Statistical Process Control based on *SPC 2nd Edition*

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Agenda

1. Setting the Stage
2. Continual Improvement and SPC
3. Shewhart Control Charts
4. Other Types of Control Charts
5. Understanding Process Capability
6. Summary and Closure

Course Goals

1. To provide a fundamental understanding of the relationship between SPC and continuous improvement.

2. To use SPC to achieve a state of statistical process control for special characteristics.

3. To assess process capability and process performance for special characteristics.

Setting the Stage



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What is SPC?

- Statistical Process Control (SPC) applies statistical methods to monitor and control a process to operate at full potential.

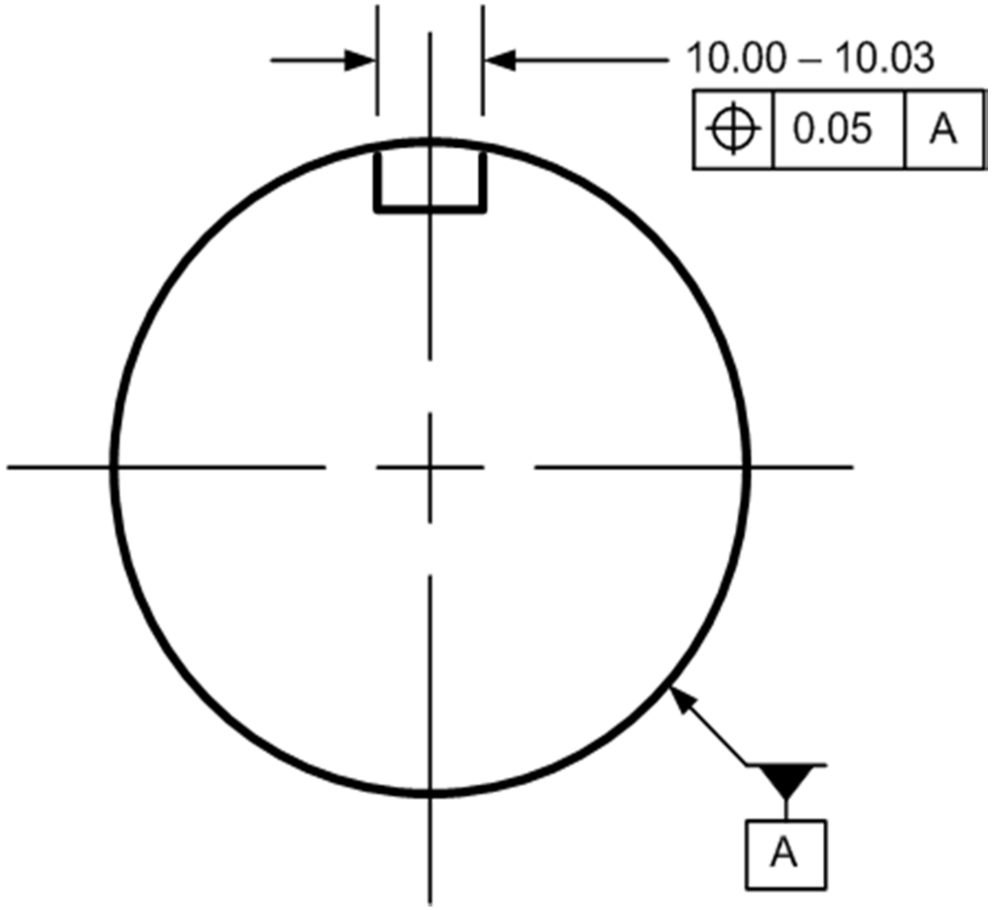
- Benefits of SPC
  - Improved Productivity
  - Reduced Scrap, Rework, Costs
  - Higher Customer Satisfaction

- Let's illustrate with an example…

Let’s Begin with an Example

- Consider the shaft on the following slide.
- Engineering has identified the size of the keyway as a critical characteristic.
- Internal procedures require Statistical Process Control (SPC) be applied.
- Cpk $\geq$ 1.67 is required.

Partial Drawing of a Shaft



In this example we are going to look at the width of the keyway in the view above.

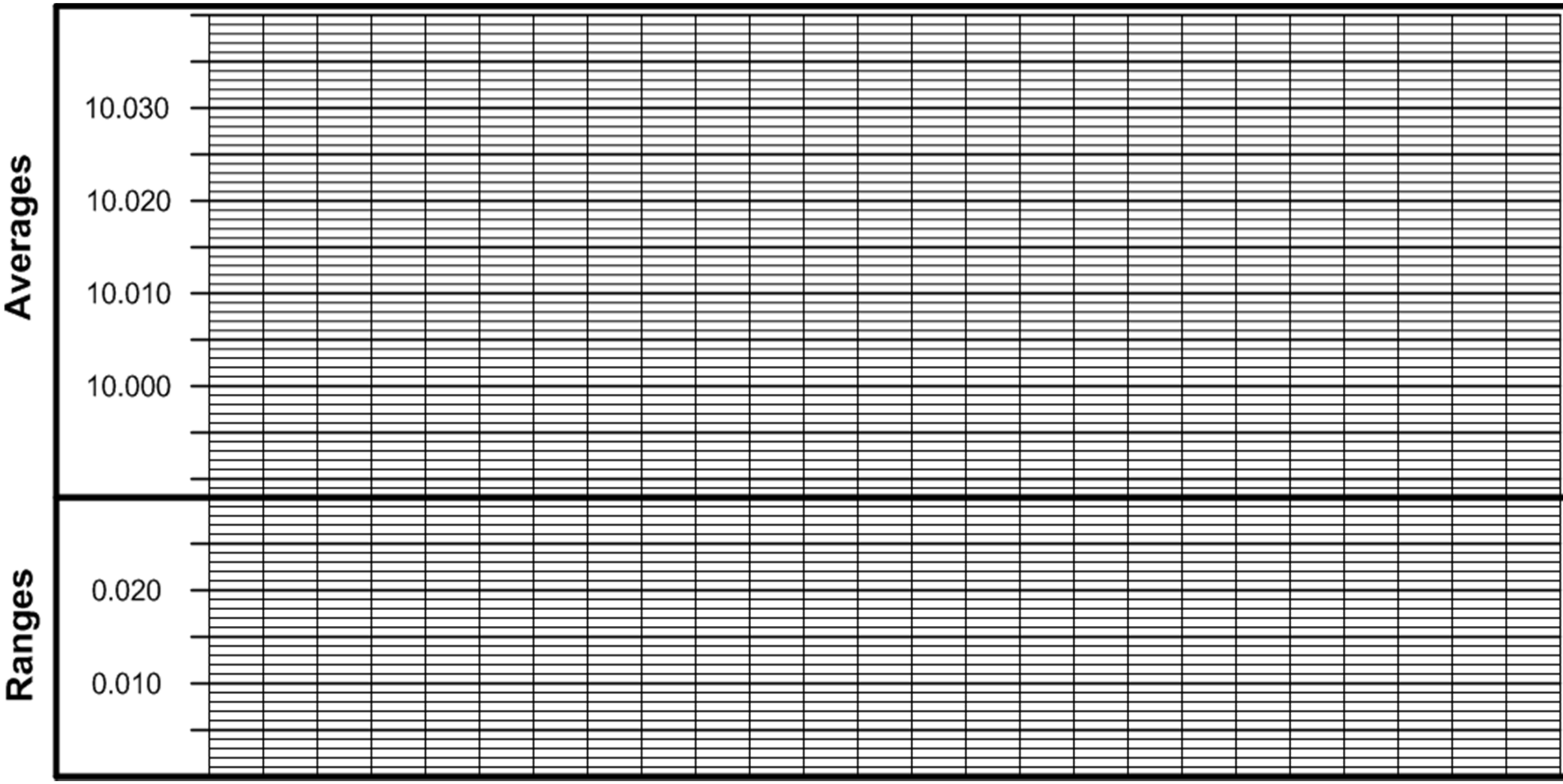
Before We Begin – Some Assumptions

- The measurement process is appropriate:
  - Resolution
  - Stability
  - Capability
- A control plan specifies an X-bar and R Chart:
  - Sample size of 4
  - Samples taken once per hour
  - Investigate out of control signals

Measure Parts – Collect Data

- X-bar and R Charts require data collection:
  - The control plan, in this case, requires n = 4.
  - We need measured data from 4 consecutive parts.
  - It also requires a sample be taken each hour.
- From each sample we make some calculations:
  - Sample Average (add measured values, divide by 4)
  - Range (largest value – smallest value)
- Then we plot the data.

Scaling the X-bar and R Charts



Sample Calculations

- Sample data for four measured values:

  10.016 10.018 10.019 10.015

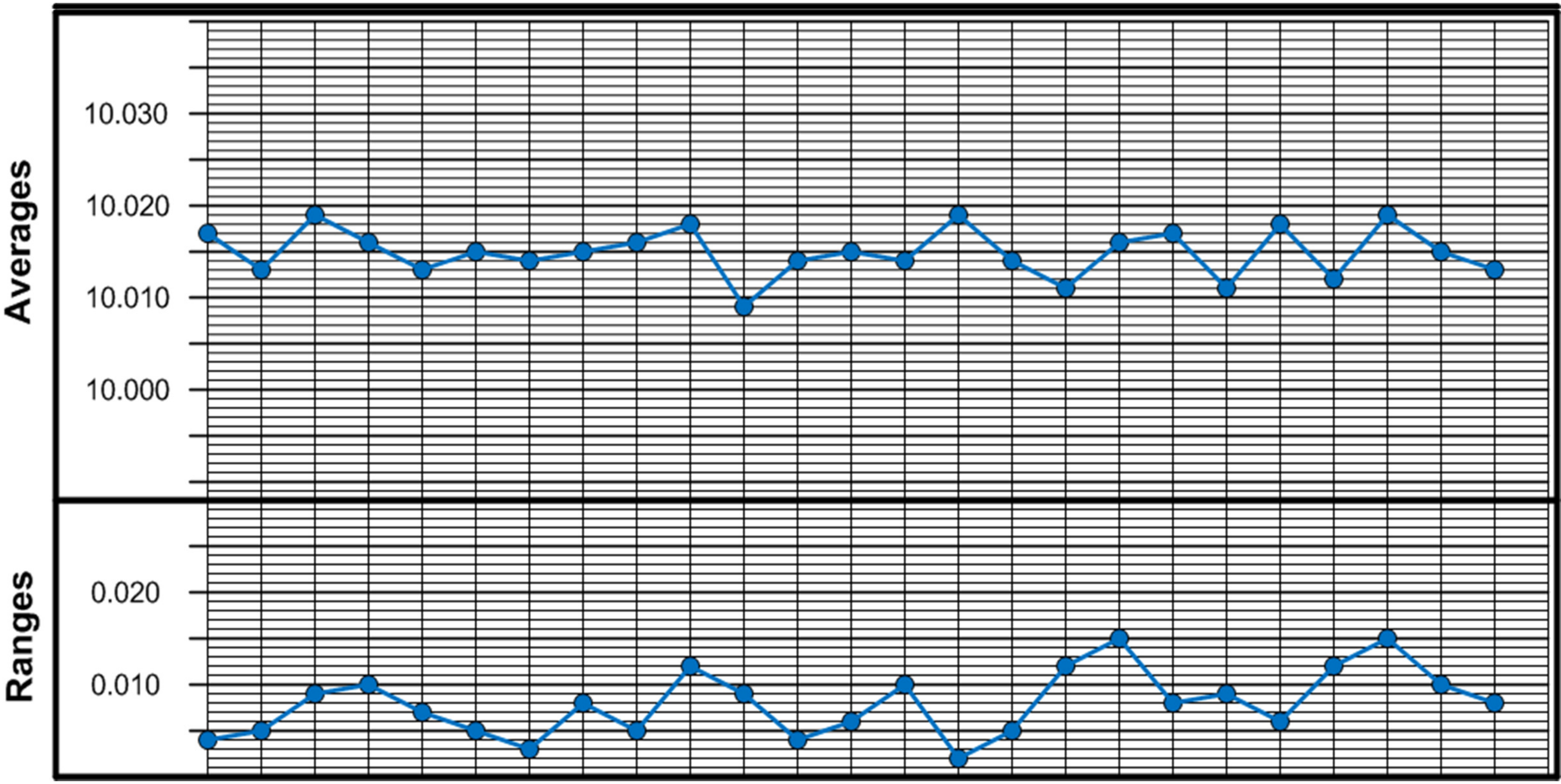
- Sample average:

  (10.016 + 10.018 + 10.019 + 10.015) / 4 = **10.017**

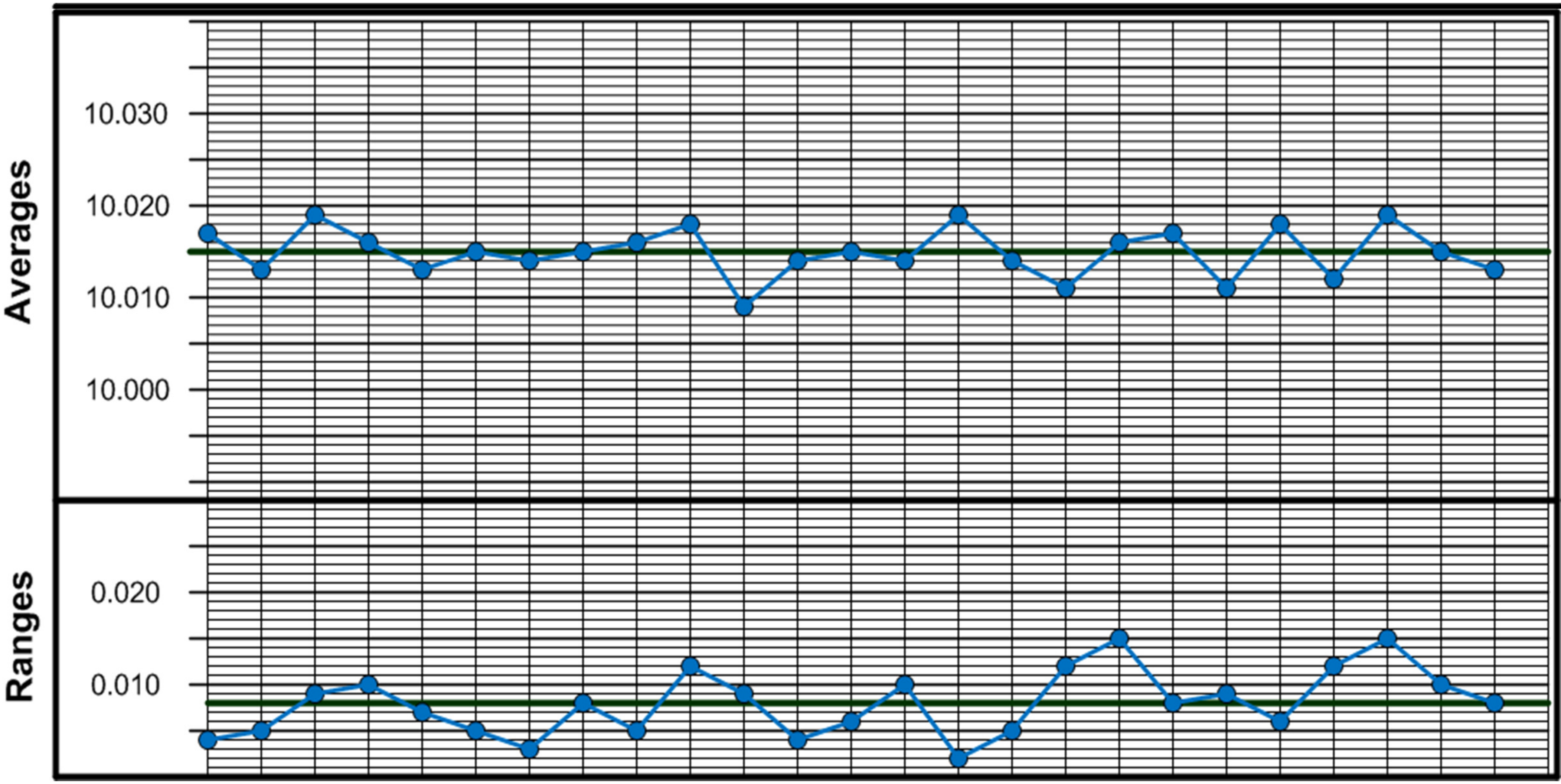
- Sample range:

