Benefits of your SPC Program



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# Agenda

- **What is Statistical Process Control?**
- **The 10 Keys**
  1. **Ensure the Purpose of SPC is Understood**
  2. **Focus on Key Characteristics**
  3. **Validate Measurement Systems**
  4. **Choose the Right Chart**
  5. **Understand Specification Limits vs. Control Limits**
  6. **Employ Effective Sampling Strategy**
  7. **Select the Right Sample Size**
  8. **Automate SPC**
  9. **Empower Operators**
  10. **Manage the Process & Drive Improvement**

# What is Statistical Process Control?

- A proactive monitoring system that detects significant process changes in key characteristics
- A tool for hearing the “voice of the process”
- Objective criteria for reacting / intervening
- Distinguishes signals from the noise
- A tool to *prevent* problems by detecting significant changes quickly

# Key SPC Principles

- **Focus on prevention rather than inspection**
- **Only processes that are in a state of statistical control (e.g. stable) can produce *predictable* outputs**
- **Monitoring and ensuring process stability eliminates the reliance on inspection processes (such as acceptance sampling)**

# History

- **Statistical Process Control Charts were invented by Walter Shewhart in the 1920s while working at Bell Labs**
- **W. Edwards Deming championed and popularized Shewhart's work (1930s through 1980s) and had an enormous impact on the success of Japanese manufacturers after WWII**
- **Currently, deployment of and the success of SPC is uneven both between and within industries**

# The Deming Philosophy

- **Management is responsible for quality**
- **Quality cannot be achieved by inspection**
- **Statistical methods are required to understand and control processes by minimizing variation**



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# The Purpose of SPC

- Control charts tell us when the system has *changed*, (out of control or unstable) so we can quickly identify the causes and prevent an issue or make an improvement
- These can be changes that are still within specification—but are statistically different than where the process was previously running.
- Note that the appropriate method to assess whether the products will meet specification consistently is Process Capability Analysis (provided that the process is stable).



## Radius

3.24

3.28

3.25

3.31

3.28

3.22

3.25

3.26

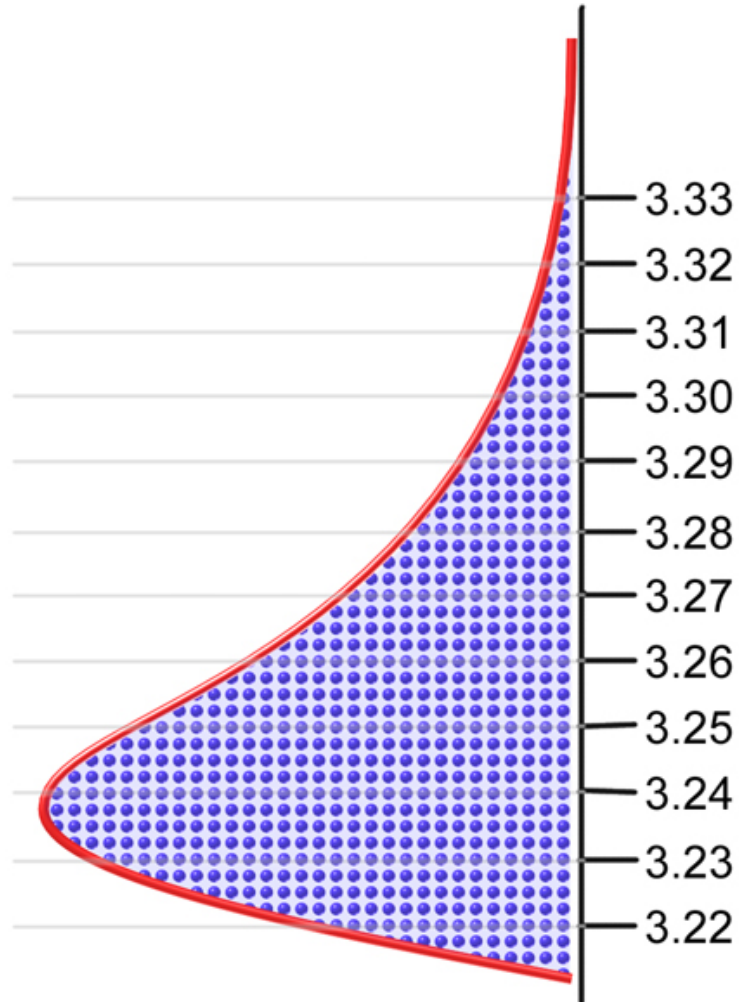
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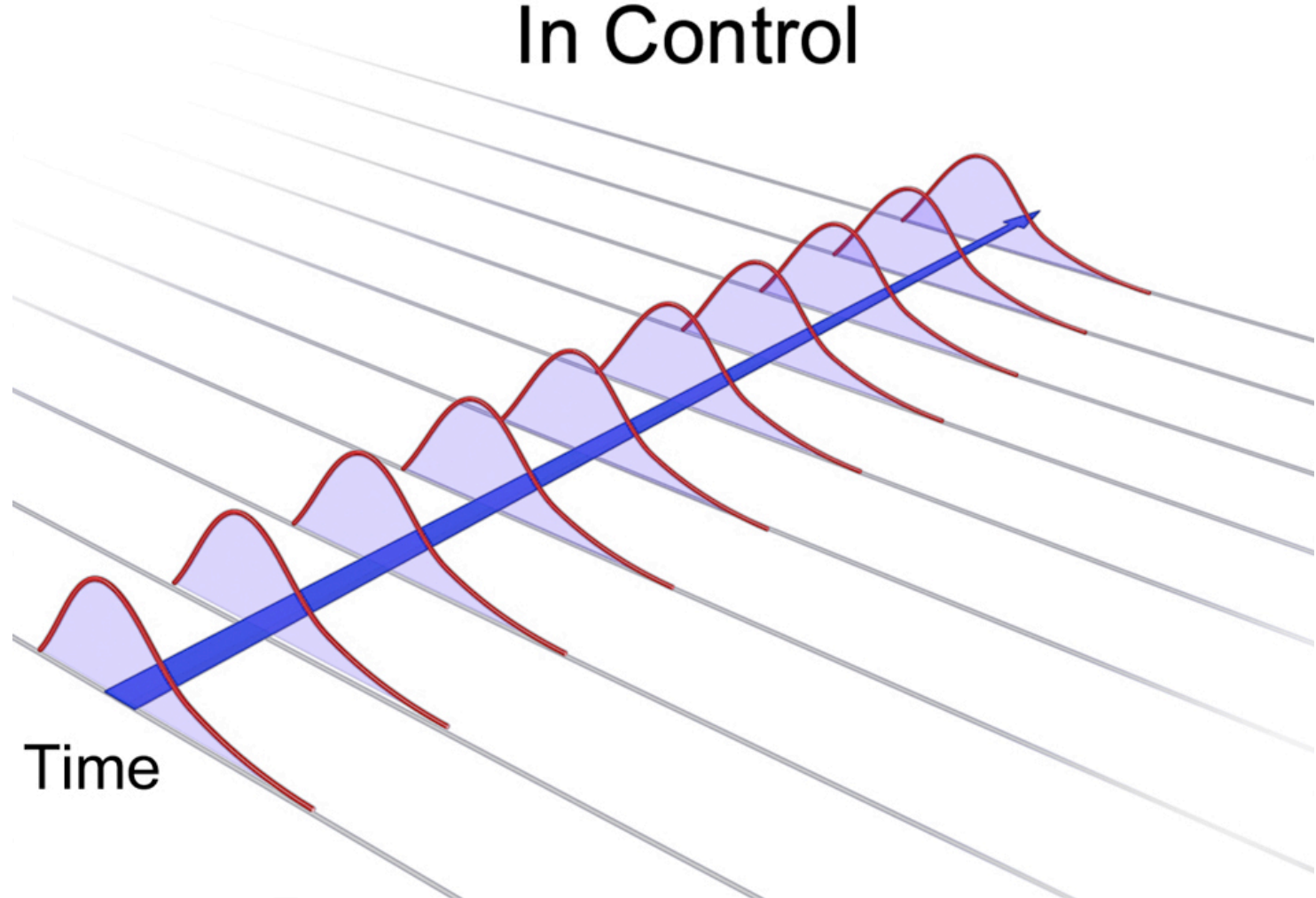
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etc.