  10.019 – 10.015 = **0.004**

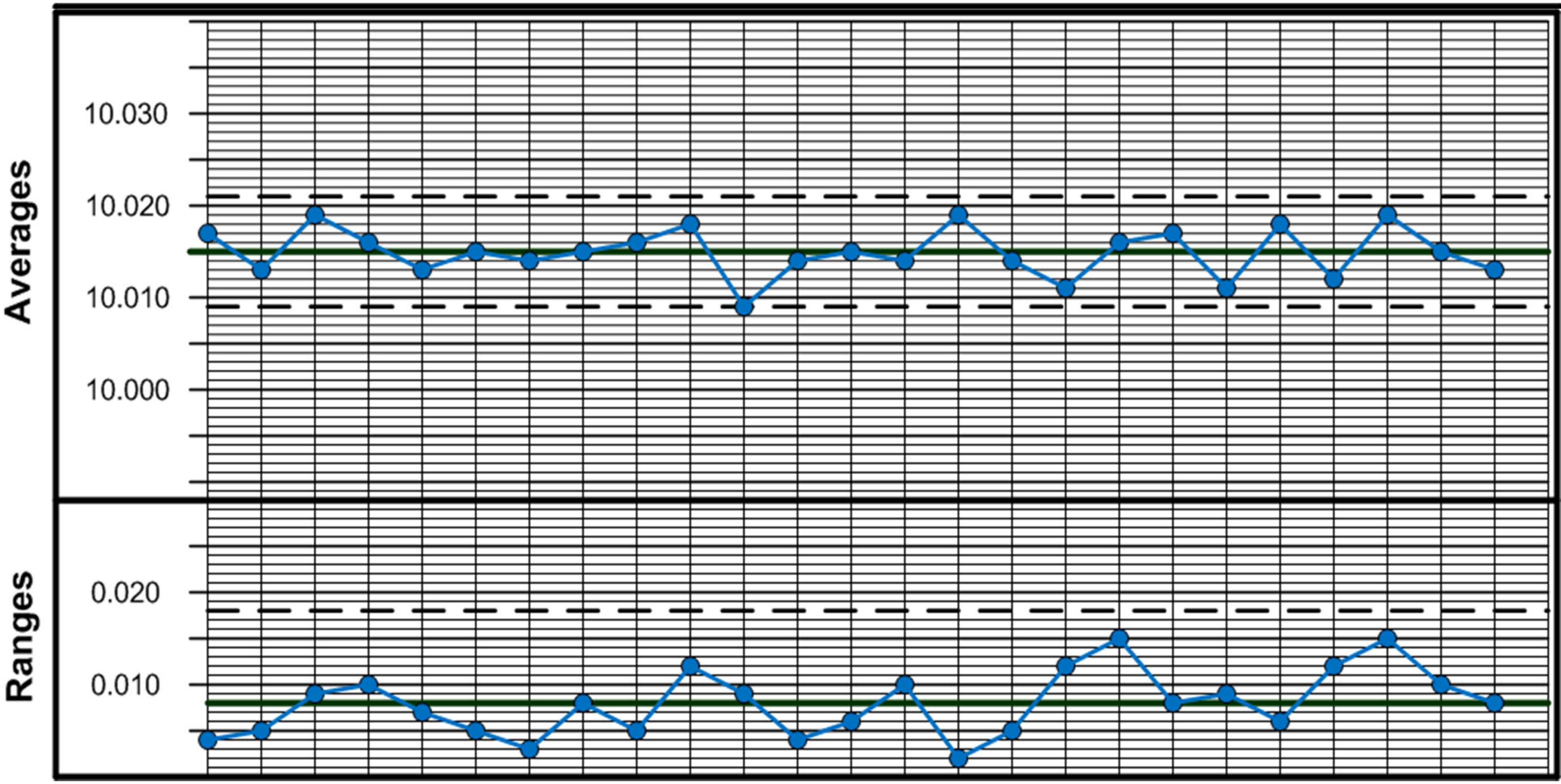
Plotting X-bar and R Values



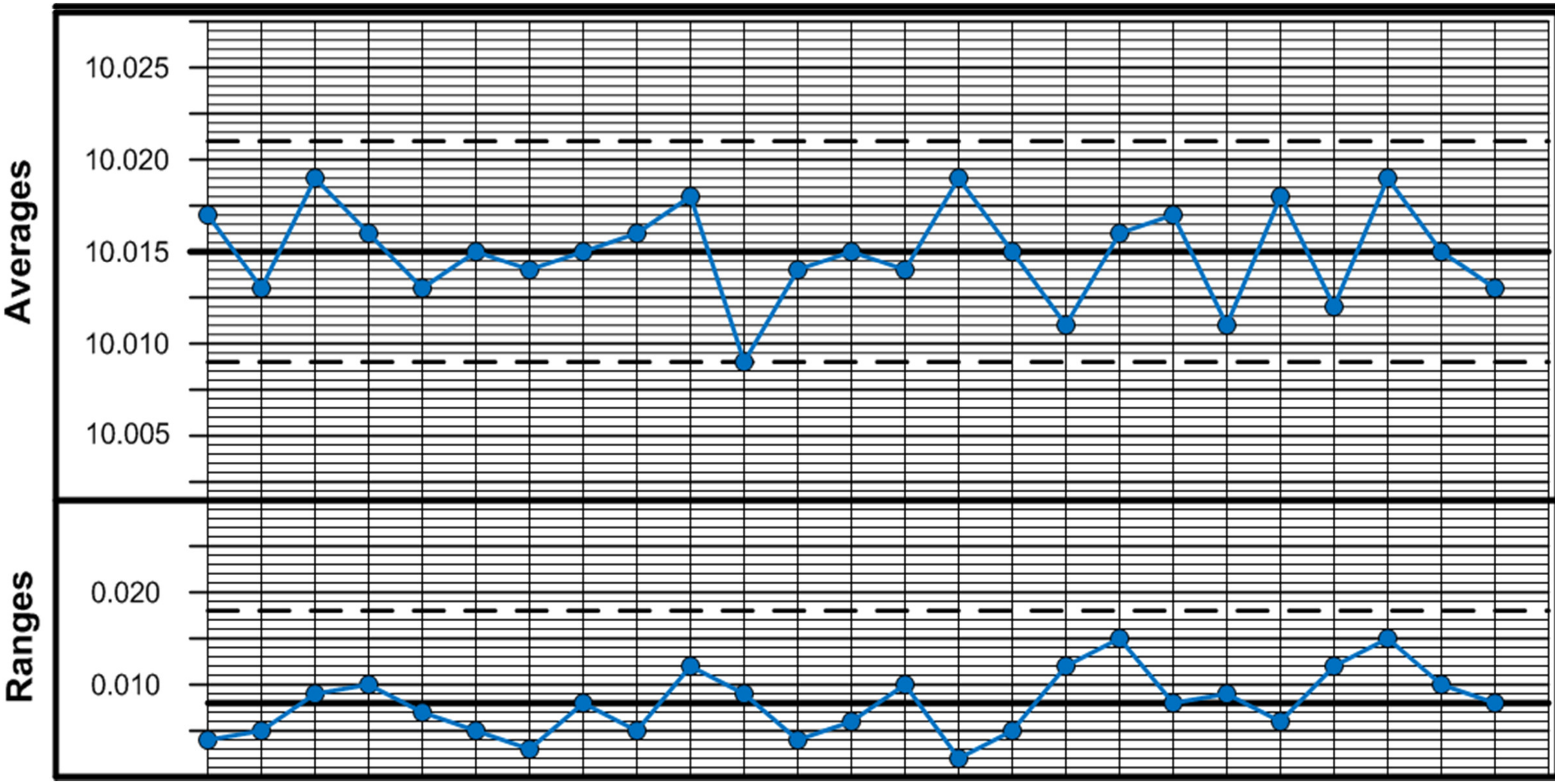
Plotting X-bar and R Averages



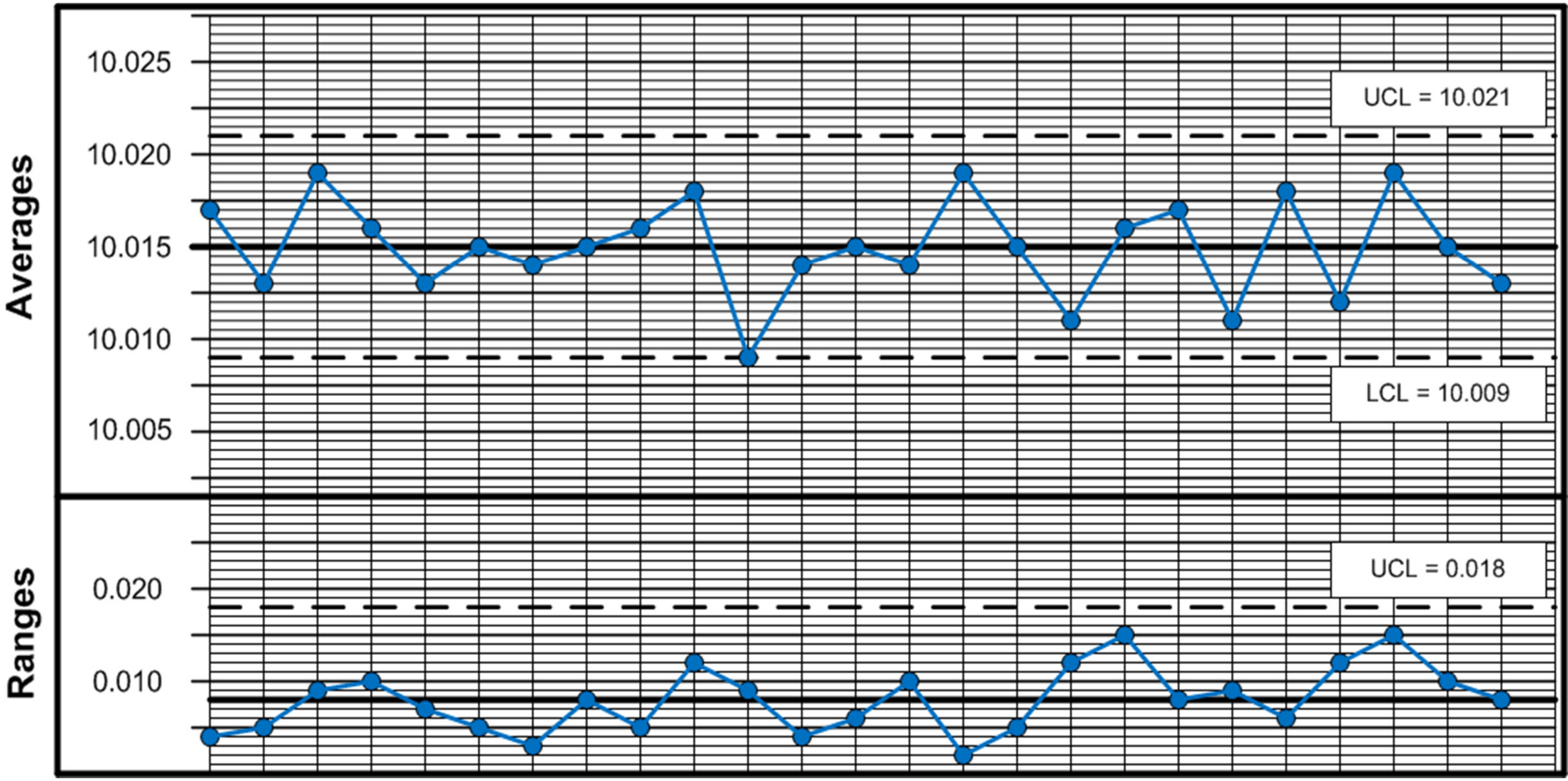
Plotting X-bar and R Control Limits



Adjusting the Scale



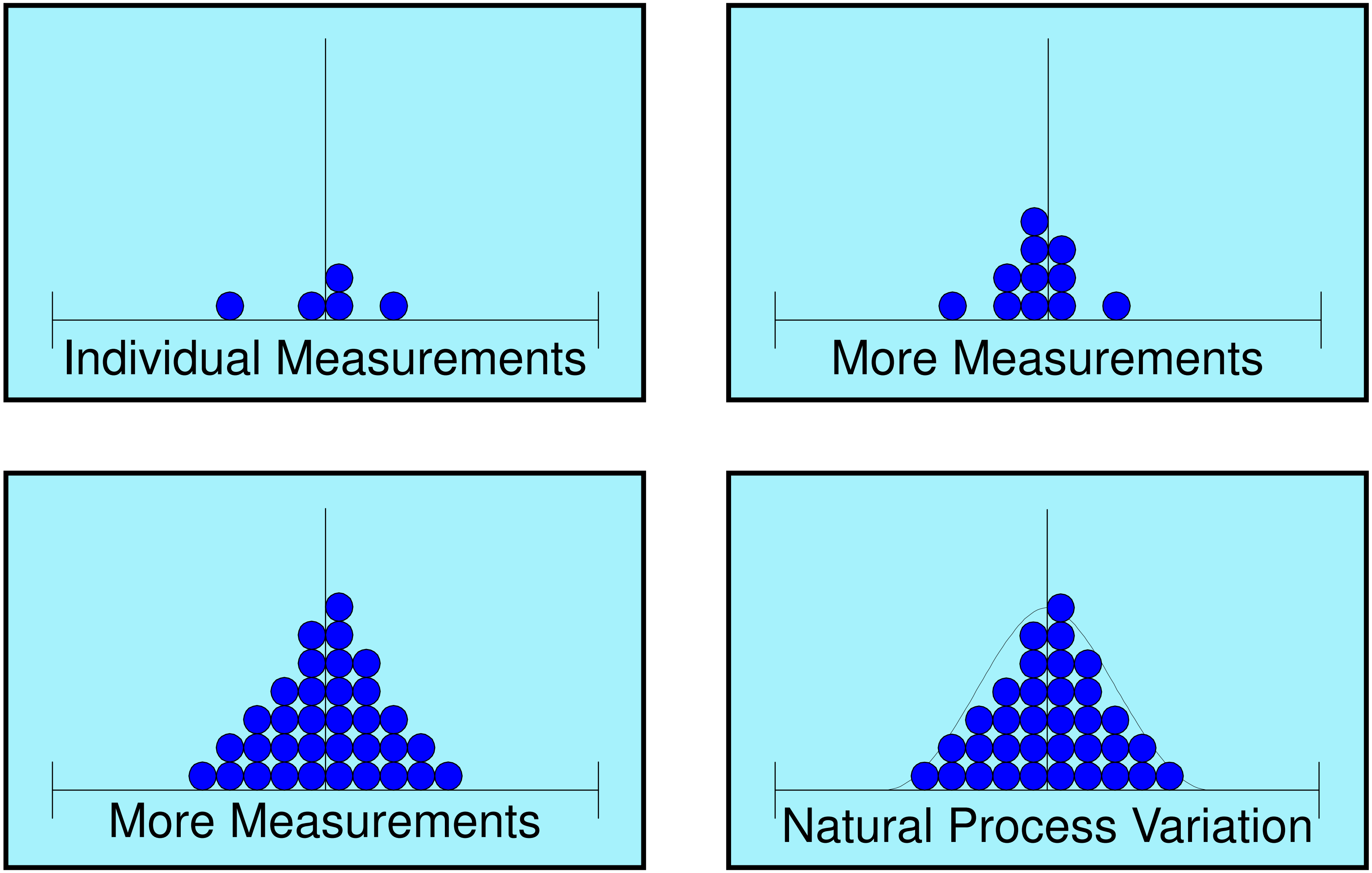
Assessing Control Charts for Stability



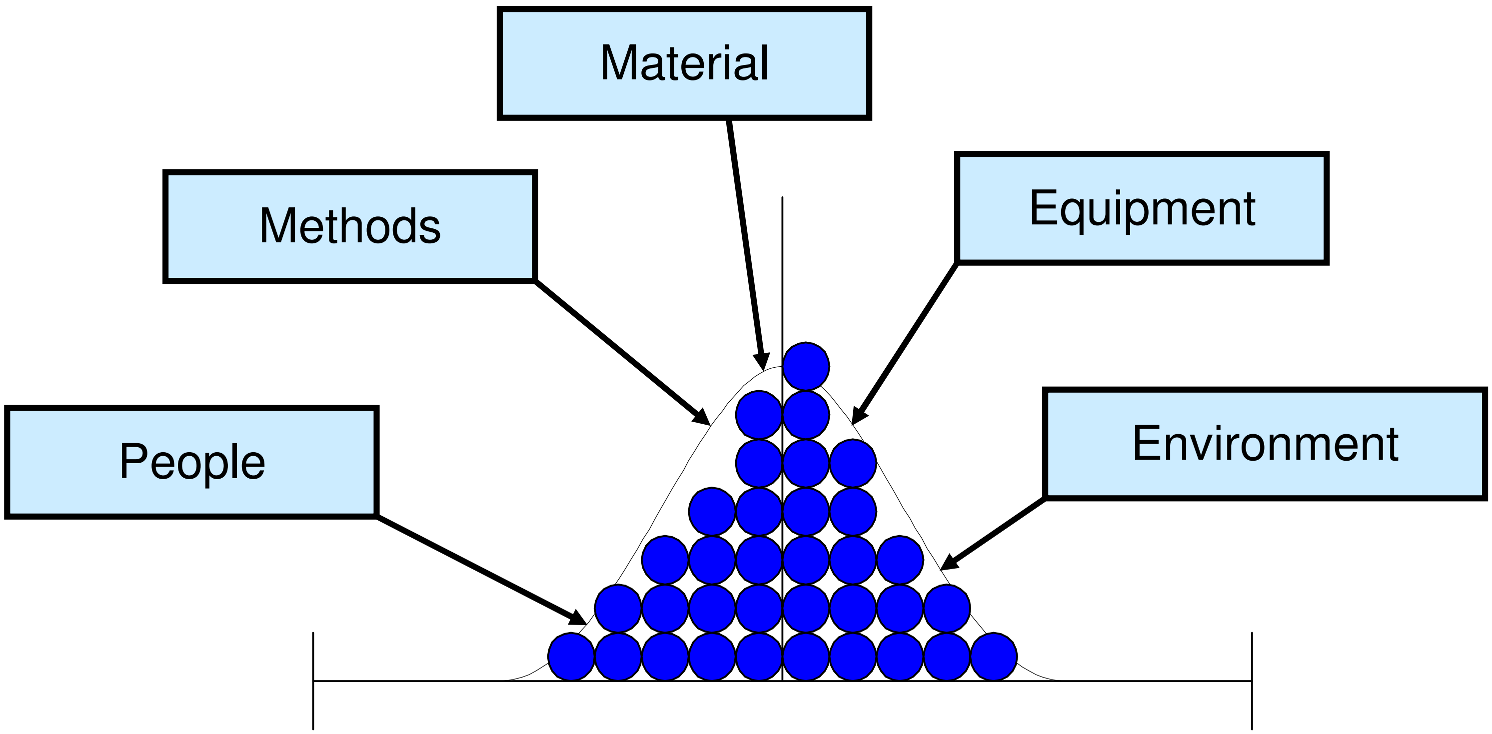
Let's Summarize

- Control charts provide a graphical interpretation of the sample data.
- The X-bar Chart looks at central tendency from one sample to the next.
- The R Chart looks at the dispersion, or spread, within each of the samples.
- We expect the plotted values to behave randomly and lie between the control limits.

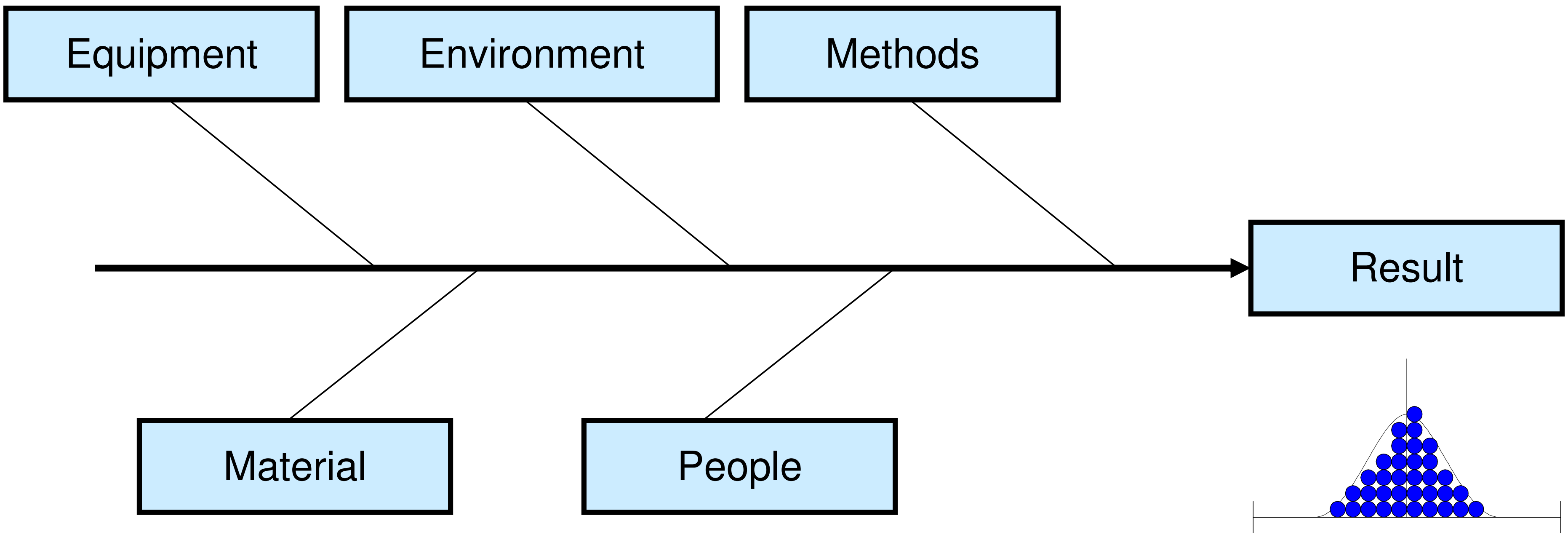
Variation in All Things



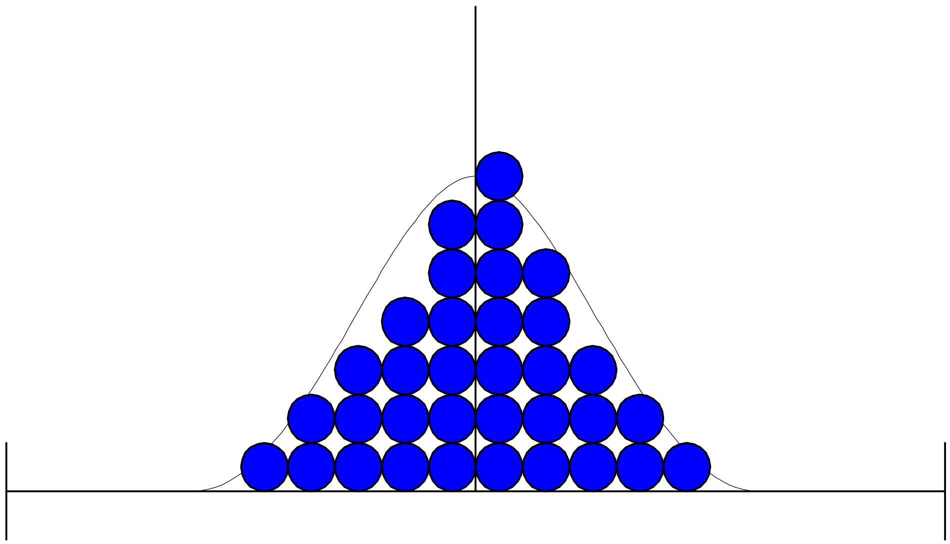
Natural Variation Inherent in the Process



Causes and Effects



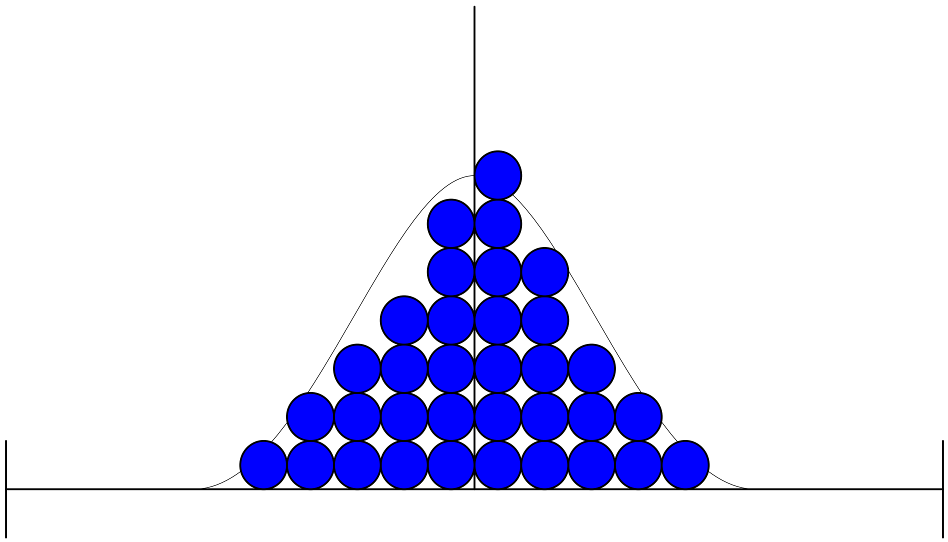
Independent and Identically Distributed



It does not matter so much that we are dealing with normally distributed random variables.

What does matter is that these variables are independent and identically distributed.

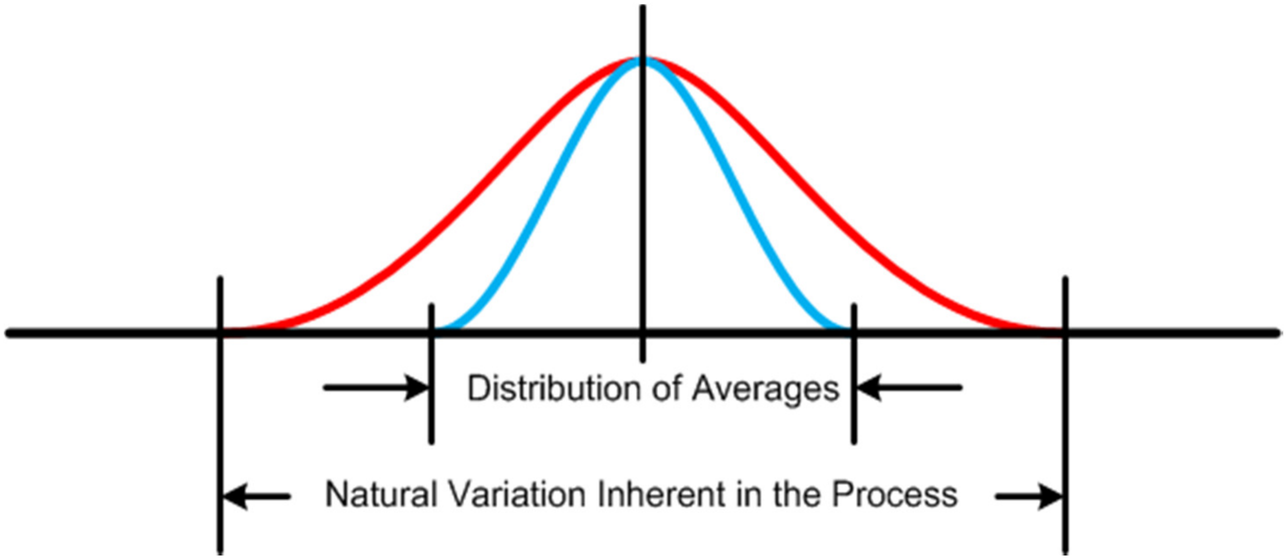
Independent and Identically Distributed



If measured data are *iid random variables*, then they will form a constant distribution with predictable shape, central tendency, dispersion.