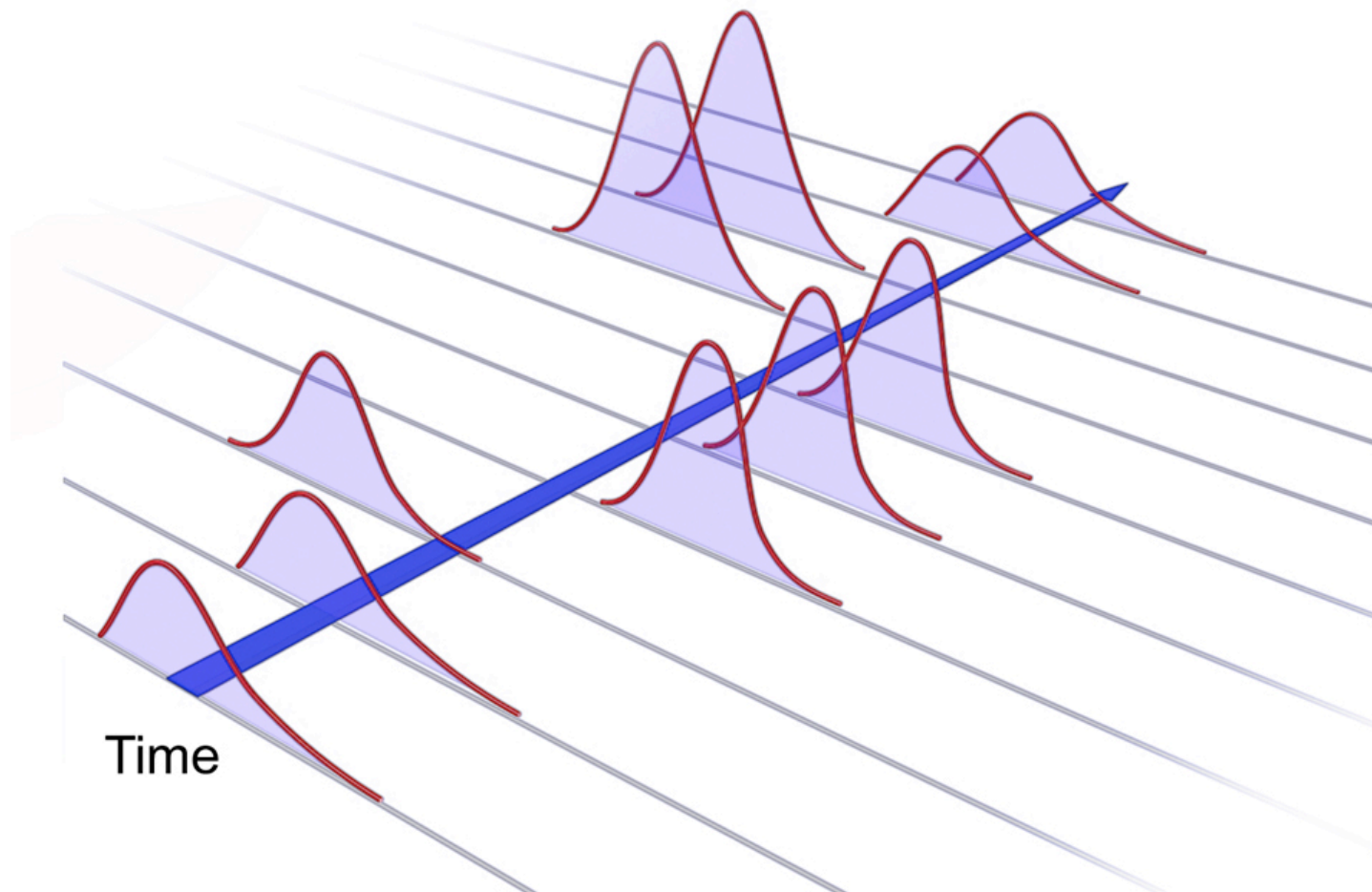


# In Control

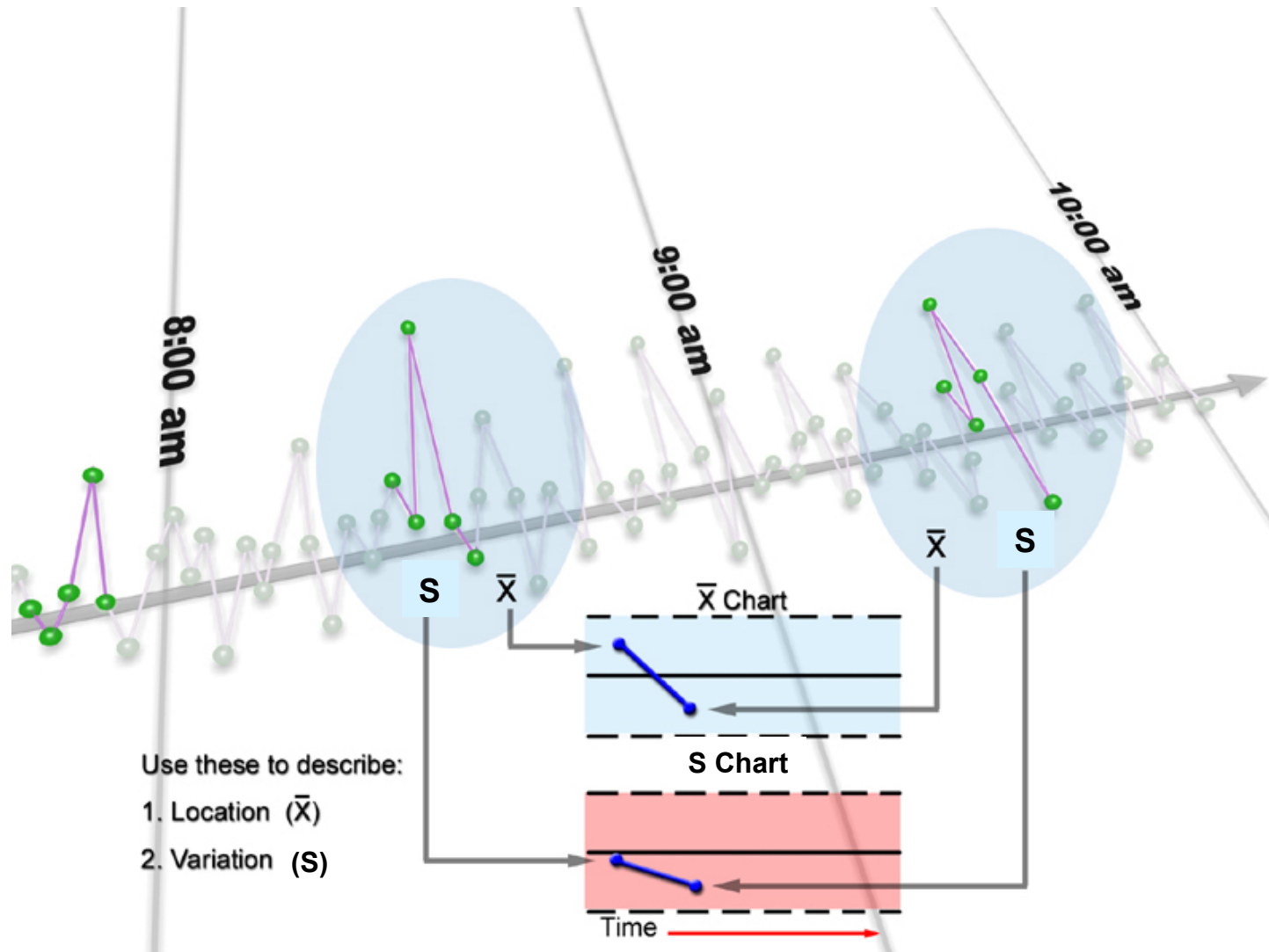


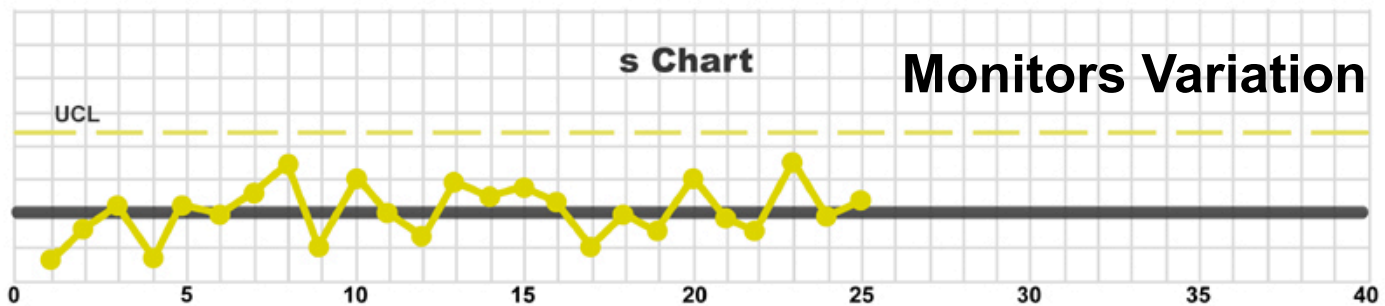
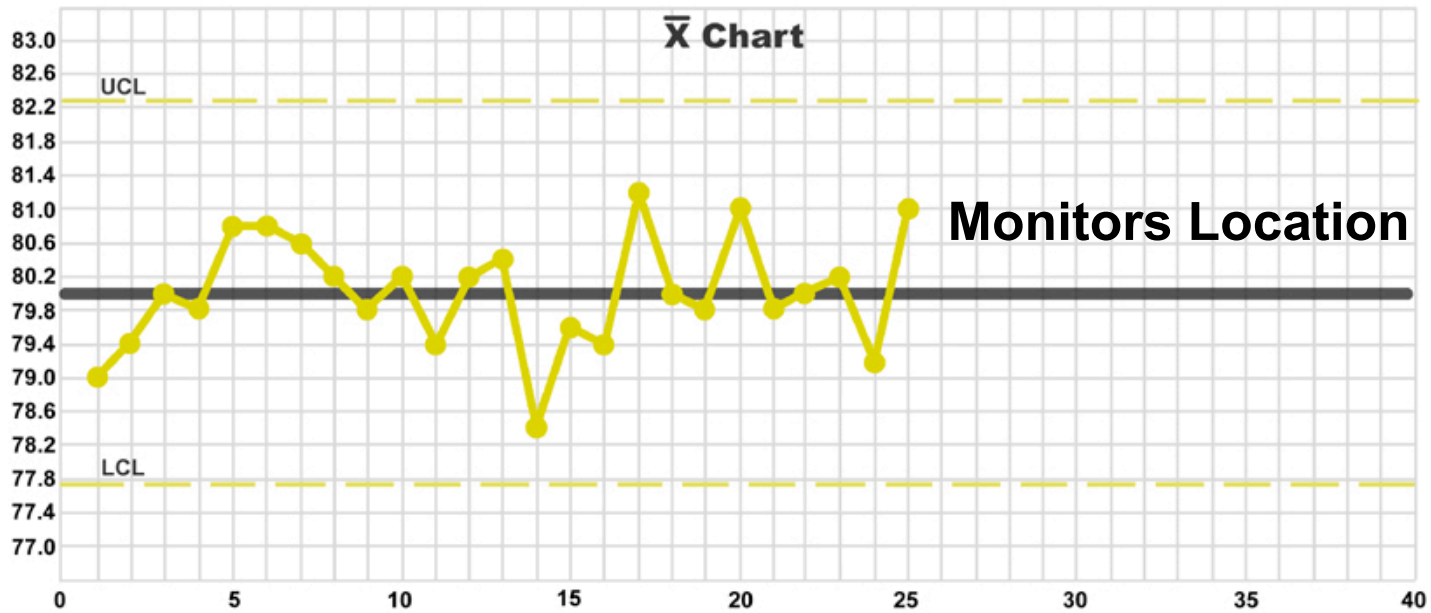
Time

# Out of Control

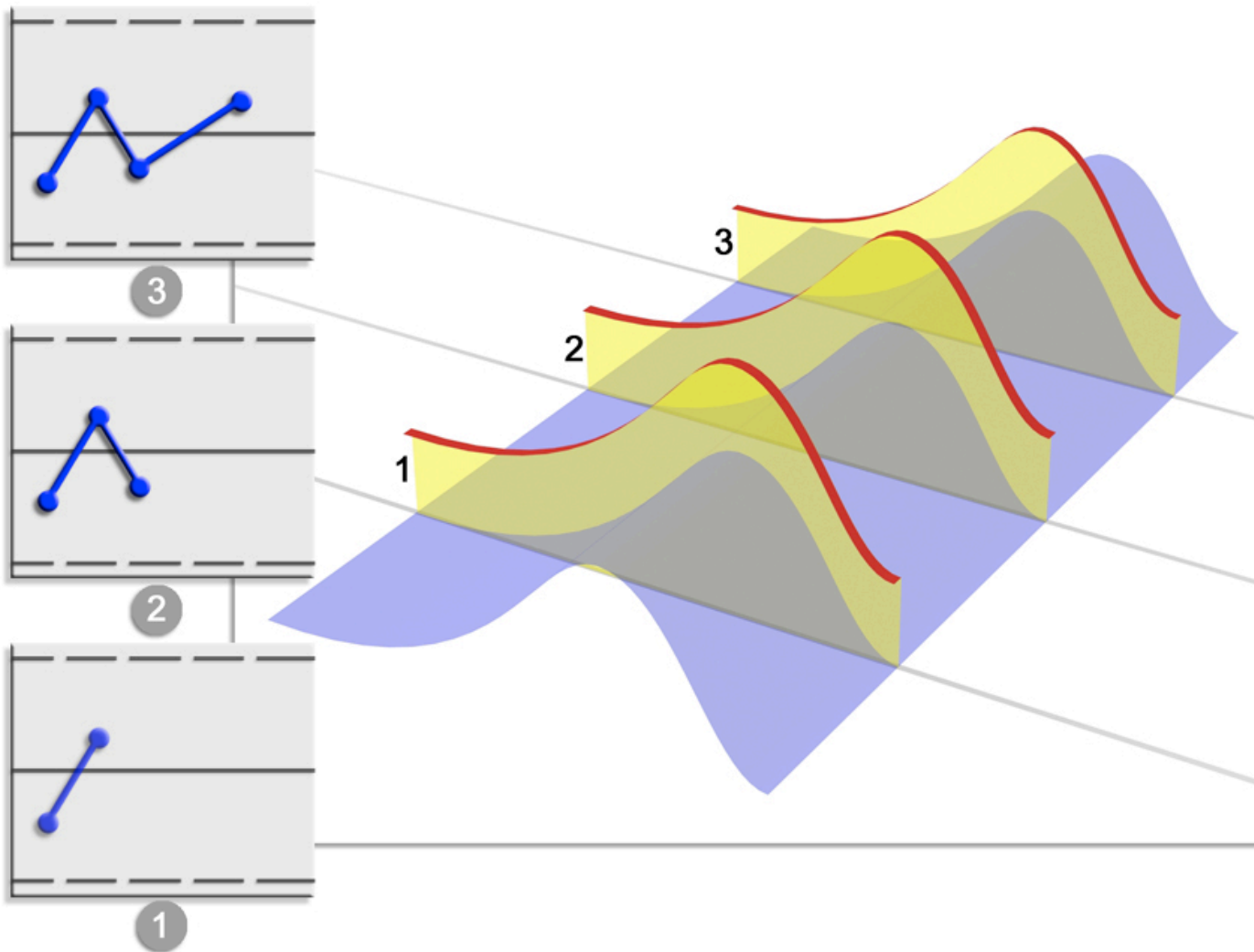


# Sampling over Time





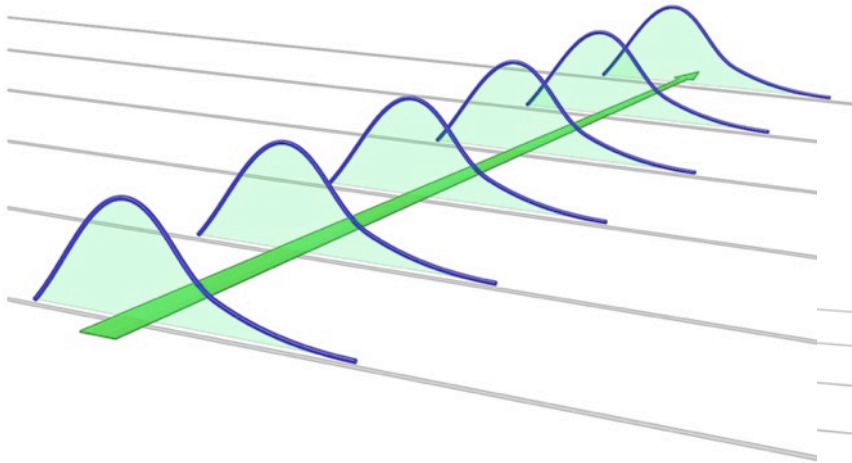
# Control Charts Monitor the Current State of the Process



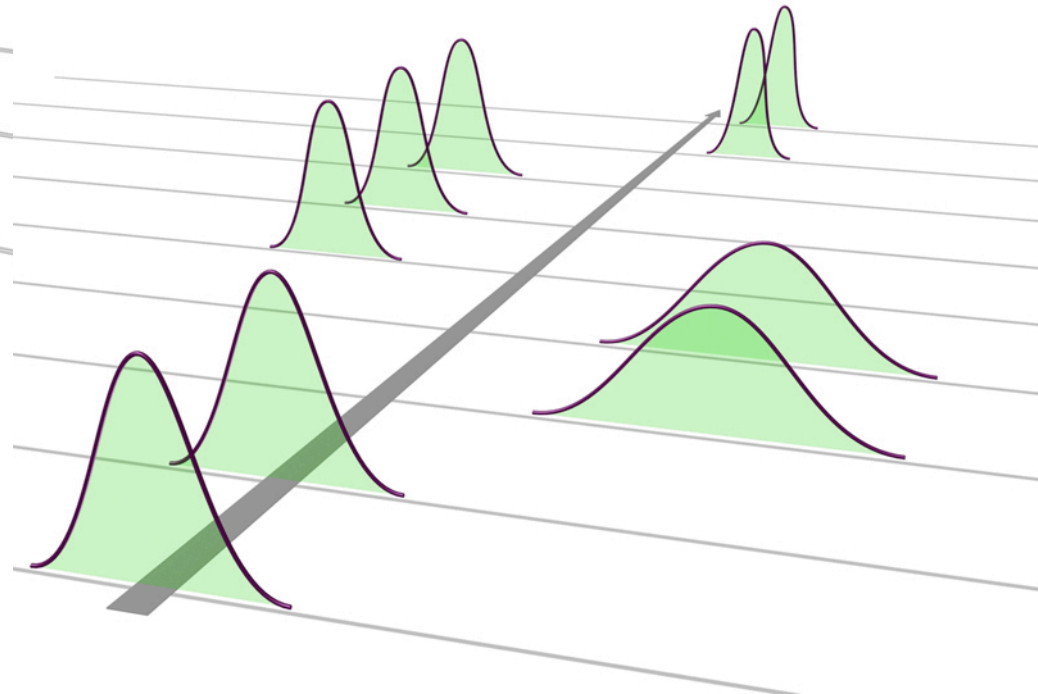
# Sources of Variation

- **Common Cause**
  - An Inherent Part of the Process
  - Random Fluctuations
  - Reflected in Control Limits
- **Special Cause**
  - Due to Assignable Causes that are not Part of the Regular Process
  - Caused by an External Change Affecting the Process
  - Should be detected by Control Charts

## Common Cause Scenario



## Special Cause Scenario





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# Identify & Focus on Key Characteristics

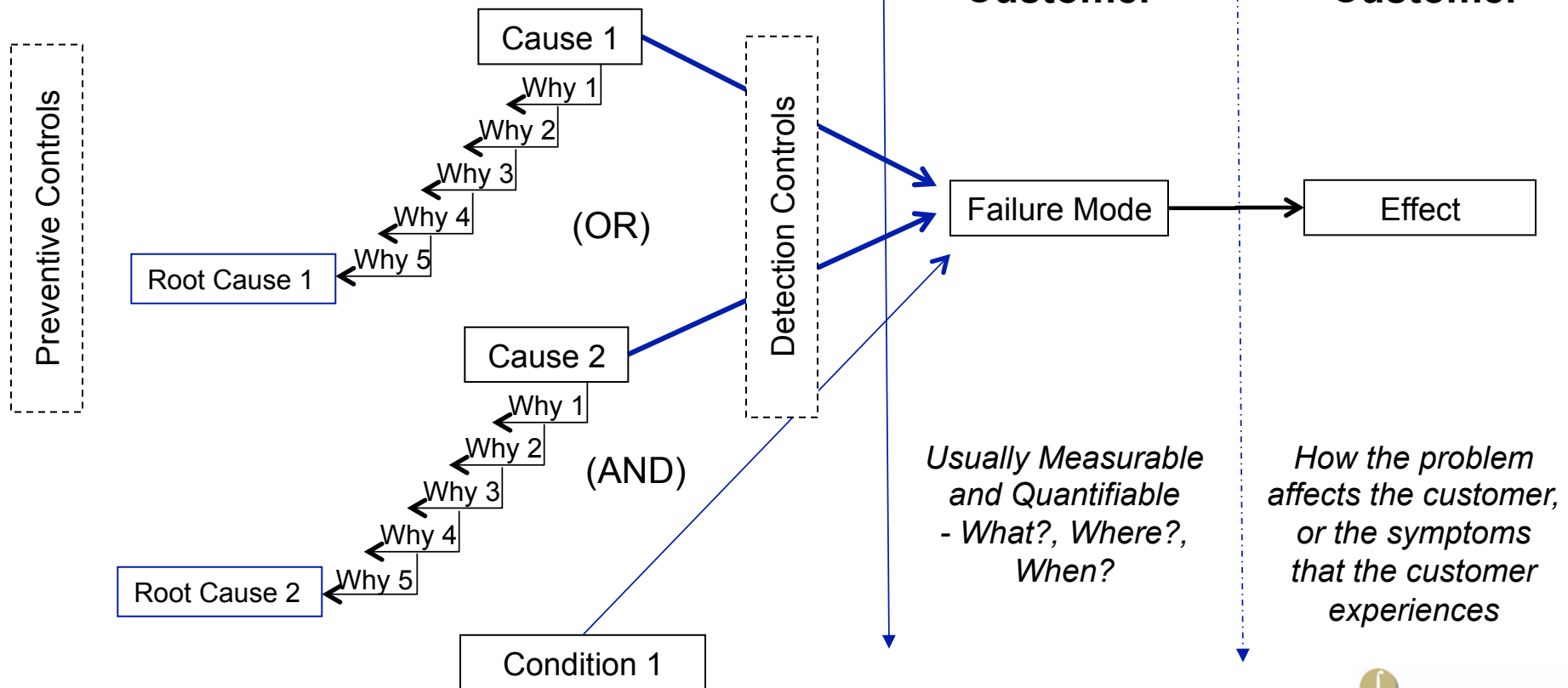
- Controlling *everything* is not feasible or efficient
- We should control those process characteristics whose variation will impair product performance, quality, and reliability
- When the significant process variables that affect a key process output are being controlled, then the process output is predictable, allowing costly inspection systems to be eliminated
- Move upstream in the process!

# Identify & Focus on Key Characteristics

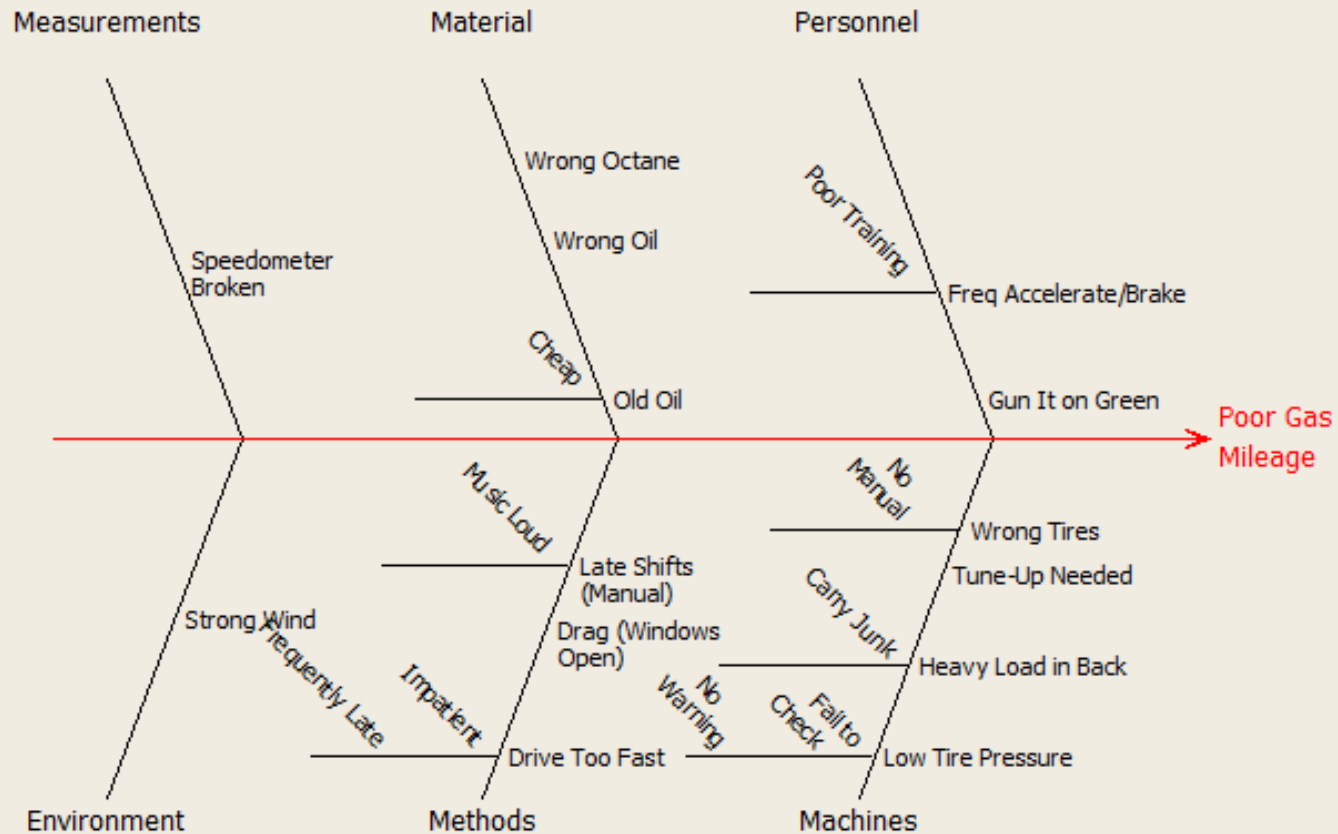
- **Methods for developing process understanding (relationships between process inputs and outputs) include:**
  - **Cause & Effect Tools**
  - **Graphical Analysis**
  - **Design of Experiments**
  - **Regression Modeling**

# Cause & Effect

**Every Problem or Effect has a cause... all the way back to the root cause**

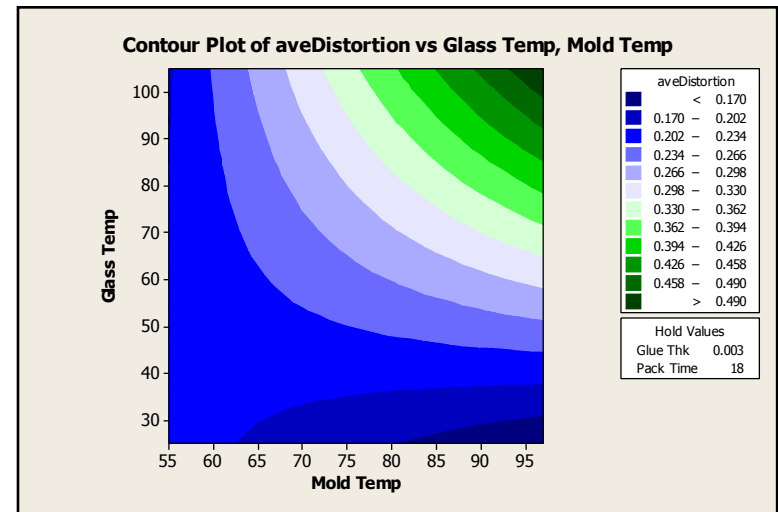
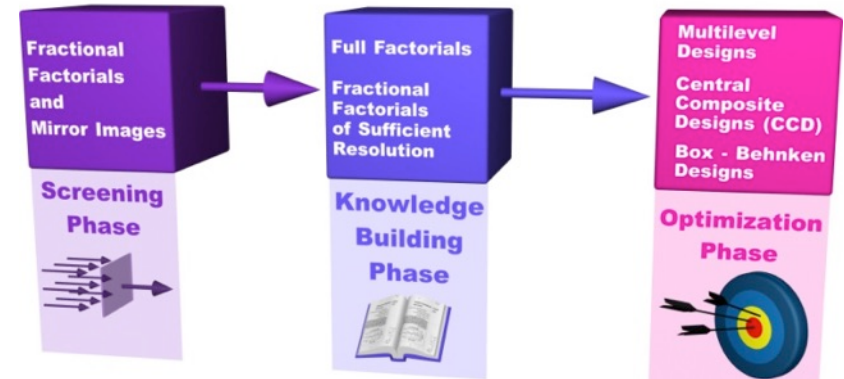
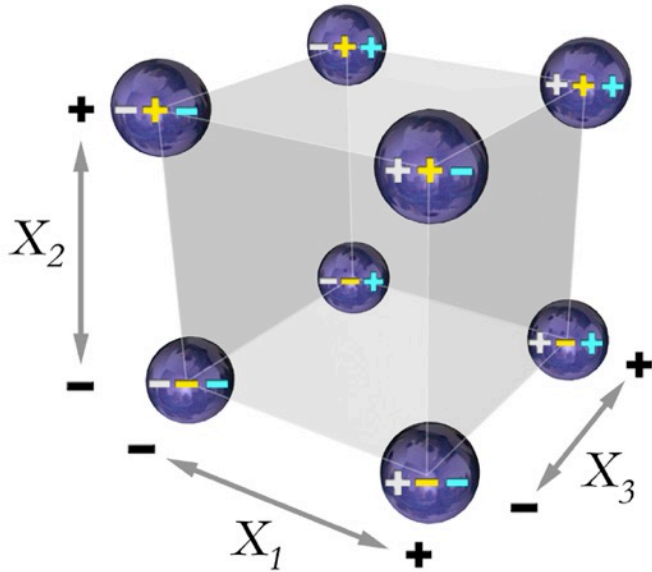


## Fishbone Diagram for Poor Gas Mileage



# Design of Experiments

Geometric Representation  
of a  $2^3$  Design



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# Validate Measurement Systems

- The effective use of data to drive decision making requires adequate measurement systems.
- When interpreting SPC charts, we assume that a signal represents the measurement of a significant change in the *process* and we react accordingly.
- However, inadequate measurement systems may result in inappropriate signals or, even worse, charts that fail to detect important process changes.



# Validate Measurement Systems

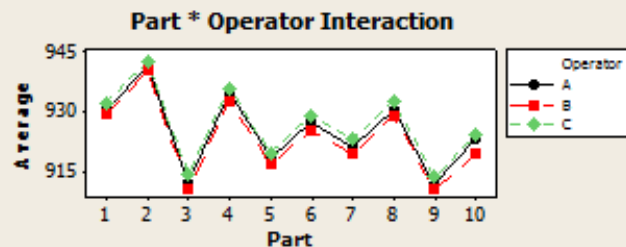
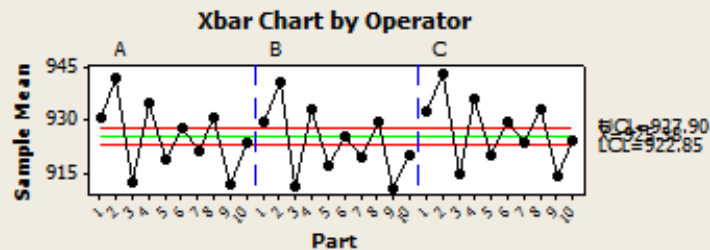
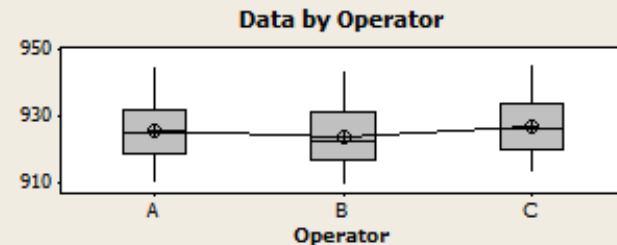
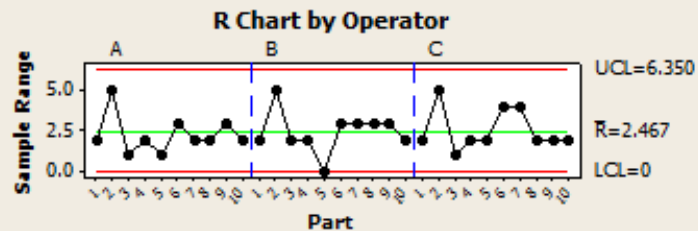
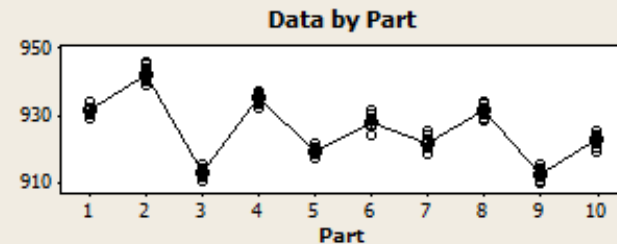
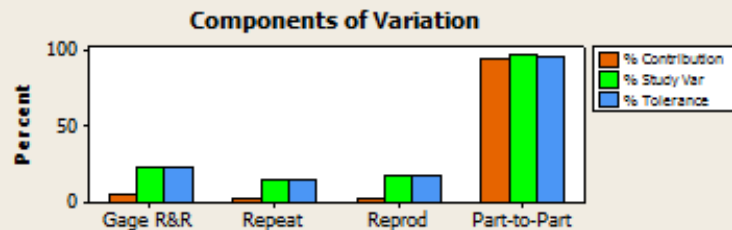
- Important measurement system characteristics include discrimination, accuracy, precision (repeatability and reproducibility), linearity, and stability.
- Techniques exist to assess measurement systems for each of these important characteristics. Skipping such assessments can lead to the use of measurement systems that are not capable of monitoring process variation or, in extreme cases, even of distinguishing between conforming and non-conforming product.
- In short, validating measurement systems is an important pre-requisite to applying SPC methods.

# Validate Measurement Systems

## Gage R&R (Xbar/R) for Data

Gage name:  
Date of study:

Reported by:  
Tolerance:  
Misc:



# Agenda

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# Choosing the Right Chart

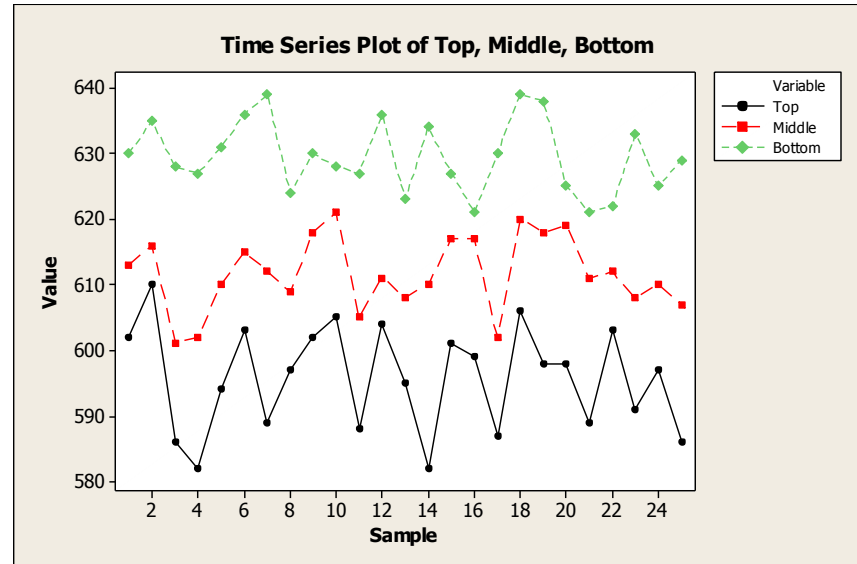
- **Factors to consider when choosing a control chart:**
  - The type of data being charted (continuous or attribute)
  - The required chart sensitivity (size of the change to be detected)
  - Whether the chart includes data from multiple locations (possibly resulting in more than one expected source of variation)
  - The ease and cost of sampling
  - Production volumes
  - The presence and frequency of production changeovers (e.g., short production runs)
  - Whether or not trending is expected (e.g., due to tool wear)