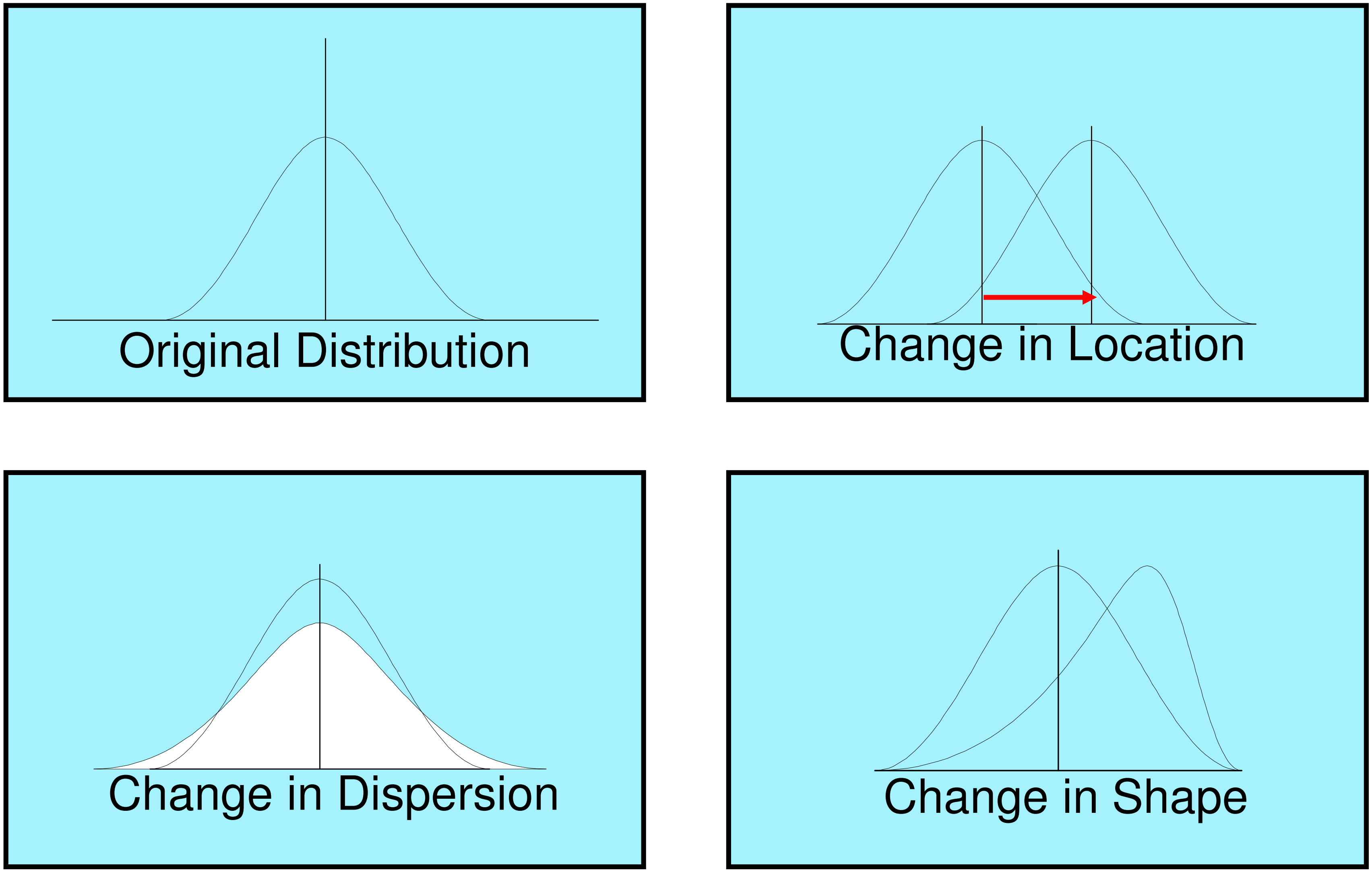
If we take sample averages from such a distribution, the sample averages will be normally distributed.

Individuals vs. Averages



Fortunately, there is a law in nature that controls the behavior of averages, and causes them to follow a normal distribution. The limits of the distribution of averages provide the basis for the control limits seen on the X-bar Chart.

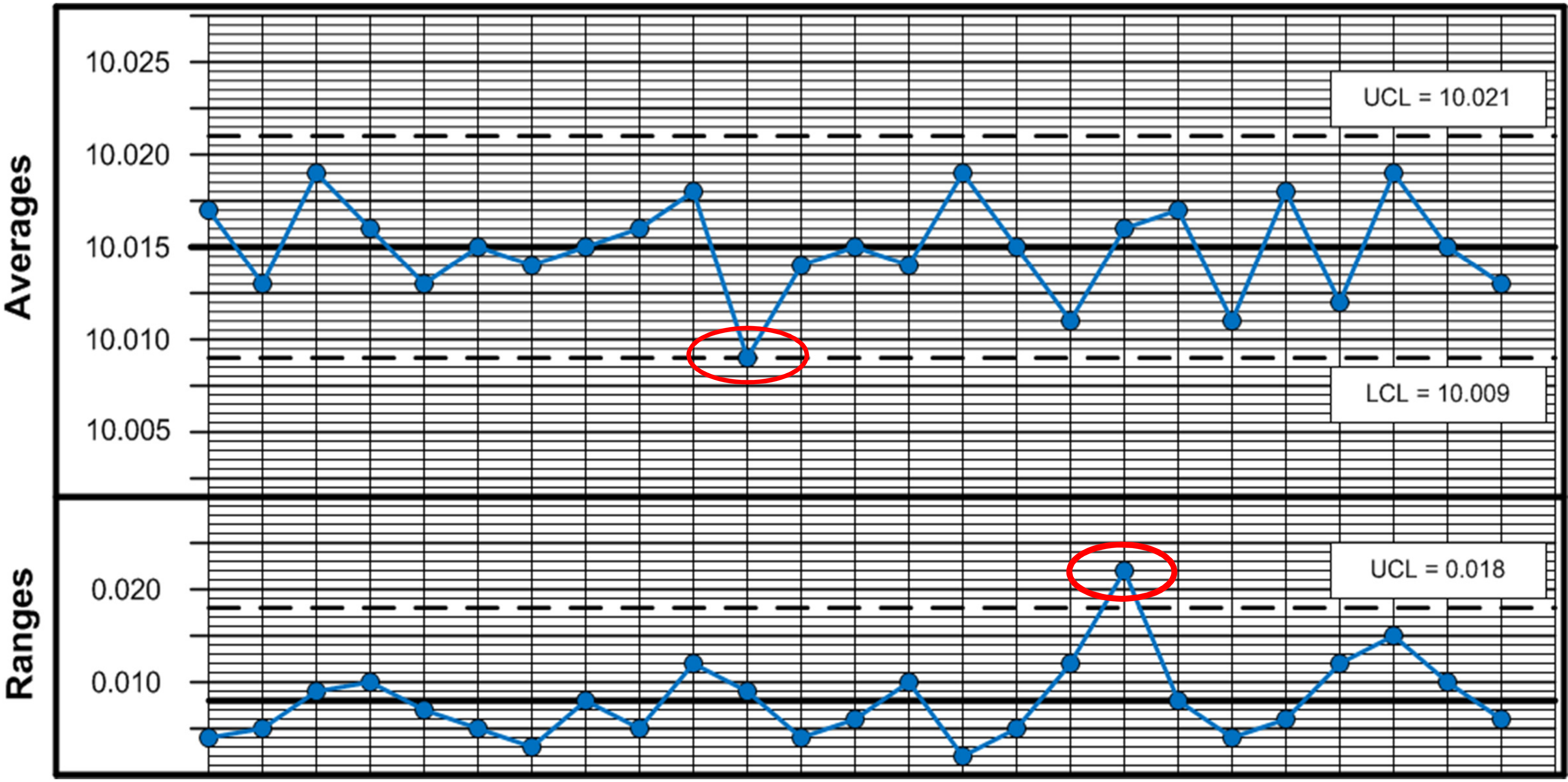
Changes in Behavior



Purpose of SPC

- The purpose of SPC is to understand the behavior of a process.
- The goal of that understanding is to predict how the process may perform in the future.
- All, so we may take appropriate action.

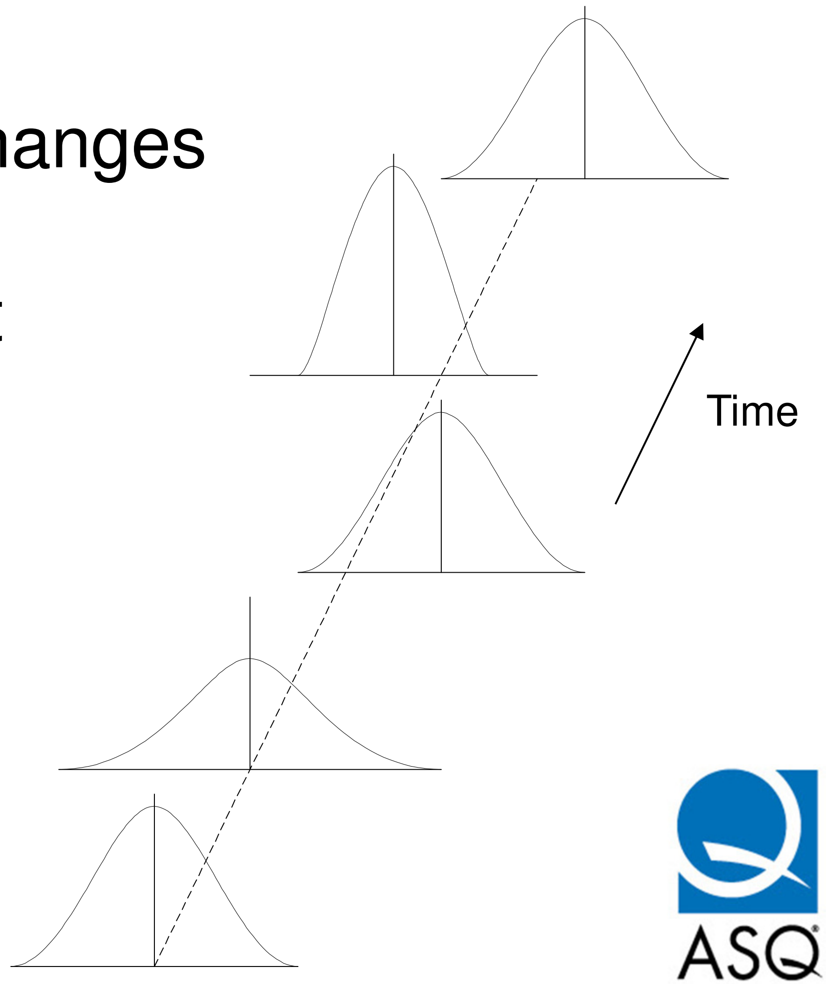
What if the Process Lacks Stability?



Some Processes Lack Stability

If the process is inconsistent, we have no basis for prediction. We use terms like:

- Presence of Unexpected Changes
- Special Causes are Present
- Significant Changes Occur
- Process Out of Control
- Unstable



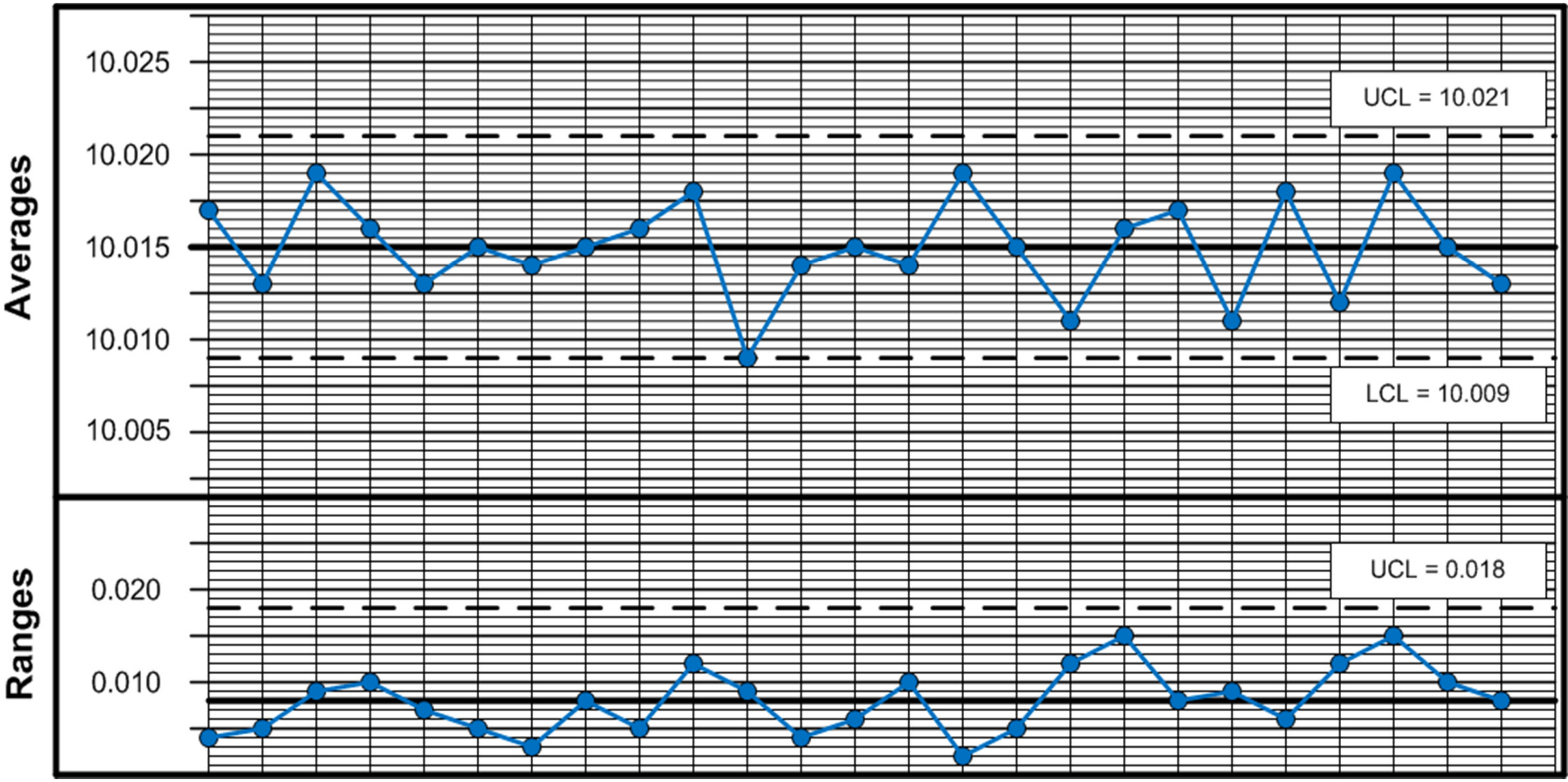
Root Cause Analysis for Instability

- *The investigation:* finding the specific special cause of the statistical signal.
- Learn how behavior is effected.
- Implement appropriate actions.
- Verify results.

Corrective Action for Instability

- We focus to identify and eliminate special causes of variation, one-by-one, by deliberate effort.
- We record what we learn about root causes and the causal system.
- We contribute to a library of lessons learned.
- We use lessons learned to prevent problems.

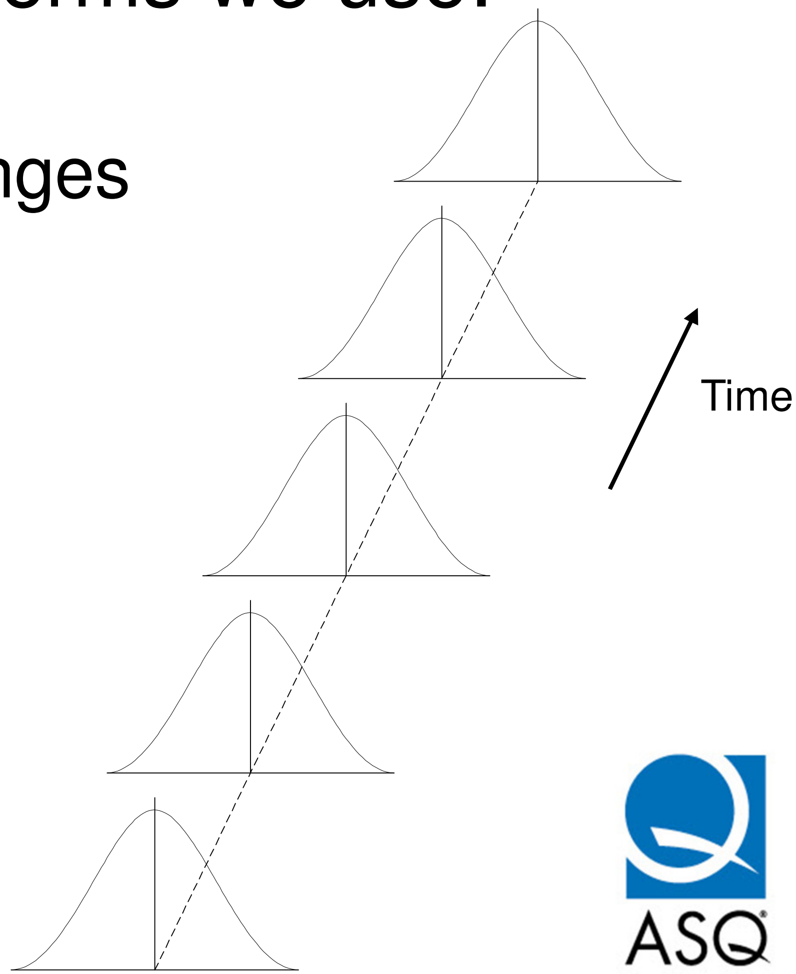
And What if the Process is Stable?



Other Processes are Predictable

If a process behaves consistently over time, we say it is predictable. Some terms we use:

- Absence of Unexpected Changes
- Common Cause Variation
- In Statistical Control
- Process is Stable



Root Cause Analysis with Stability

- *The investigation:* find significant causes of variation (the 80 – 20 Rule applies here).
- Learn how behavior is effected.
- Implement appropriate actions.
- Verify results.

Corrective Action with Stability

- We focus the system with deliberate effort.
- We record what we learn about root causes and the causal system.
- We contribute to the library of lessons learned.
- We use lessons learned to prevent problems.

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Two Frequent Mistakes

Two types of mistakes are frequently made in attempts to improve results. Both are costly.

Mistake 1. To react to an outcome as if it came from a special cause of variation, when it actually came from common causes.

Mistake 2. To treat an outcome as if it came from common causes of variation, when it really came from a special cause.

The Genius of Dr. Walter A. Shewhart

Invented a set of tools that give us a rational basis to know whether data is random or is affected by assignable causes.

It All Begins with Process Stability

"A process may be in statistical control; it may not be. In the state of statistical control, the variation to expect in the future is predictable."

"If the process is not stable, then it is unstable. Its performance is not predictable."

W. Edwards Deming, Ph.D.

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4. Other Types of Control Charts
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Continual Improvement
and
Statistical Process Control

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Seven Questions to Guide Us

1. What is meant by a system of process control?
2. How does variation impact process output?
3. How can data tell us whether a problem is local in nature or does it apply to broader systems?
4. What is meant by a process being stable or capable?
5. What is meant by a continuous cycle of improvement?
6. What are control charts and how are they used?
7. What benefits may we expect from using control charts?

Deming's Red Bead Experiment

White Bead Factory

Vacancies: 10

6 Willing Workers

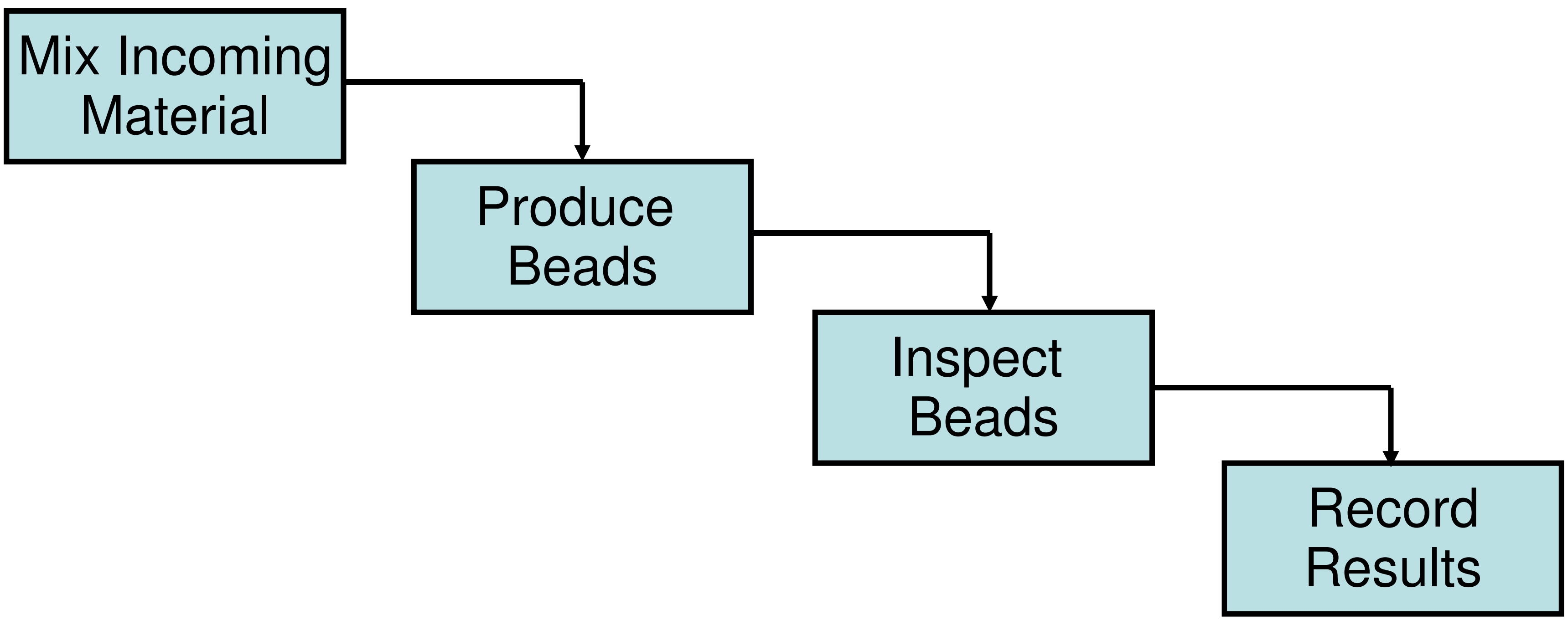
2 Inspectors

1 Inspector General

1 Recorder

Red Beads and Life

"Our procedures are rigid. There will be no departure from procedures, so that there will be no variation in performance."



Red Beads and Life

To the willing workers: *"Your job is to make white beads, not red ones."*

We reward good performance – merit raise.

We penalize poor performance – probation.

Red Beads and Life

"The foreman is perplexed. Our procedures are rigid. Why should there be variation?"

Red Beads and Life

"What was wrong with the wonderful idea to keep the place opened with the best workers?"

"The three best workers in the past had no more chance than any other three to do well in the future."

4 Paddles, 2 Sets of Beads

Paddle	Set of Beads	Average
1	A	11.3
2	B	9.6
3	B	9.2
4	B	9.4

"No one could project what average will cumulate for any given paddle."

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A Most Important Lesson

Knowledge of the proportion of red beads in the incoming material provides no basis for predicting the proportion red in the output.

The work loads were not drawn by random numbers from the supply.

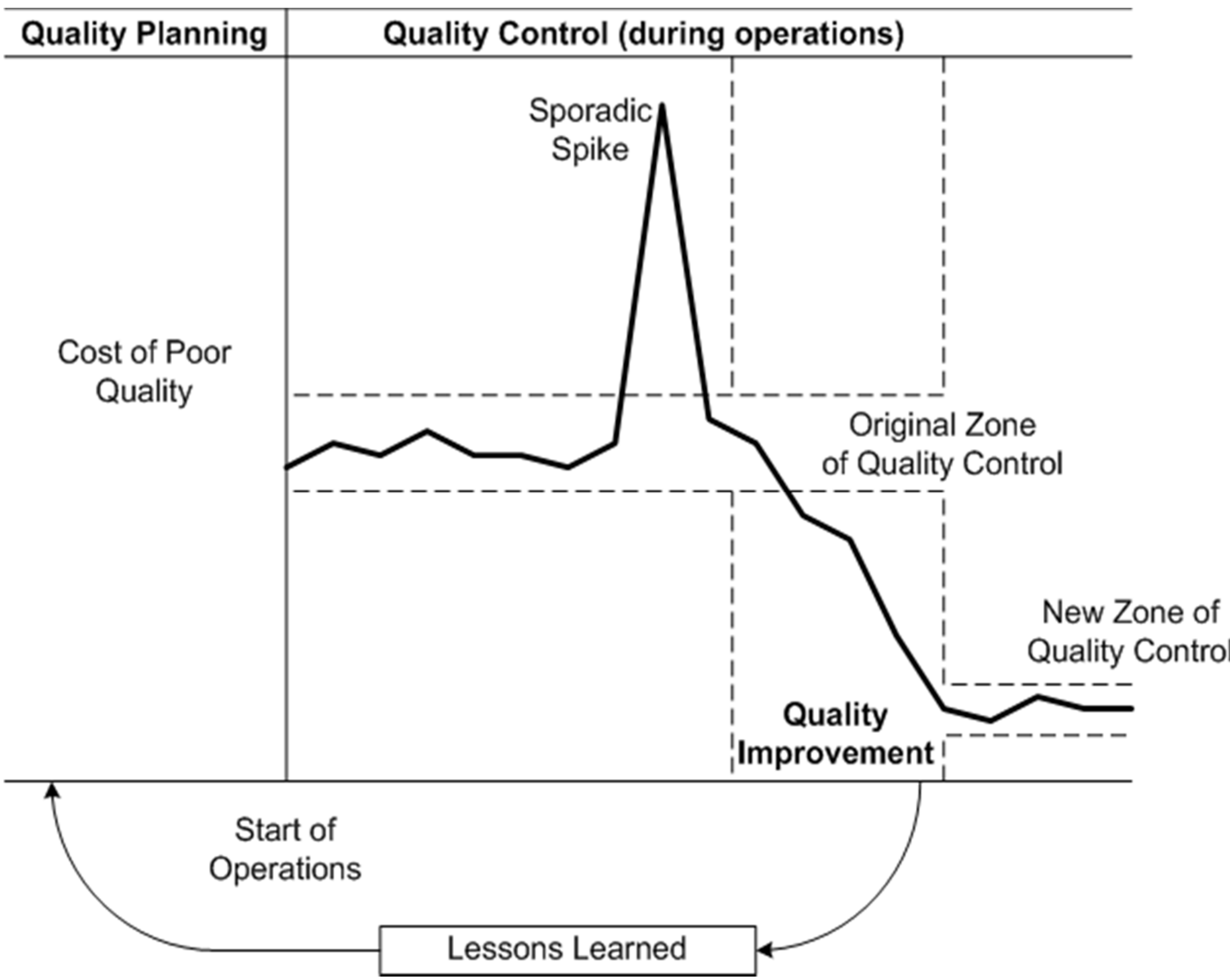
They were drawn by mechanical sampling.