# Choosing the Right Chart

- **Traditional control charts (e.g.,  $\bar{X}$ /R,  $\bar{X}$ /MR) were developed in the 1920's when production systems were far more primitive.**
- **Often, these traditional charts are inappropriate at managing and identifying changes that occur in modern day manufacturing systems.**
- **Newer charting techniques have been developed to accommodate modern manufacturing methods (e.g., Within/Between charts, Cusum charts)**

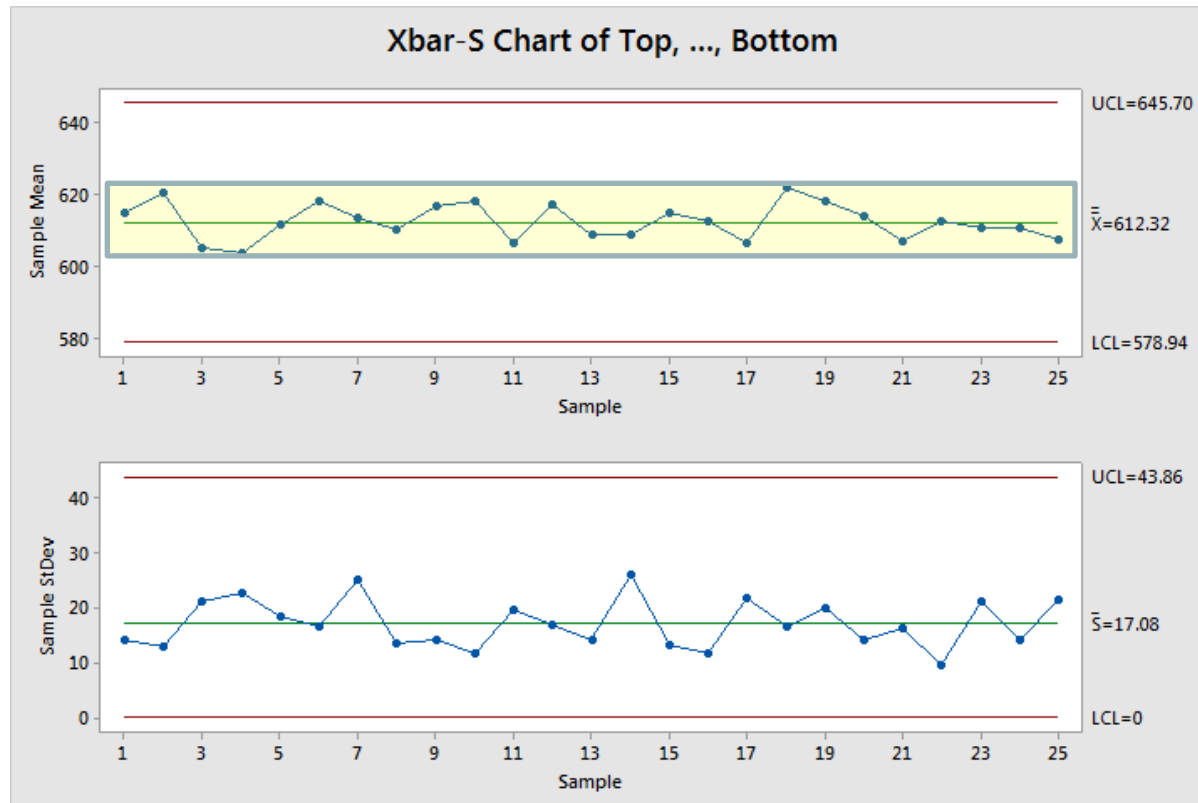
# Example Where Traditional Charts are Inappropriate

Sample	Top	Middle	Bottom
1	602	613	630
2	610	616	635
3	586	601	628
4	582	602	627
5	594	610	631
6	603	615	636
7	589	612	639
8	597	609	624
9	602	618	630
10	605	621	628
11	588	605	627
12	604	611	636
13	595	608	623
14	582	610	634
15	601	617	627
16	599	617	621
17	587	602	630
18	606	620	639
19	598	618	638
20	598	619	625
21	589	611	621
22	603	612	622
23	591	608	633
24	597	610	625
25	586	607	629



***A Significant Difference  
Exists Between the Locations  
that we sample from***

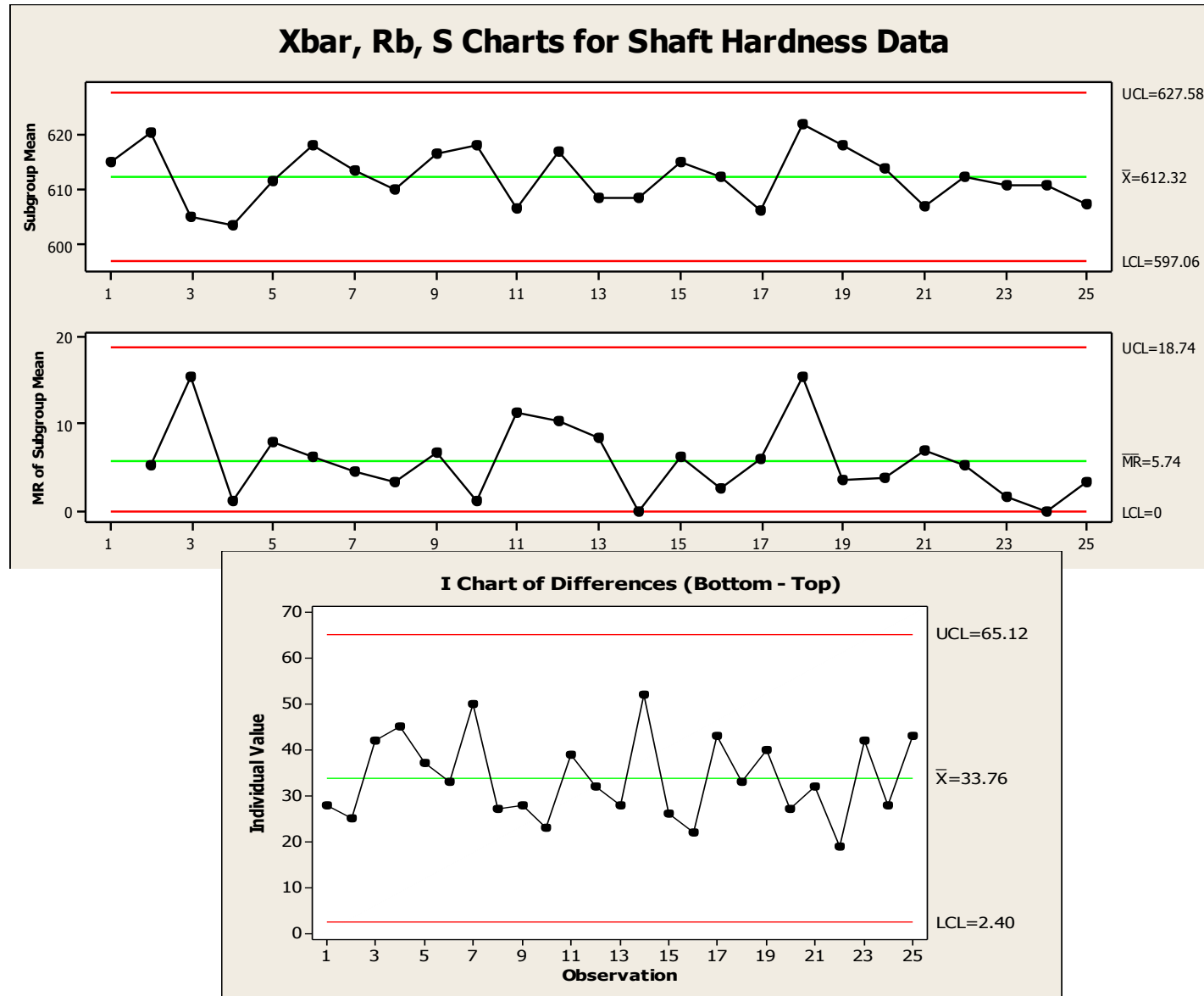
# Example of Rational Sampling Violation



## The Problem

- The control limits for the Xbar chart are based on *within sample* variation, but in this case, the *within sample* variation is much bigger than the *between sample* variation (reflecting location to location differences)

# Example of Rational Sampling Violation





# Control Chart Selection

## VARIABLE CHARTS

Data Type	Chart(s)	Monitors	Applications
Variable	X-Bar and S	Process average and standard deviation	High volume, single characteristic Sample size 2 or larger
Variable	X-Bar and R	Process average and range	High volume, single characteristic Sample size between 2 and 5
Variable	X and MR	Process average and moving range	Sensitivity not required Sampling is costly Long Cycle Time Note: Normality of data must be considered
Variable	Deviation from Nominal (DNOM), R or S	Process average and range (or standard deviation)	Short Production Runs (Multiple parts) All parts have similar standard deviation
Variable	Standardized DNOM, R or S	Process average and range (or standard deviation)	Short Production Runs (Multiple parts) Part standard deviations differ
Variable	X-Bar, Rb, d	Process average, range between and difference between extreme locations	Multiple locations within subgroup Location averages are statistically different
Variable	X-Bar, Rb, Rw X-Bar, Rb, S	Process average, range (or std dev) within and range between subgroup	Multiple locations within subgroup Variation within and between subgroups different Location averages are not statistically different
Variable	CUSUM	Cumulative deviations from mean	Charts for individuals when X and MR are not sensitive enough
Variable	EWMA	Exponentially weighted moving average	Charts for individuals when X and MR are not sensitive enough

# Control Chart Selection

## ATTRIBUTE CHARTS

Data Type	Chart	Monitors	Applications
Attribute	np	Number of Defectives	Pass/Fail Data Constant Sample Size $n > 3/p$
Attribute	p	Proportion Defective	Pass/Fail Data Constant or Variable Sample Size $n > 3/p$
Attribute	standardized p	Standardized Proportion Defective	Pass/Fail Data Variable Sample Size $n > 3/p$ can be used for short production runs
Attribute	c	Number of Defects	Multiple types of defects on unit Constant Sample Size $n$ such that $c > 7$
Attribute	u	Number of Defects per unit	Multiple types of defects on unit Constant or Variable Sample Size $n$ such that $c > 7$
Attribute	standardized u	Standardized Number of Defects per unit	Multiple types of defects on unit Variable Sample Size $n$ such that $c > 7$ can be used for short production runs

# Agenda

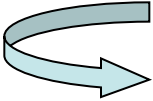
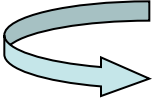
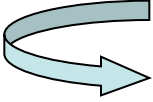
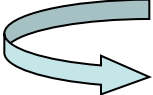
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# Spec Limits vs. Control Limits





- Control limits represent the range over which we expect *statistics*, such as process averages or standard deviations, to fall.
- On the other hand, specification limits are limits of conformance pertaining to *individual values* such as a part dimension or material properties.
- Control limits should only be determined by actual process data whereas specification limits are determined by an engineer, designer, or customer.

# Control Limits are Limits of *Expected Variation*

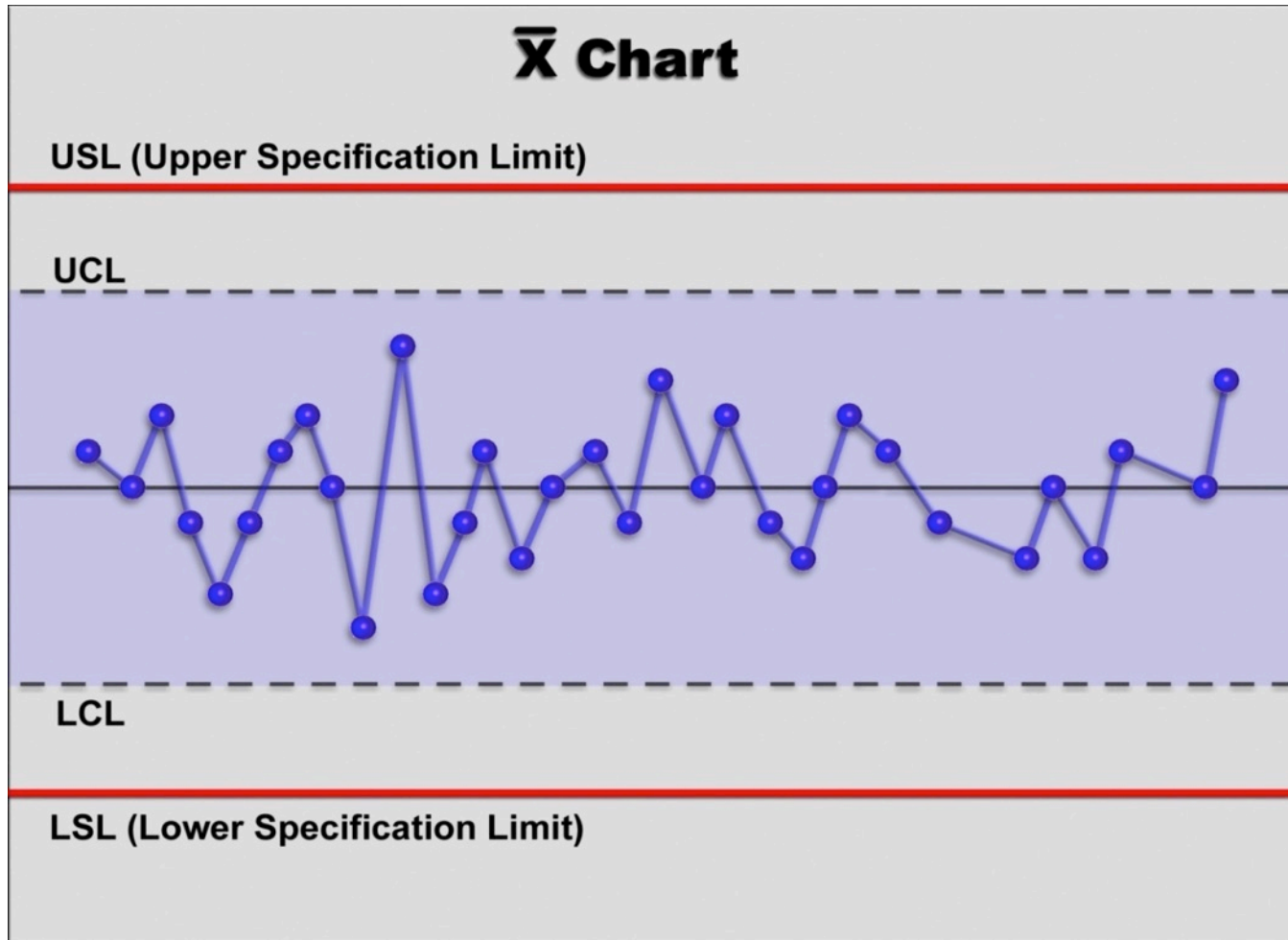
## Specification Limits

-  are determined by a **Person**
-  are based on **Product Function**
-  are used to assess **Conformance**
-  apply to **Individual Parts**

## Control Limits

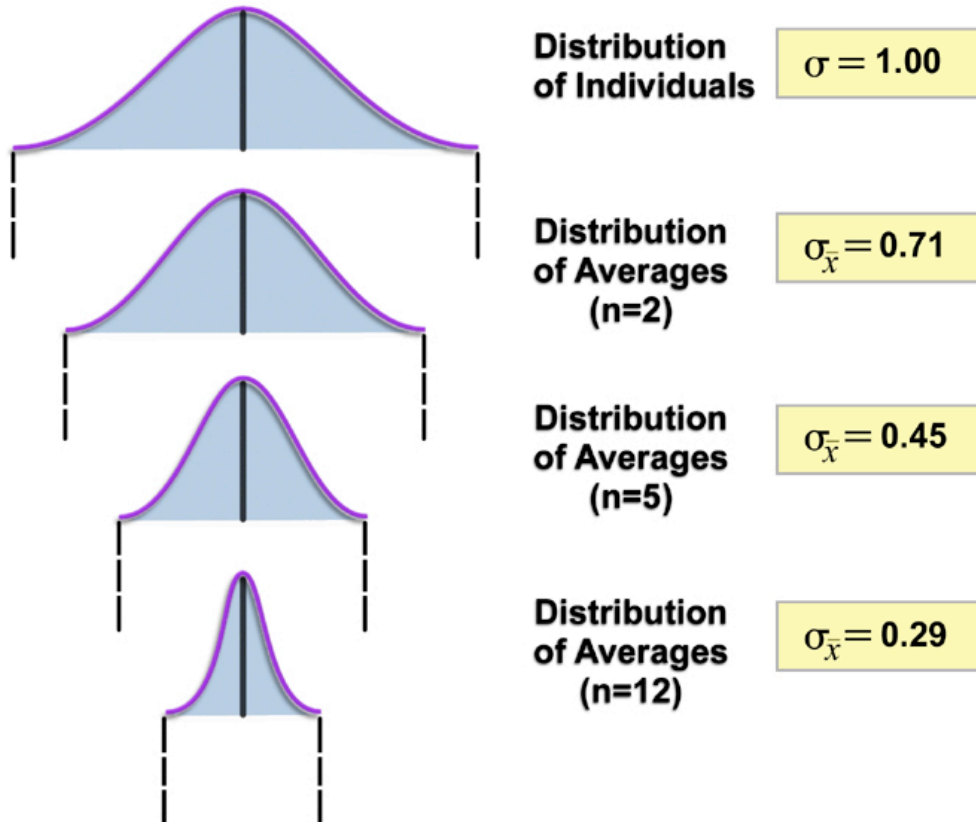
-  are determined by a **Person**  
**The Process**
-  are based on **Product Function**  
**Process Variation**
-  are used to assess **Conformance**  
**Stability**
-  apply to **Individual Parts**  
**Statistics**

# Spec Limits and Control Limits

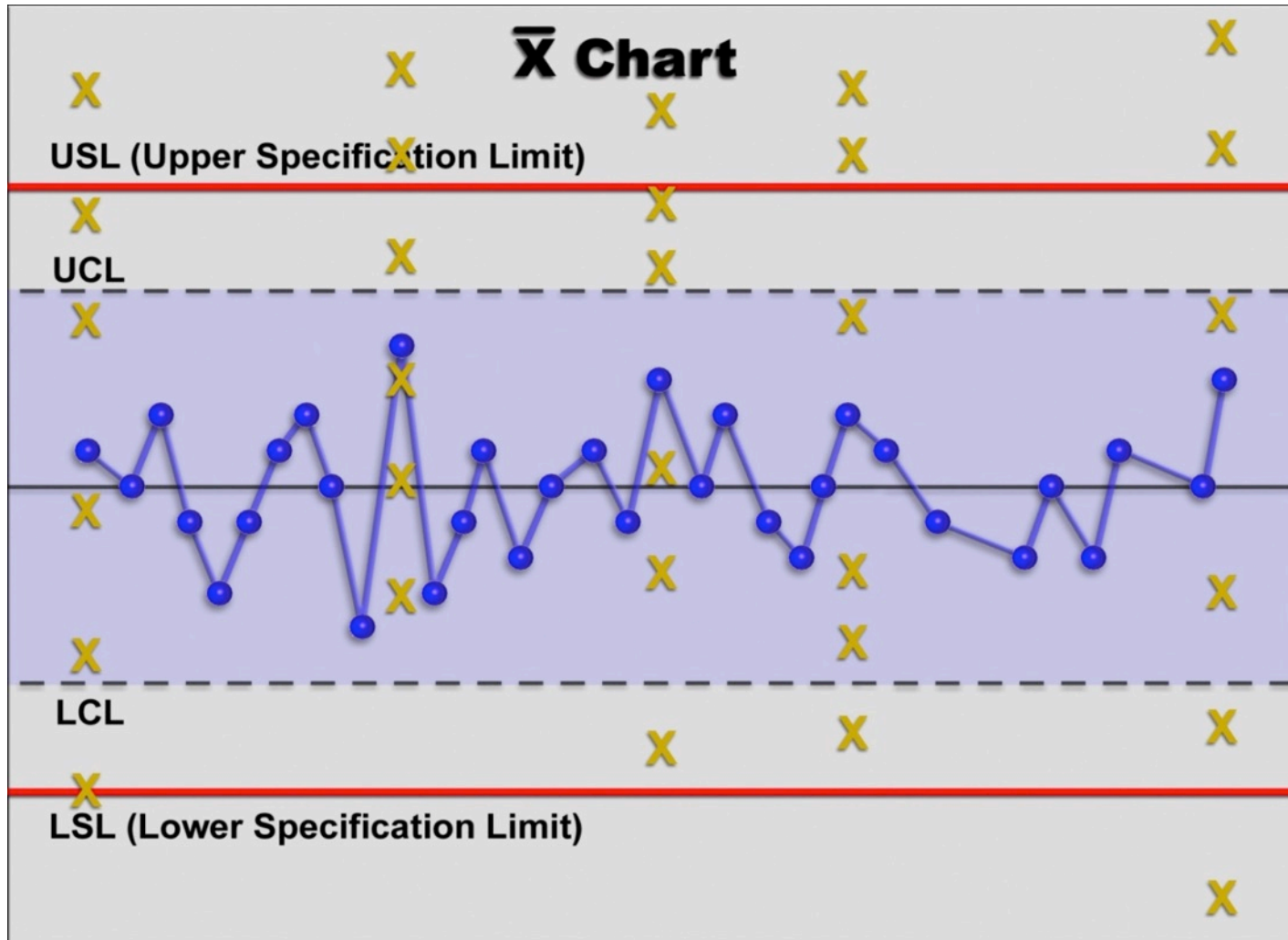


# Spec Limits and Control Limits

## Sensitivity



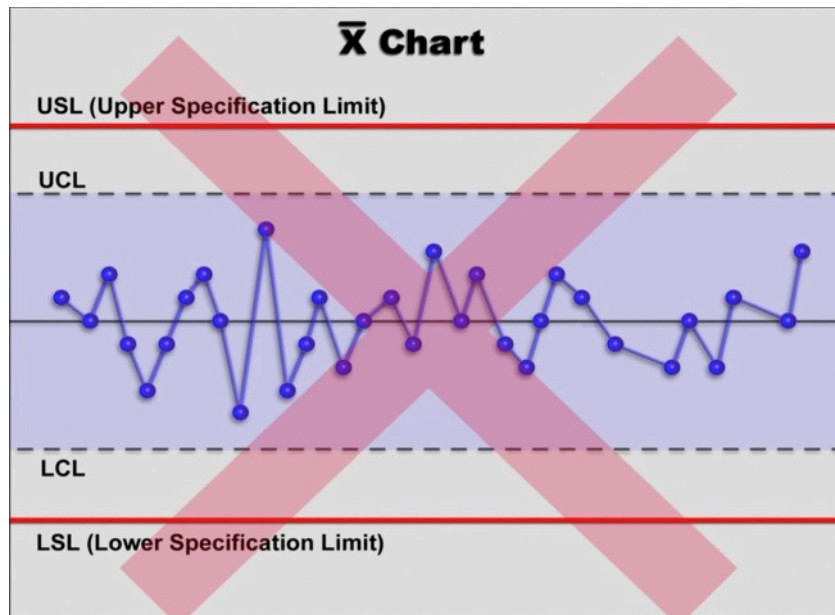
# Spec Limits and Control Limits





# Spec Limits and Control Limits

***Specification limits do not belong on control charts.***  
**Because averages have considerably less variation than individual measurements, they cannot be compared to specification limits which are typically intended to apply to individual measurements.**



# Capability

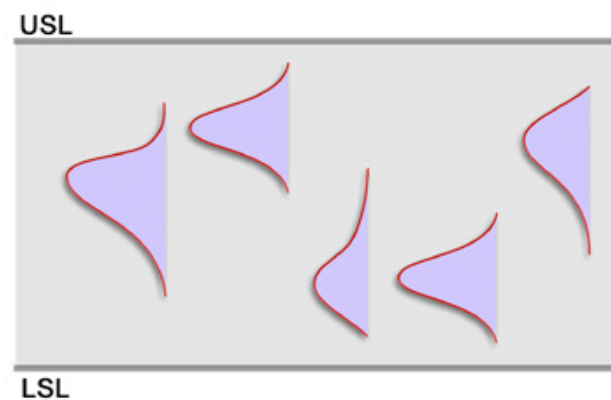
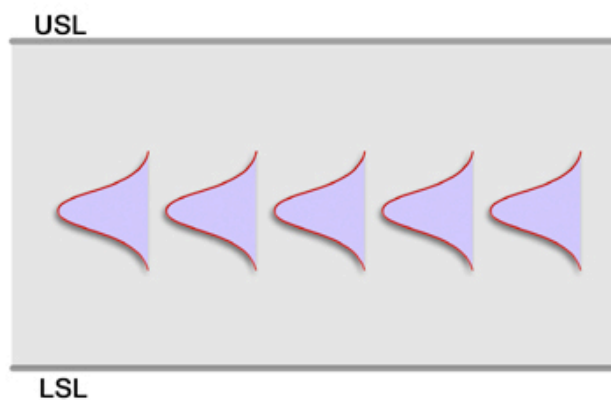
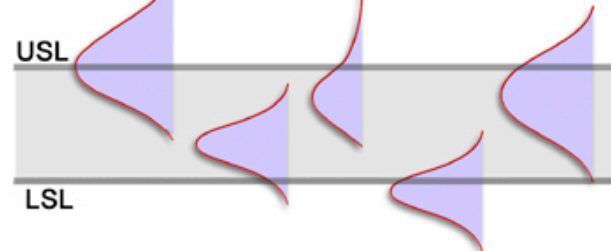
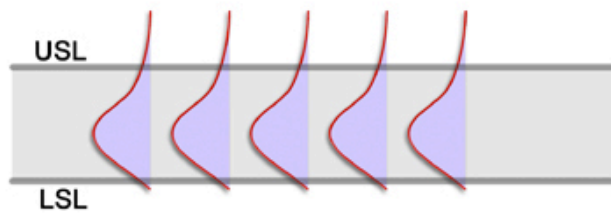
NO

YES

## Stability

YES

NO



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# Effective Sampling Strategy

- **The manner in which data is collected has a significant impact on the performance of control charts. The goal is to be able to adequately distinguish the signals (special cause sources of variation) from the noise (common cause sources of variation).**
- **Control limits should reflect common cause variation only, so that special causes are actually detectable. Sampling schemes should be designed to ensure that special cause sources of variation, if they exist, are not reflected in the control limits.**

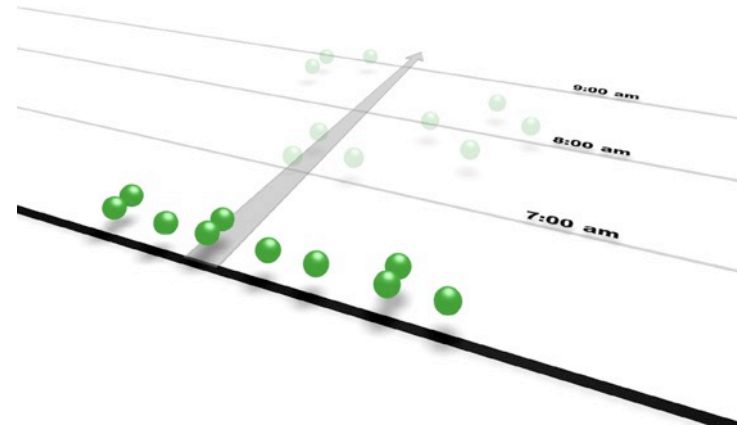
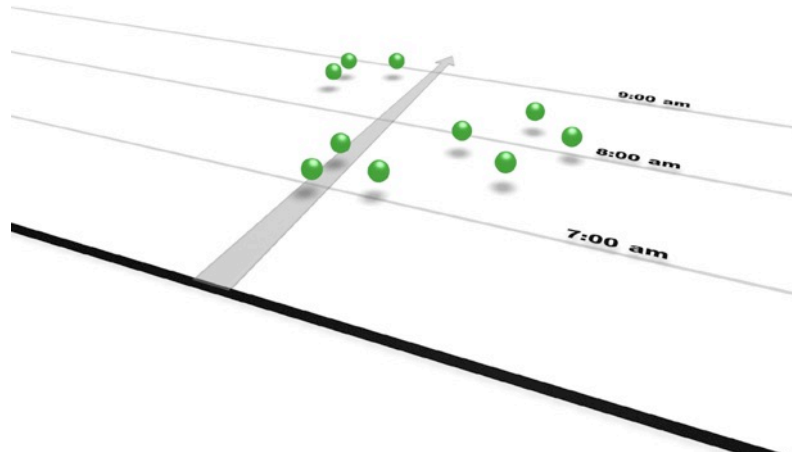
# Effective Sampling Strategy

- Traditional control charting methods (such as Xbar and R/S charts) assume that the sampling process produces *rational* samples. That is, all measurements come from a single distribution.
- However, many types of production processes do not lend themselves to rational sampling, such as sampling from multiple cavities, filling heads, or spindles, where a statistical difference may exist between the locations. The within subgroup variation may overstate the common cause variation (non-rational samples)

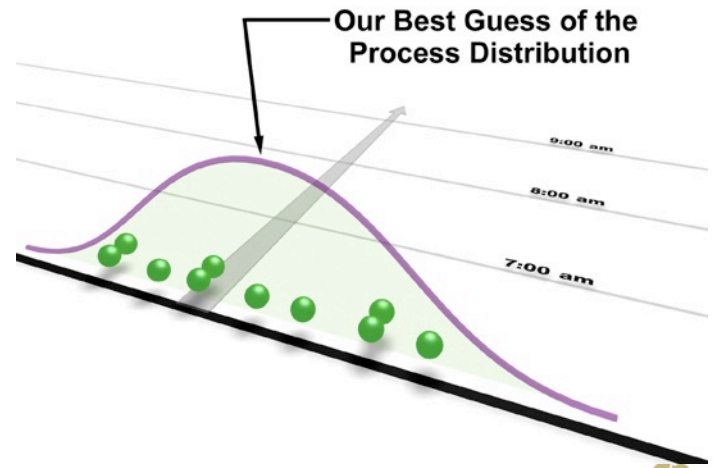
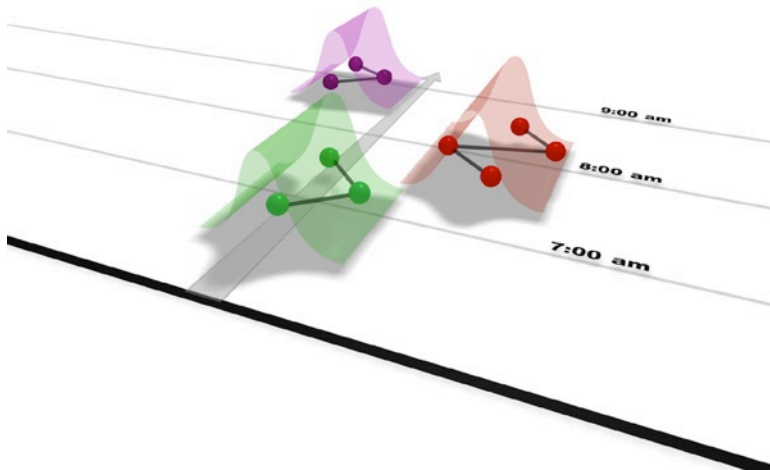
# Effective Sampling Strategy