Red Beads and Life

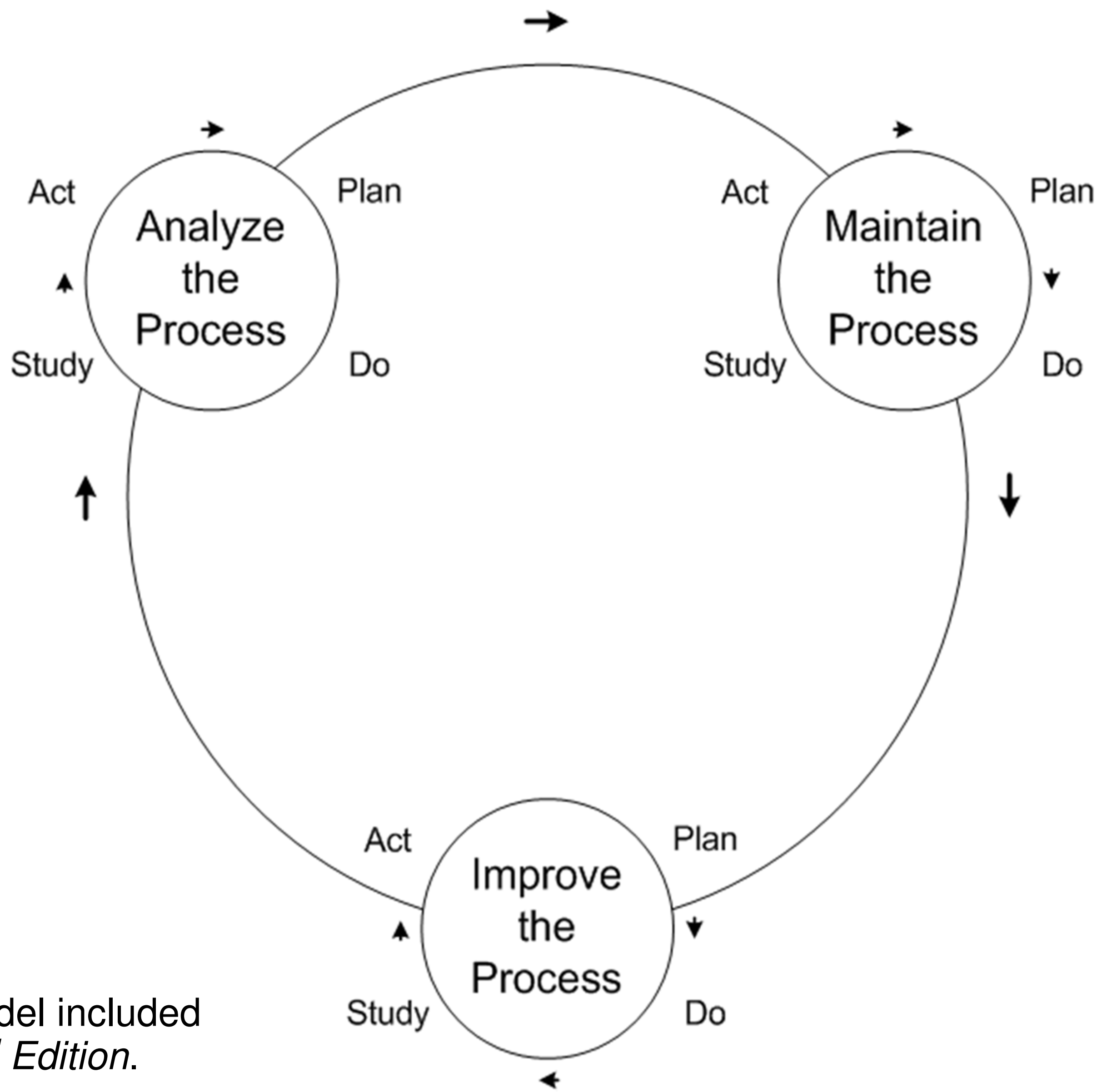
"The system turned out to be stable. The variation and level of output of the willing workers, under continuance of the same system, was predictable."

"The foreman himself was a product of the system."

The Juran Trilogy® Diagram

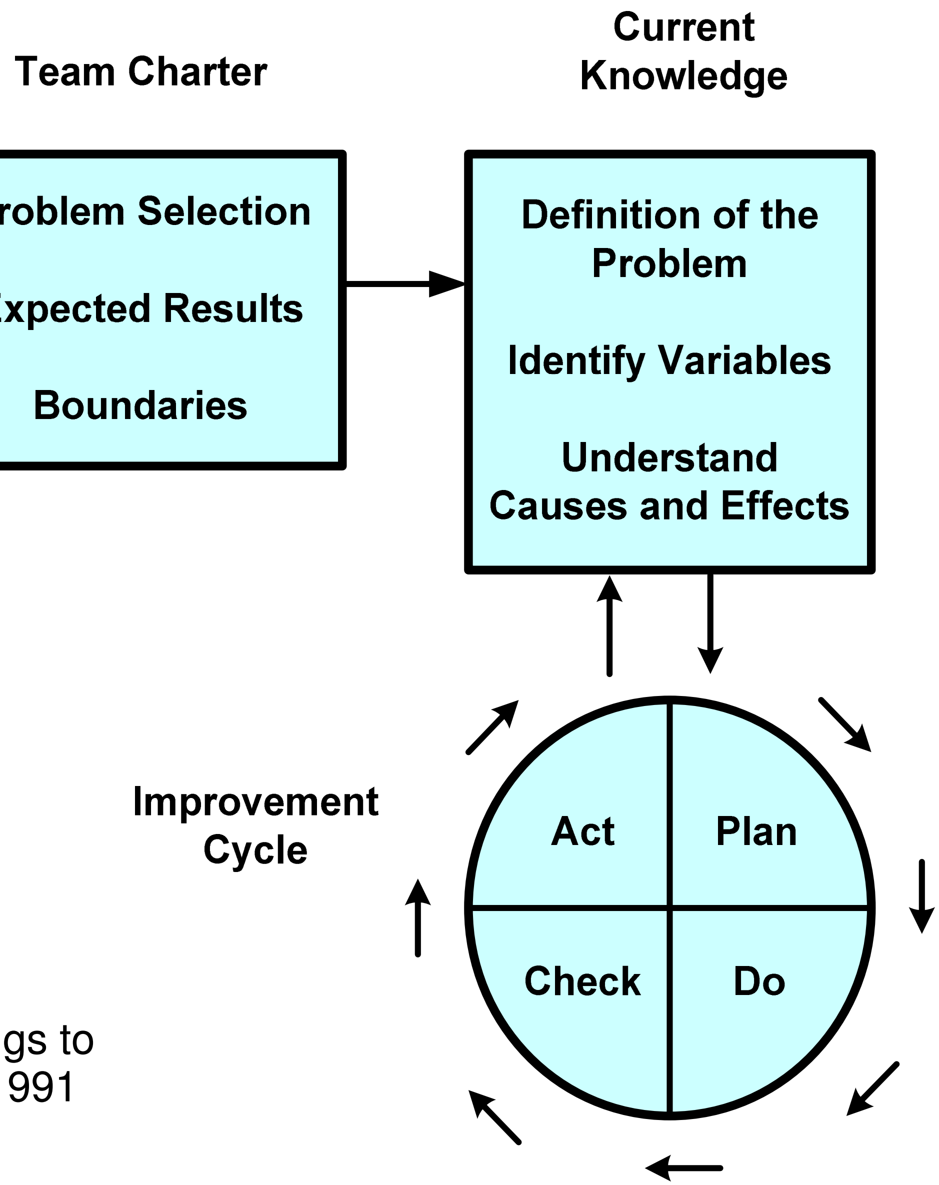


Process Improvement Cycle



This is the model included in the *SPC 2nd Edition*.

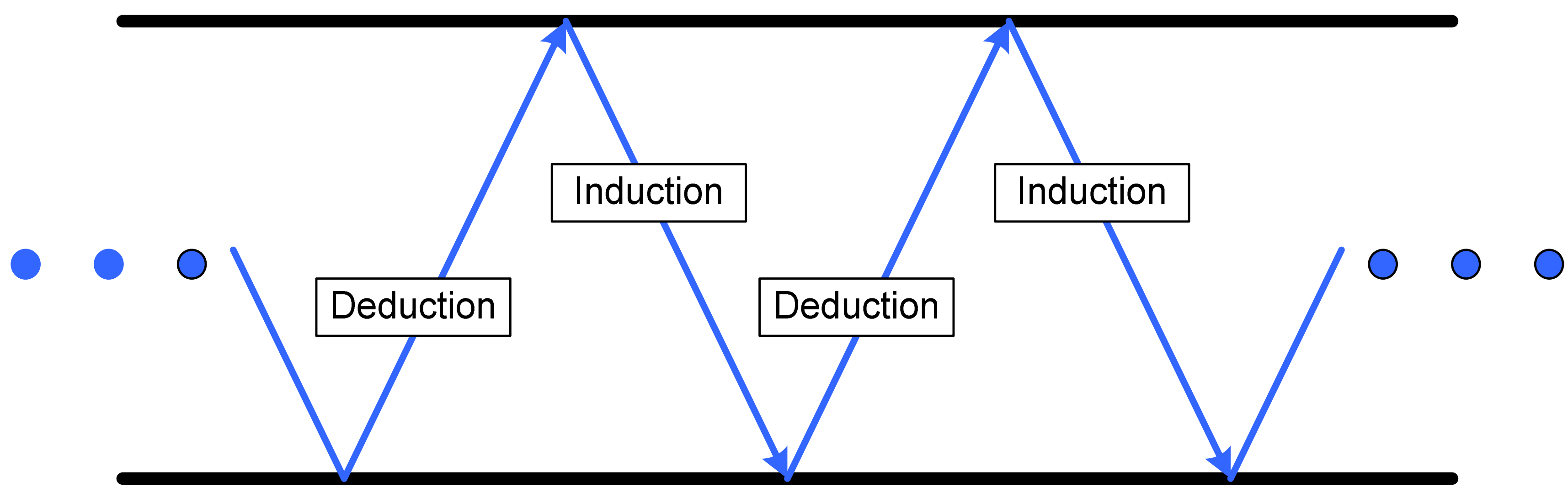
One Model for Improvement



Credit for this model belongs to
Moen, Nolan & Provost, 1991

Learning is an Iterative Process

Facts, Phenomema, Data



Hunches, Hypotheses, Conjecture, Model, Theory

Box, Hunter & Hunter, 1977

Control Charts

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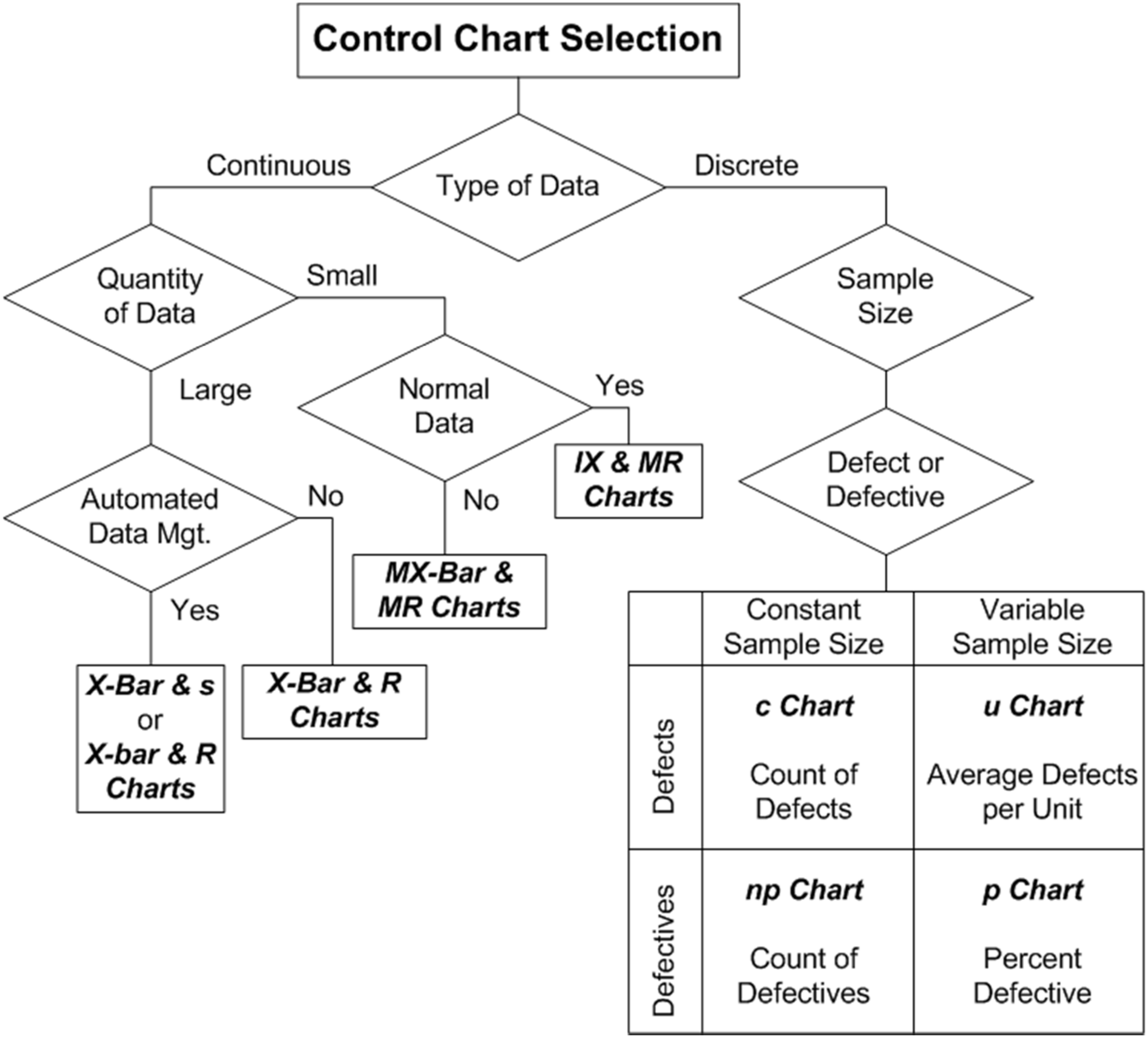
Common Variables Control Charts

- X Bar and R Charts
  - Data is plentiful.
- X Bar and s Charts
  - Data is plentiful, calculations are automated.
- Individual X and Moving Range Charts
  - Limited data exists.
- Moving Average and Moving Range Charts
  - Limited data from a non-normal distribution

Common Attributes Control Charts

- p Chart for Fraction Defective
  - Subgroup Size May Vary
- c Chart for Number of Defects
  - Subgroup Size Constant
- np Chart for Number of Defectives
  - Subgroup Size Constant
- u Chart for Number of Defects per Unit
  - Subgroup Size May Vary

Control Chart Decision Flow Chart



Dr. Shewhart's Ideal Bowl

- This is a photograph of Dr. Shewhart's ideal bowl experiment.

- He randomly sampled numbered tags from this bowl with replacement as he developed his theories for SPC.