- **Often, continuous and batch processes will understate the common cause variation (if common cause variation does not manifest over the short term).**
- **If rational samples are not obtained or if common cause variation does not captured within subgroups, then the control limits will not reflect the desired limits of expected variation. In such case, an alternative sampling strategy or an alternative charting technique must be employed.**

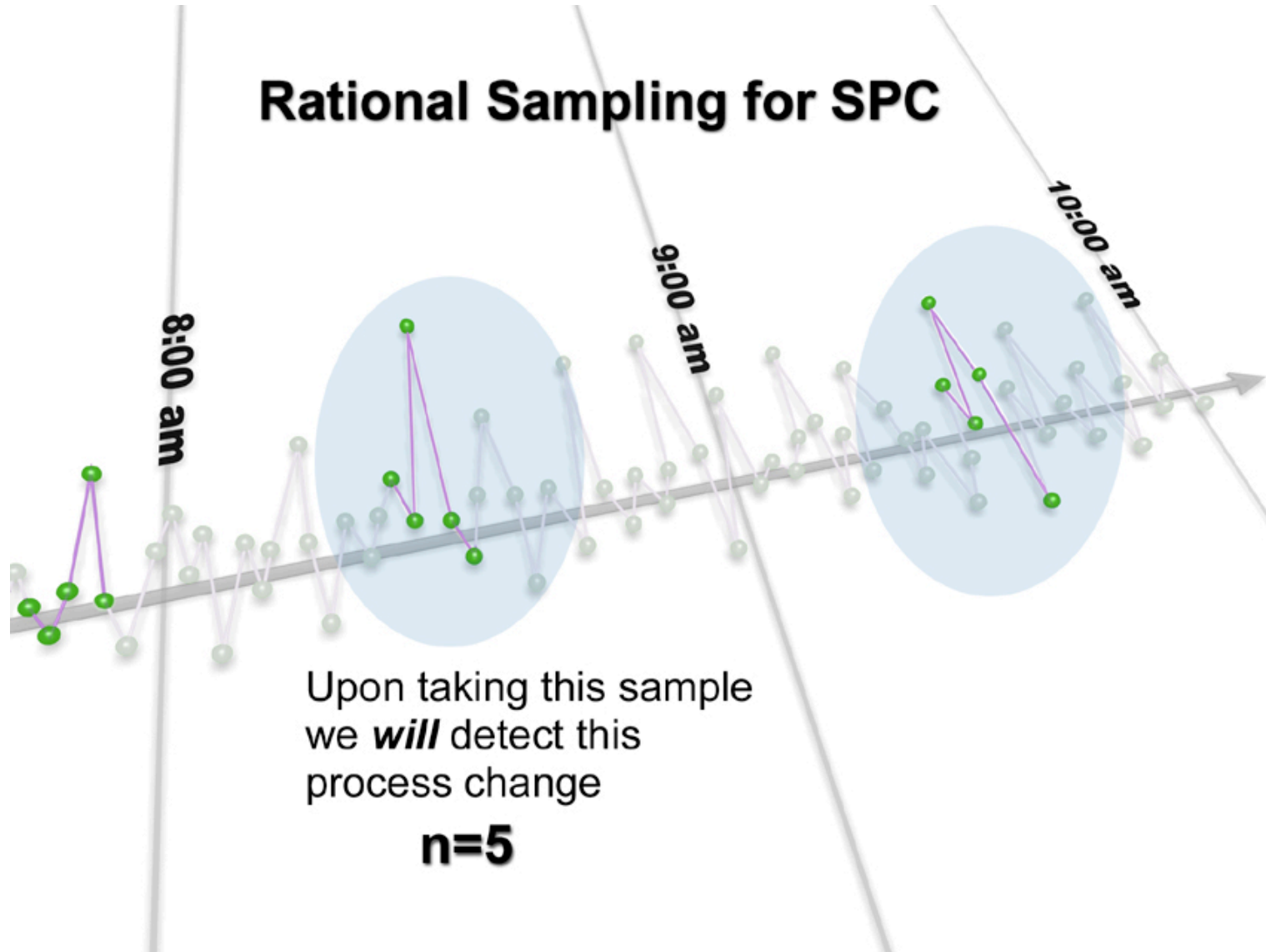
# Sampling Issues in SPC



Reality



## Rational Sampling for SPC

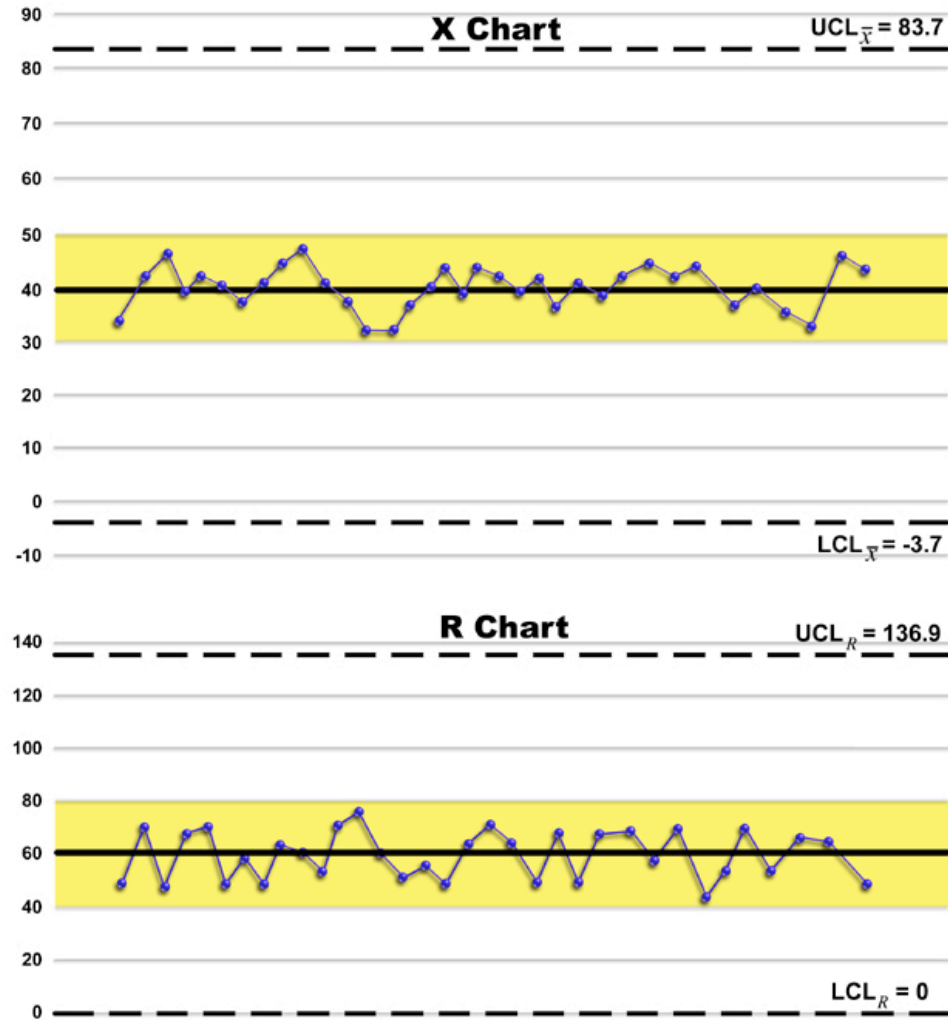




# **Examples of Potential Rational Sample Violations**

- **Several Locations on a Unit**
- **6 Cavity Mold**
- **Milling Operation – 4 Parts per Cycle**
- **Continuous Flow Processing**
- **A Systematic Sample that is Not Rational with Time**

# Example of Rational Sampling Violation



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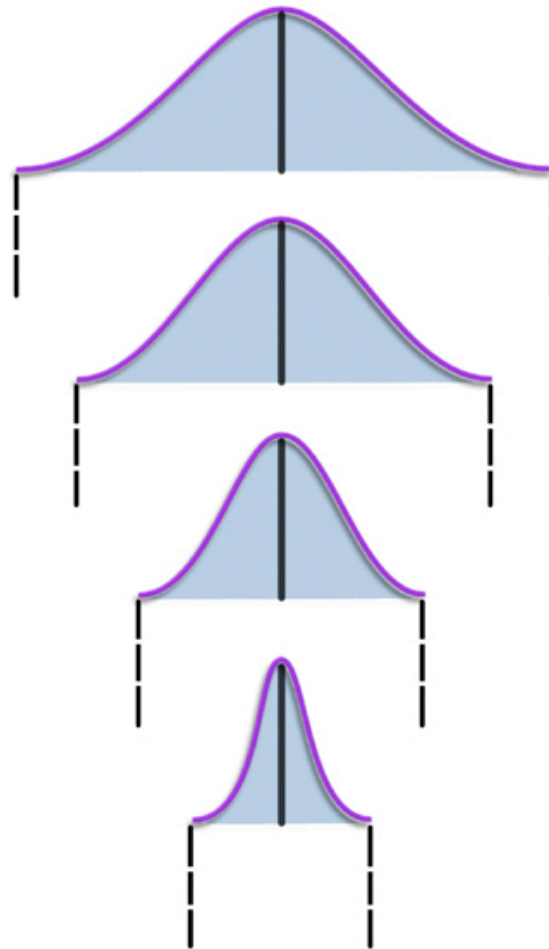
# Select the Right Sample Size

- **Sample size refers to the number of measurements taken within each subgroup. Charts of averages have the ability to vary their sensitivity to detect process changes based upon the sample size.**
- **Small sample sizes, such as Individuals charts ( $n=1$ ), lack the power to detect small process changes. On the other hand, excessively large sample sizes can result in control charts that indicate instability even when the process change is not of practical concern.**

# Select the Right Sample Size

- **The sample size can have a dramatic impact on whether signals are obtained for a given process change such as a mean shift. Before we design a chart, we should have some idea of what degree of process change we would want to detect if it occurred.**
- **Selecting an appropriate sample size allows a control chart to produce signals when we need them and minimize the chance that we'll be alerted of changes that are of little or no practical significance. Note that the sample size may need to be modified over time to reflect process improvement or process degradation.**