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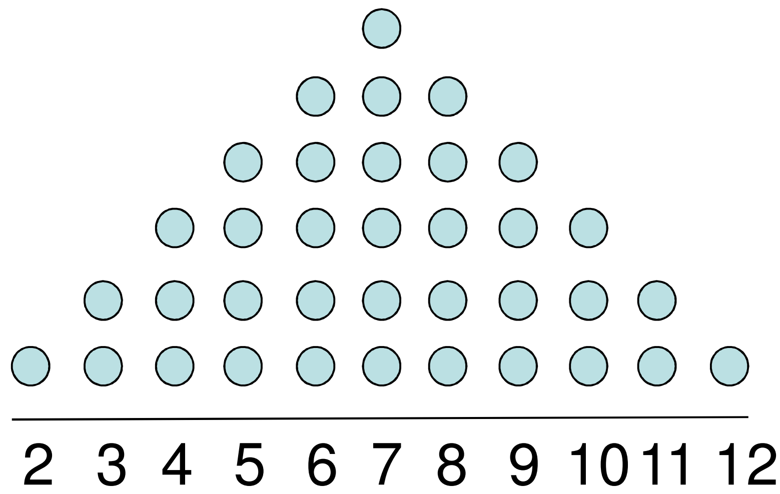
An Ideal Bowl Experiment

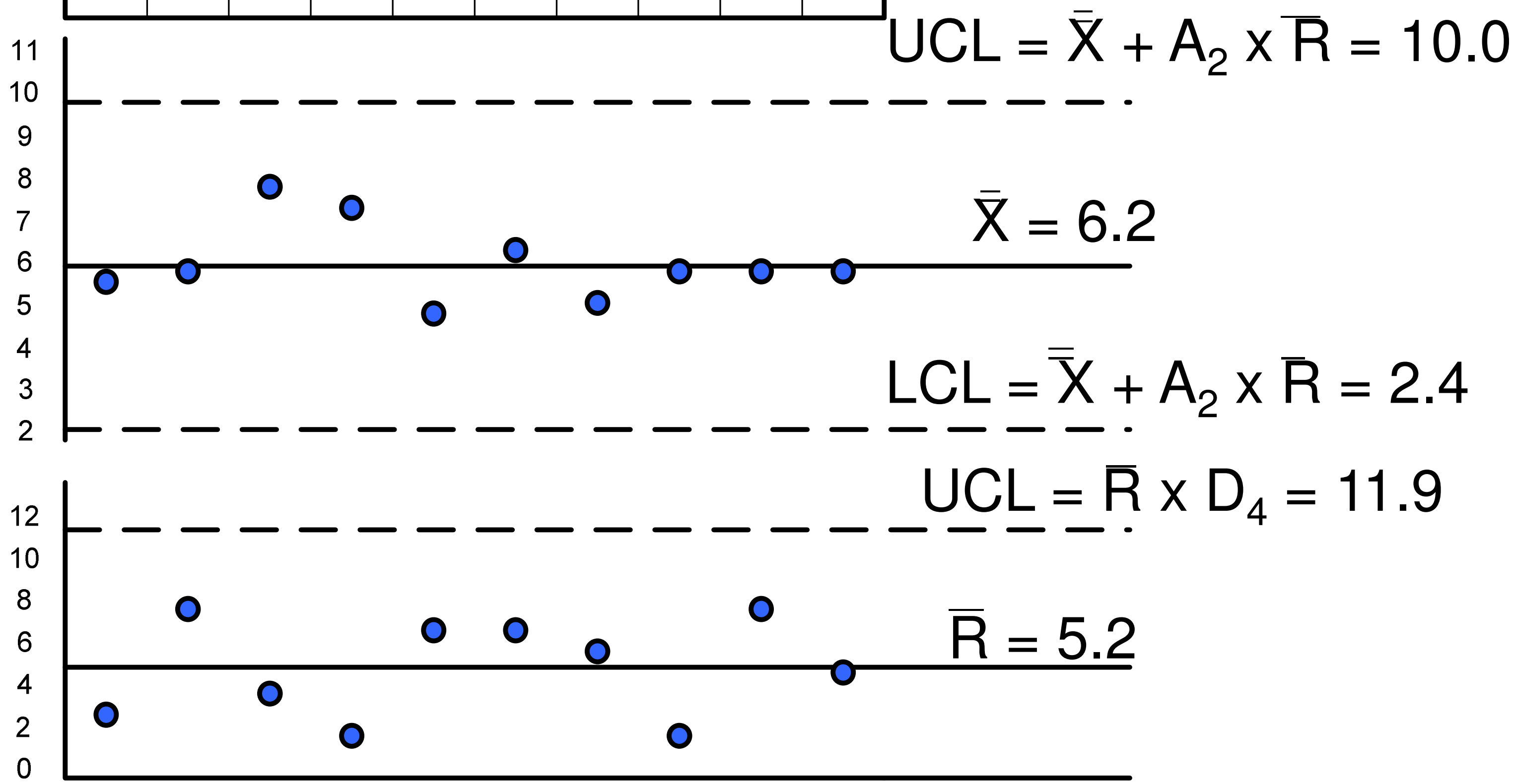


- This is a distribution of the sum of two fair dice.
- Each individual solution is equally likely.
- From this distribution we draw samples of four with replacement.

X Bar and R Chart

Sample Data from Ideal Bowl: n = 4

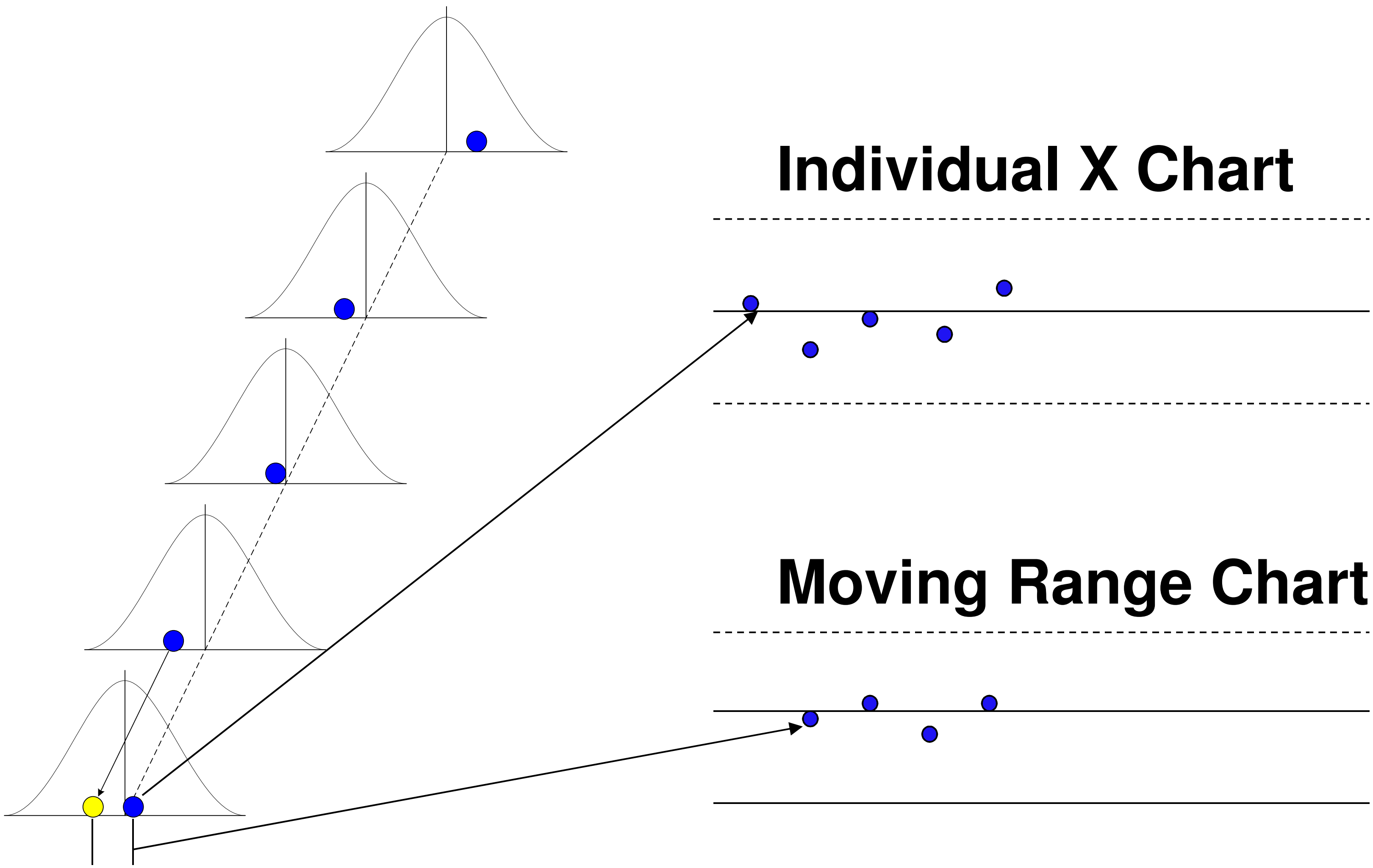
4	2	6	6	2	2	2	5	3	4
5	5	7	8	3	7	5	6	4	5
7	7	9	8	6	8	8	6	6	6
7	10	10	8	9	9	8	7	11	9



X Bar and R Chart Constants

n	A_2	D_3	D_4	d_2
2	1.88	0	3.27	1.13
3	1.02	0	2.57	1.69
4	0.73	0	2.28	2.06
5	0.58	0	2.11	2.33
6	0.48	0	2.00	2.53