# Sensitivity



**Distribution  
of Individuals**

$$\sigma = 1.00$$

**Distribution  
of Averages  
(n=2)**

$$\sigma_{\bar{x}} = 0.71$$

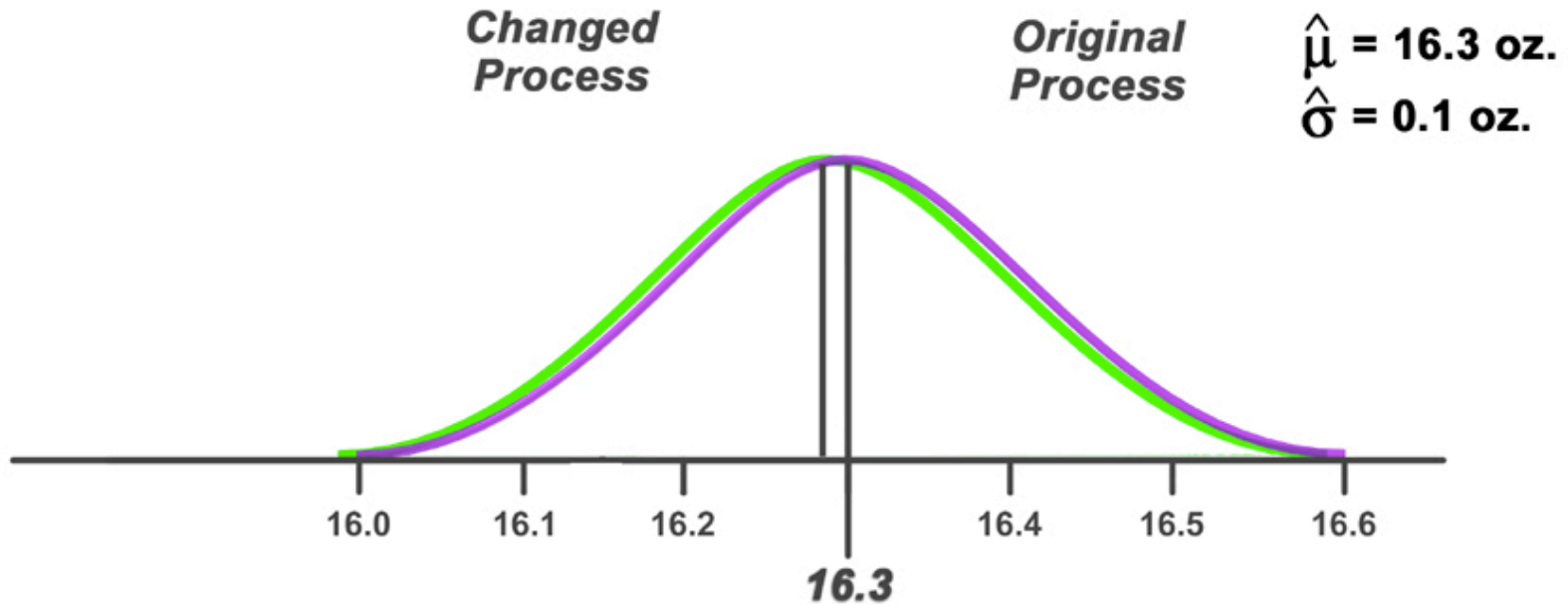
**Distribution  
of Averages  
(n=5)**

$$\sigma_{\bar{x}} = 0.45$$

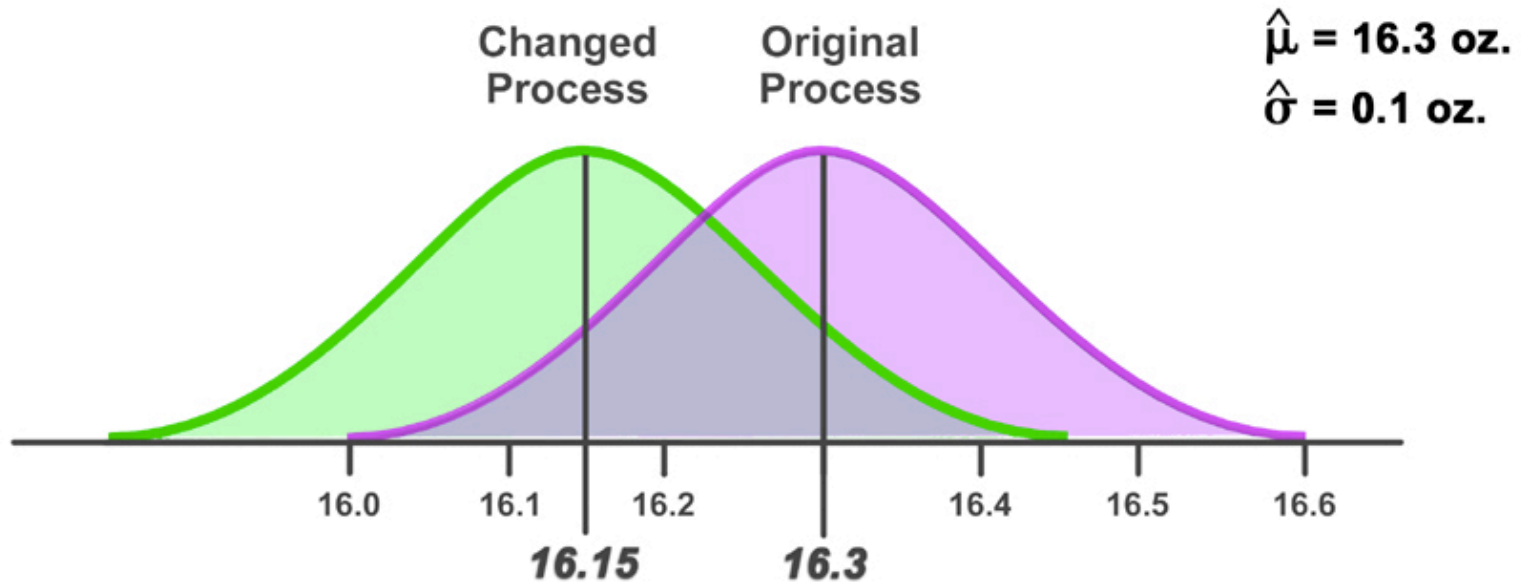
**Distribution  
of Averages  
(n=12)**

$$\sigma_{\bar{x}} = 0.29$$

# Select the Right Sample Size



# Select the Right Sample Size

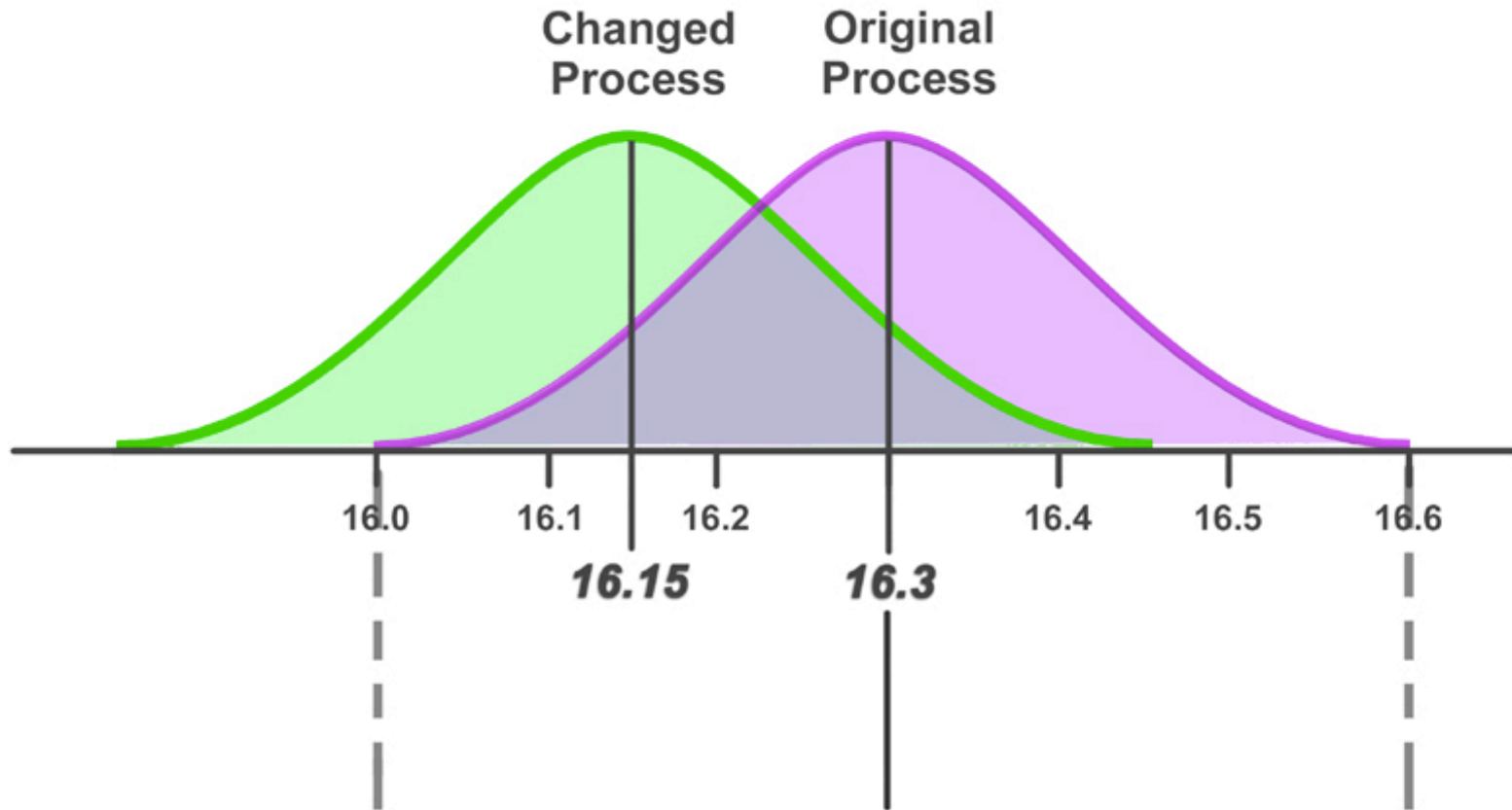




# Select the Right Sample Size

$$\hat{\mu} = 16.3 \text{ oz.}$$

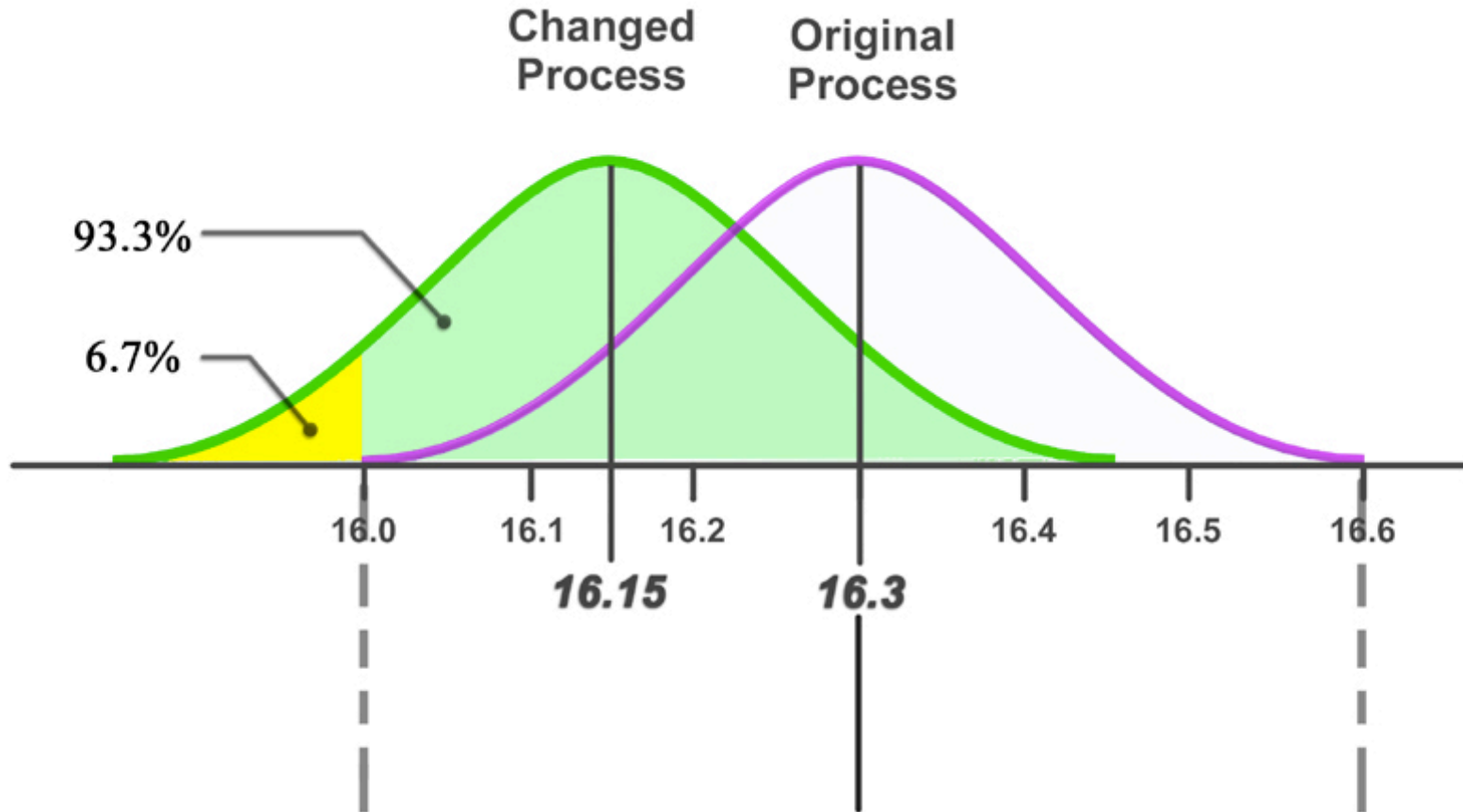
$$\hat{\sigma} = 0.1 \text{ oz.}$$



# Select the Right Sample Size

$$\hat{\mu} = 16.3 \text{ oz.}$$

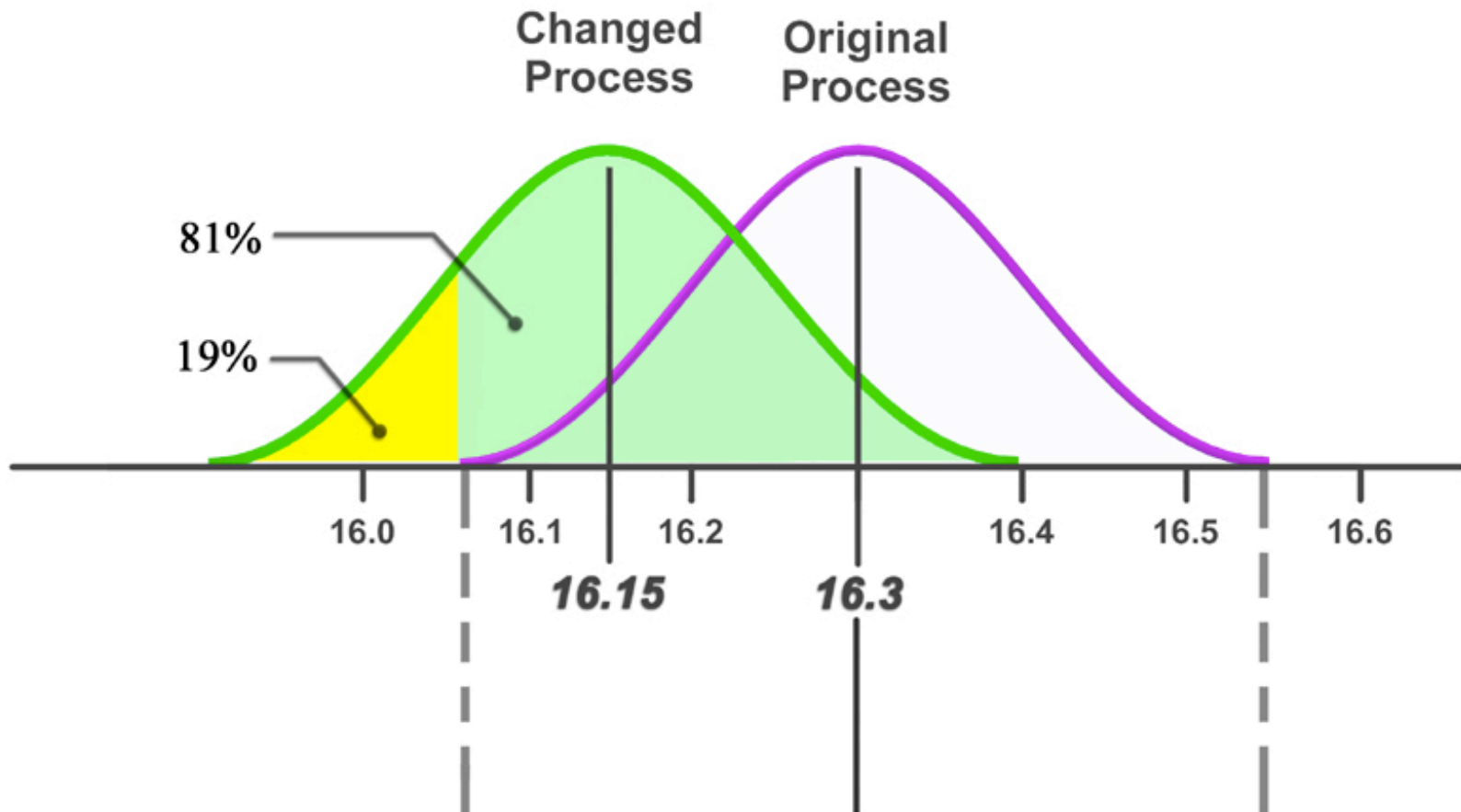
$$\hat{\sigma} = 0.1 \text{ oz.}$$



# Select the Right Sample Size

$$n = 2$$

$$\sigma_{\bar{x}} = .071$$



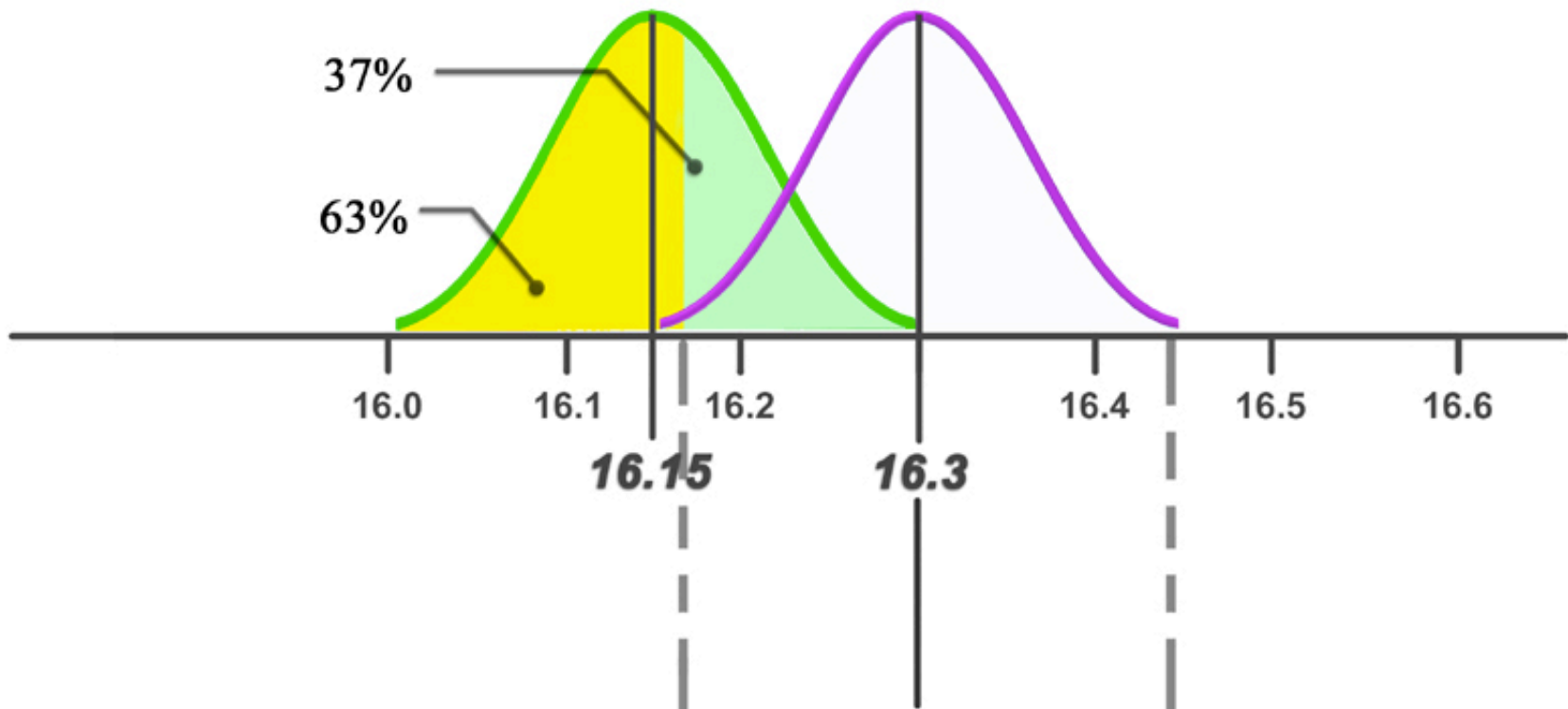
# Select the Right Sample Size

$$n = 5$$

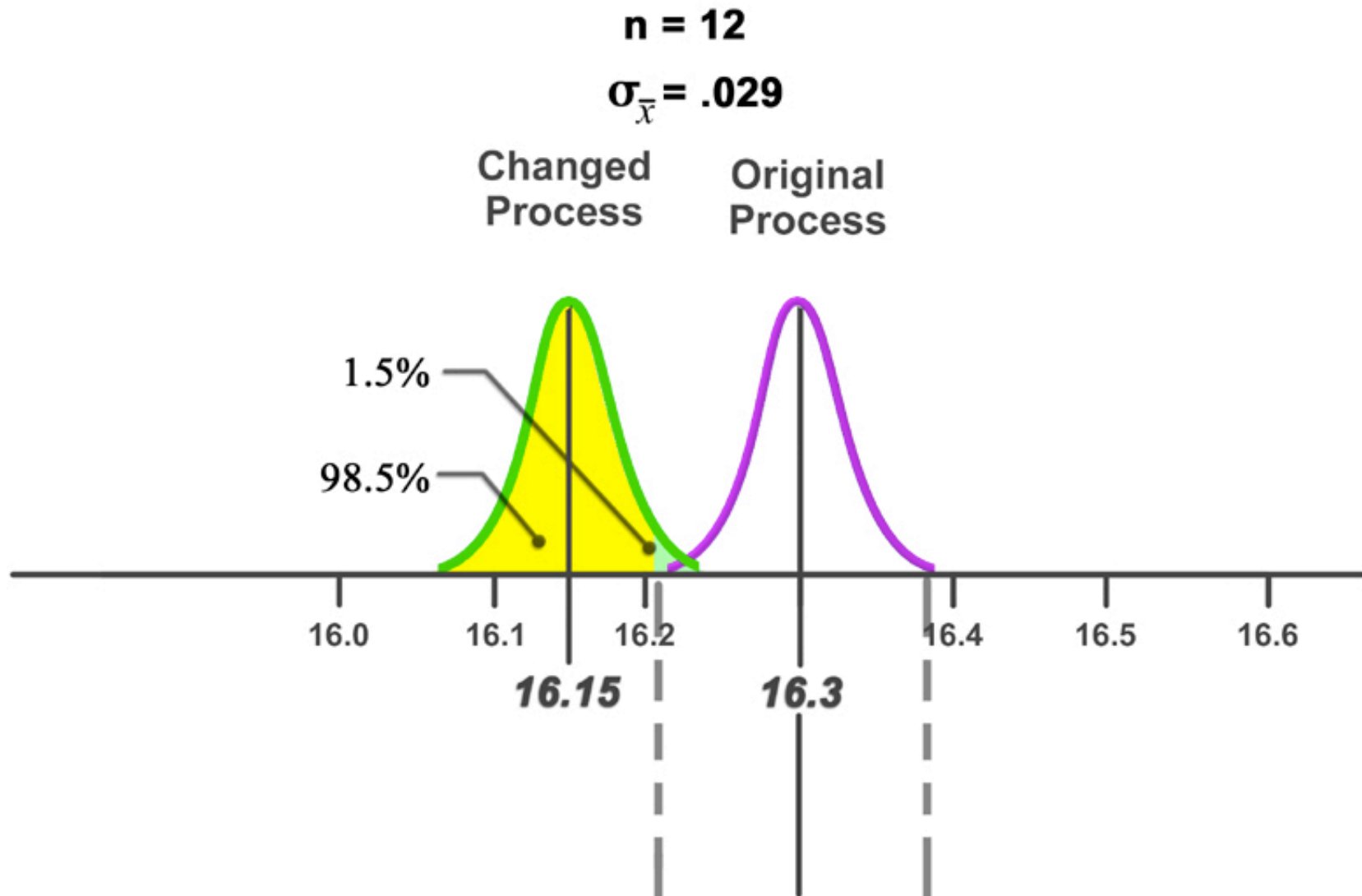
$$\sigma_{\bar{x}} = .045$$

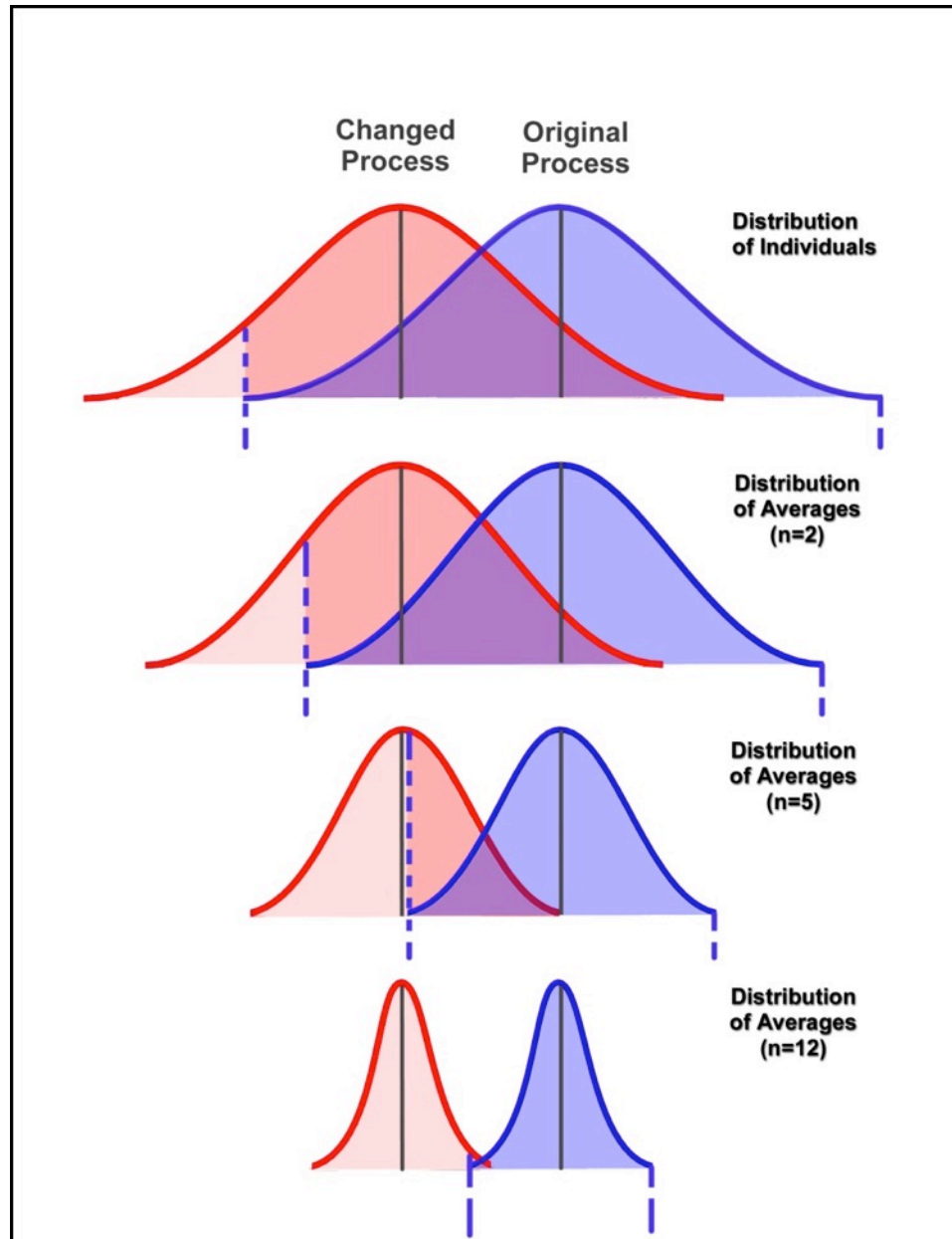
Changed  
Process

Original  
Process



# Select the Right Sample Size





## Effect of Sample Size on Chart Sensitivity

# Sample Size Guidance

Power = .99		Power = .95		Power = .90	
# std dev shift	sample size (n)	# std dev shift	sample size (n)	# std dev shift	sample size (n)
1	28	1	22	1	18
1.5	13	1.5	10	1.5	8
2	7	2	5	2	5
2.5	5	2.5	3	2.5	3
3	3	3	2	3	2
Power = .85		Power = .80		Power = .70	
# std dev shift	sample size (n)	# std dev shift	sample size (n)	# std dev shift	sample size (n)
1	16	1	15	1	12
1.5	7	1.5	7	1.5	6
2	4	2	4	2	3
2.5	3	2.5	2	2.5	2
3	2	3	2	3	1

Choosing Power:



**Risk Tolerance?**  
**Current Capability?**  
**Sampling Frequency?**

# Agenda

- **What is Statistical Process Control?**
- **The 10 Keys**
  1. **Ensure the Purpose of SPC is Understood**
  2. **Focus on Key Characteristics**
  3. **Validate Measurement Systems**
  4. **Choose the Right Chart**
  5. **Understand Specification Limits vs. Control Limits**
  6. **Employ Effective Sampling Strategy**
  7. **Select the Right Sample Size**
  8. **Automate SPC**
  9. **Empower Operators**
  10. **Manage the Process & Drive Improvement**



# Automate SPC

- **SPC is most effective when applied as close to the point of production as possible. If sampling and charting is performed after the end of a run, discovering that the process was not in control after-the-fact may prevent a questionable shipment, but the cost of additional inspection, scrap and/or rework is already generated.**
- **With automated, in-line SPC systems, control tests can signal operators of a problem and prompt action to address special cause variation before the manufacture of nonconforming product.**

# Automate SPC

- By providing real-time feedback, automated SPC systems become preventative, rather than merely reactive, monitoring tools.
- Automated SPC systems also reduce the opportunity for human transcription error and ensure that control test rules are consistently applied and alarm conditions are recorded for further investigation.



# Agenda

- **What is Statistical Process Control?**
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# Empower Operators

- **In some shops, operators view SPC as a stick to make sure they are doing their jobs. If a process goes out of control, the operator is blamed for “not controlling the process”.**
- **As a result, operators may frequently tweak (over-control) the process in an attempt to keep it on target. Instead, operators (and management) should receive adequate training in how SPC can help them manage the process effectively.**
- **They should be empowered to stop the process (when appropriate) and be rewarded for taking actions to identify and remove special cause sources of variation.**

# Agenda

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# Manage the Process (Drive Improvement)

- When a control chart identifies a change, an appropriate response is for personnel to determine the *cause(s)* of the change.
- Instead, when a control chart shows a change, operators or supervisors often try to make an adjustment without knowing what to adjust or how much to adjust (adding variation to the process)
- If we instead resist knee-jerk responses and investigate the source of the change, then something has been learned—and random and potentially harmful adjustments can be avoided

# **Manage the Process (Drive Improvement)**

- **Effective process control requires discipline in managing the charting process so that reaction plans are followed, systemic issues are identified, and improvements are realized over time.**
- **Managing the process involves reacting to chart signals, identifying root causes of process changes and systematically working to eliminate them.**
- **It also means knowing when to recalculate control limits and possibly modify sample sizes.**
- **Only by managing the charting process can an SPC program fulfill its potential of driving process improvement and product quality.**

# Statistical Process Control & Process Capability Course



**An online, self-paced, interactive course taught & supported by Steven Wachs**

**Hosted on the Accendo Reliability platform**

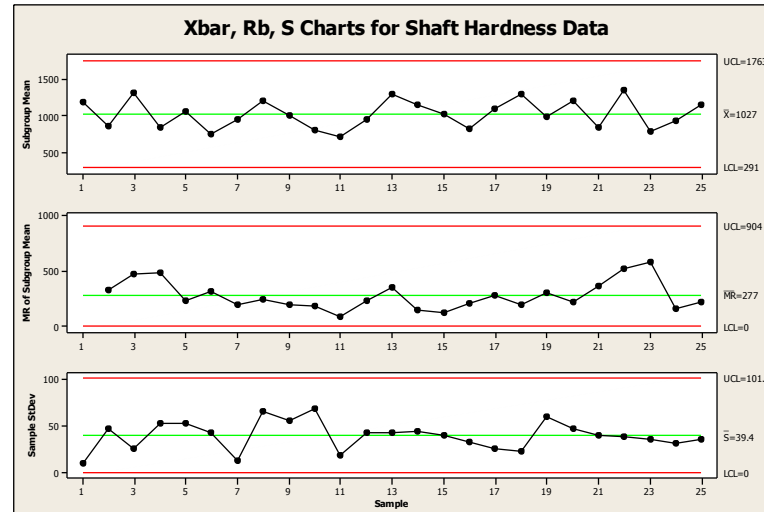
**Approximately 30 Hours of content**

**Course fee: \$999 per participant (with multi-participant discounts)**

**<https://accendoreliability.com/spc-pc/>**



# 10 Keys for Maximizing the Benefits of your SPC Program



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