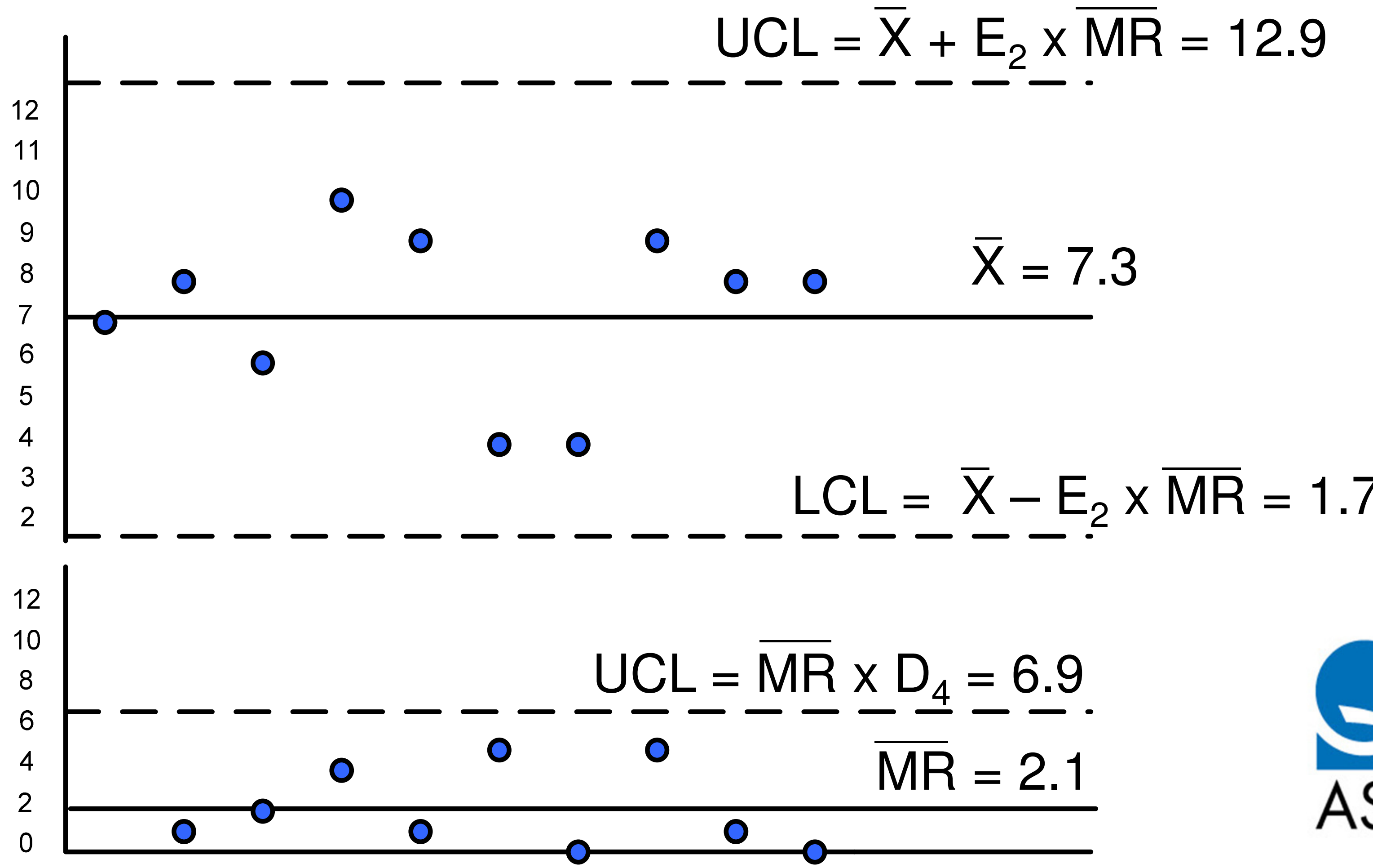
Individual X and Moving Range Chart



Individual and Moving Range Charts

Sample Data from Ideal Bowl: Moving Range based on n = 2

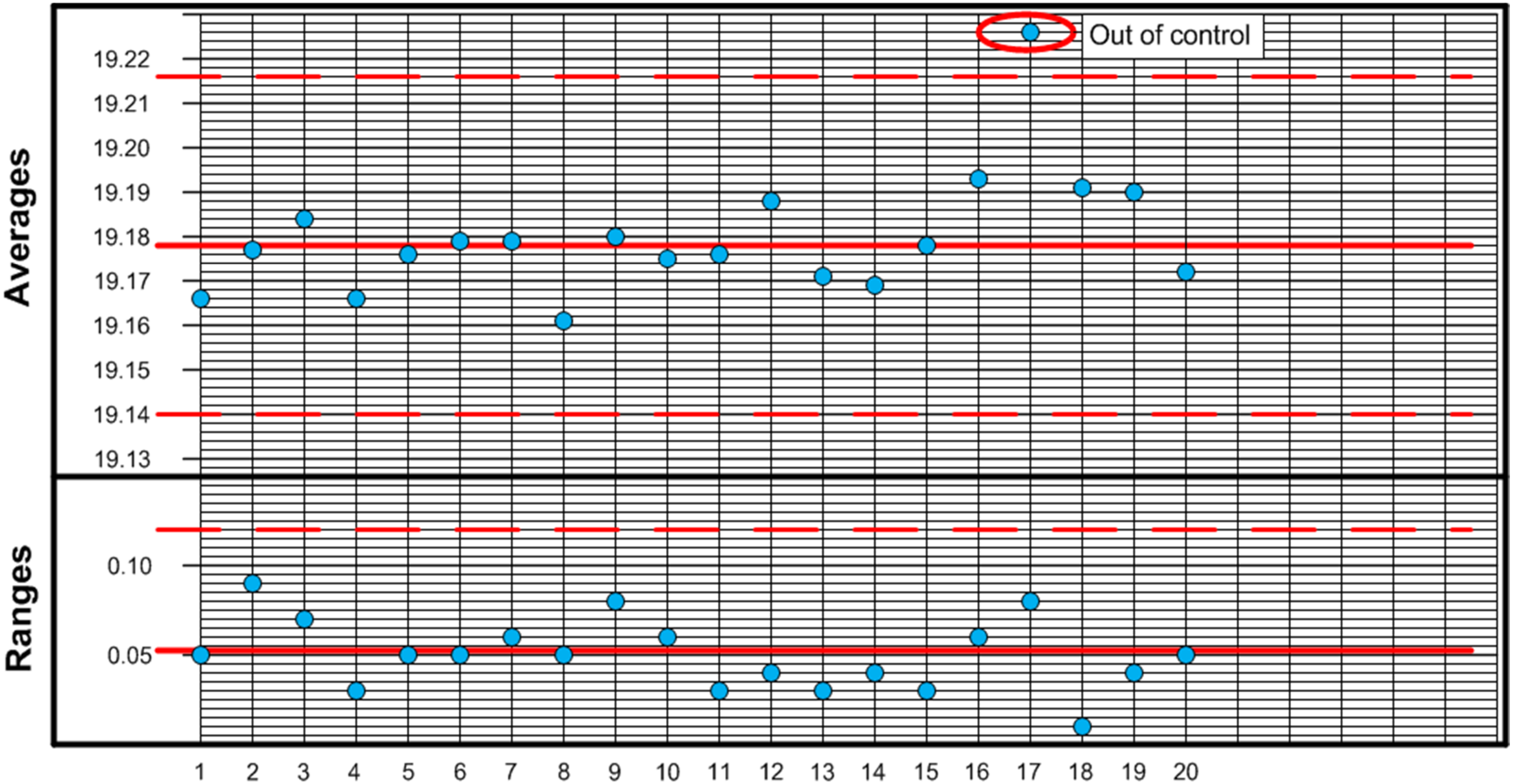
7	8	6	10	9	4	4	9	8	8



IX and MR Chart Constants

n	E_2	D_3	D_4
2	2.66	0	3.27
3	1.77	0	2.57
4	1.46	0	2.28
5	1.29	0	2.11

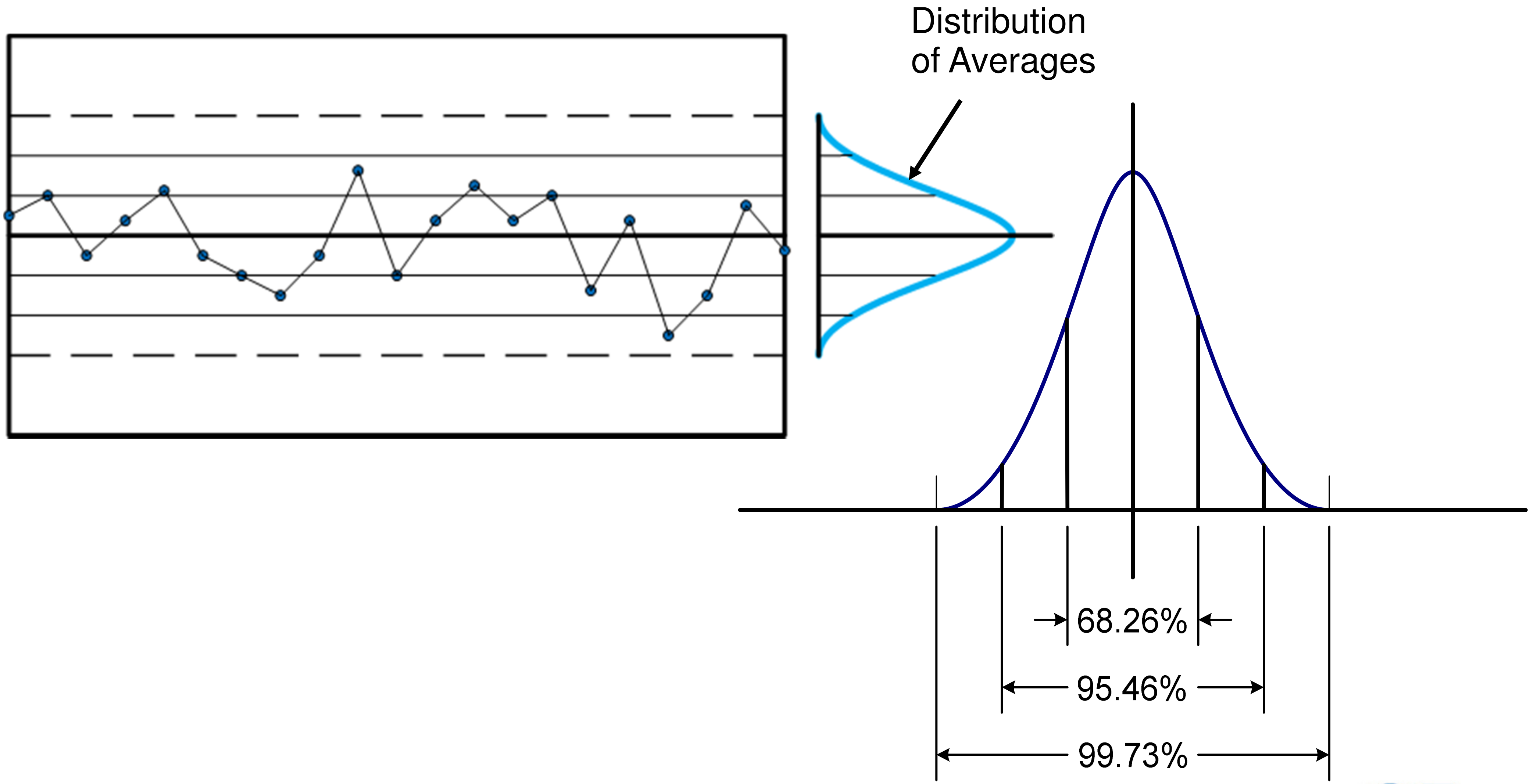
Sample X-bar and R Chart



Sample Event Log

Subgroup	Time	Date	Description of Operations
223	8:30 a.m.	1-6-2012	Normal
224	10:30 a.m.	1-6-2012	Normal
225	1:00 p.m.	1-6-2012	Normal
226	3:00 p.m.	1-6-2012	Broken pin on Carrier #42, off line for repair.
227			

Statistical Signals



How to Identify *Out-of-Control* Signals

Typical Criteria for Special Causes	
1	1 point beyond the control limits.
2	7 points in a row above or below the center line.
3	6 points in a row all increasing or decreasing.
4	14 points in a row alternating up and down.
5	2 out of 3 points beyond 2 standard deviations from center line (same side).
6	4 out or 5 points beyond 1 standard deviation from center line (same side).
7	15 points in a row within 1 standard deviation on either side of the center line.
8	8 points in a row more than 1 standard deviation from the center line (either side).

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Calculations for X-Bar and R Charts

Sample Average

$$\bar{X} = \frac{\sum x_i}{n}$$

Grand Average

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{k}$$

Sample Range

$$Range = x_{\max} - x_{\min}$$

Average Range

$$\bar{R} = \frac{\sum R}{k}$$

Control Limits for Averages

$$UCL, LCL = \bar{\bar{X}} \pm A_2 \bar{R}$$

UCL for Ranges

$$UCL_{Range} = D_4 \bar{R}$$

LCL for Ranges

$$LCL_{Range} = D_3 \bar{R}$$

Standard Deviation of Individuals

$$\sigma_i = \frac{\bar{R}}{d_2}$$

Standard Deviation of Averages

$$\sigma_{\bar{X}} = \frac{\sigma_i}{\sqrt{n}}$$

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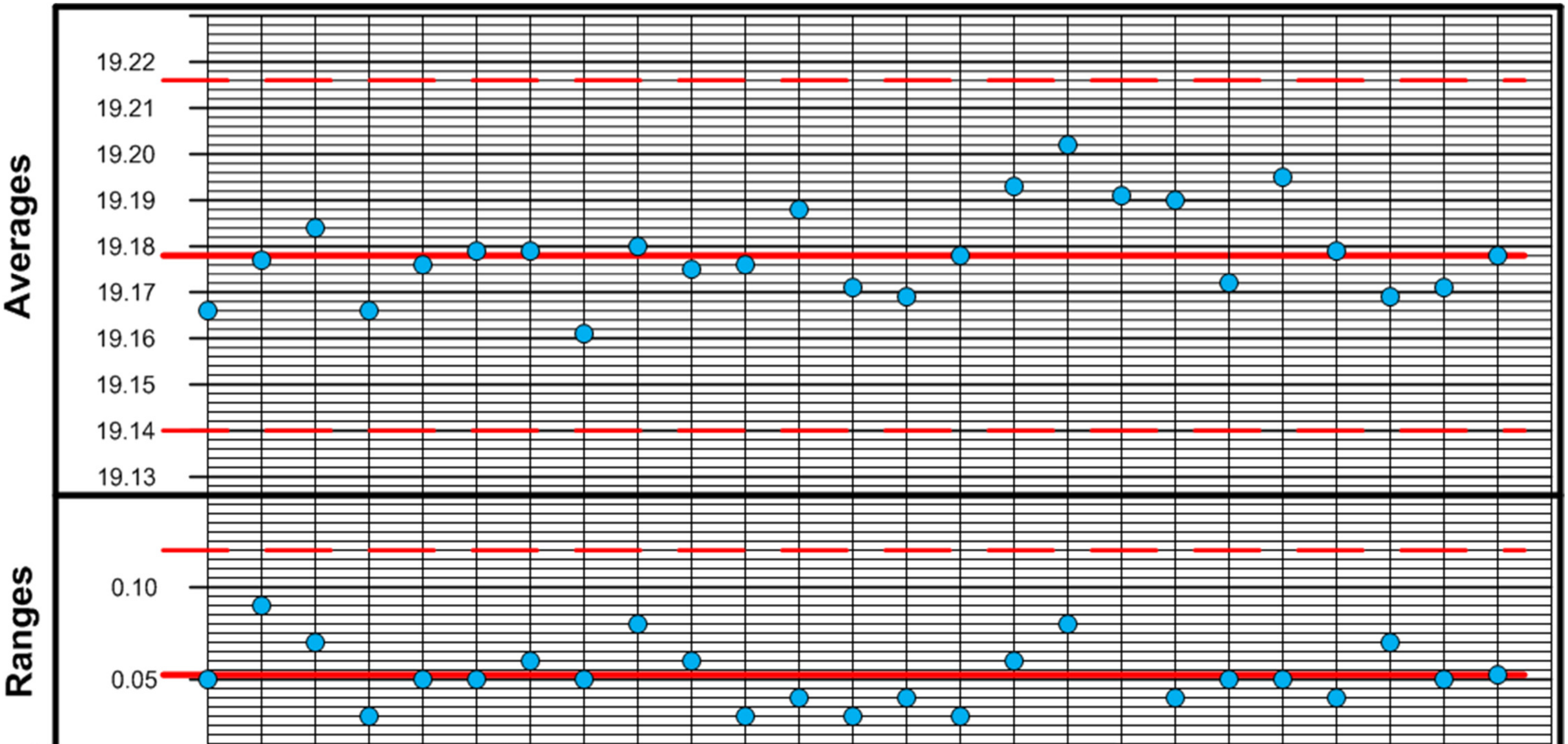
X-Bar and R Chart Worksheet



First Three Subgroups			Final Five Subgroups					
Data	Subgroup 1	Subgroup 2	Data	Sample 21	Sample 22	Sample 23	Sample 24	Sample 25
x1	19.17	19.14	x1	19.20	[illegible]	19.16	19.20	19.19
x2	19.14	19.23	x2	19.14	[illegible]	[illegible]	19.18	19.17
x3	19.20	19.16	x3	19.20	[illegible]	19.16	19.13	19.14
x4	19.15	19.18	x4	19.20	19.21	19.18	19.17	19.18
Average	**19.166**	**19.177**	Average	**19.186**	**19.185**	**19.179**	**19.169**	**19.171**
Range	**0.05**	**0.09**	Range	**0.06**	**0.05**	**0.04**	**0.07**	**0.05**

Grand Average = 19.178 mm
UCL Averages = 19.216
LCL Averages = 19.140
Average Range = 0.052
UCL Ranges = 1.190
LCL Ranges = 0

What You Should be Able to Do?

- Select and appropriate control chart.
- Plot data.
- Calculate and plot average values.
- Calculate and plot control limits.
- Assess charts for statistical stability.

Other Types of Control Charts

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Other Types of Control Charts

- Probability Based Charts
  - Stoplight Control
  - Pre-Control
- Short Run Control Charts
  - Deviation from Nominal
  - Standardized X-bar and R Charts
  - Standardized Attributes Control Charts
- Charts for Detecting Small Changes
  - CUSUM Chart (Cumulative Sum)
  - EWMA Chart (Exponentially Weighted Moving Average)

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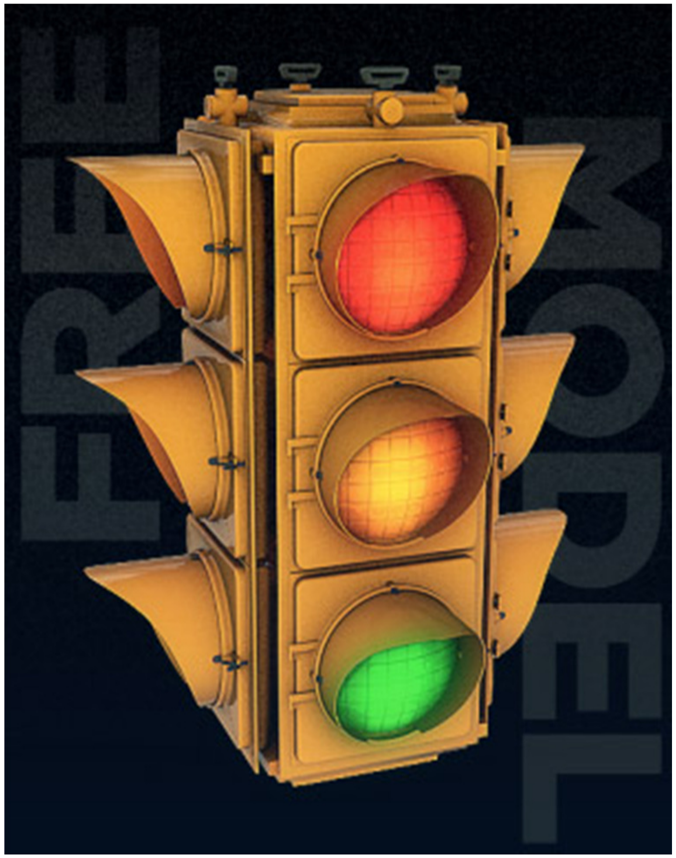
Probability Based Charts

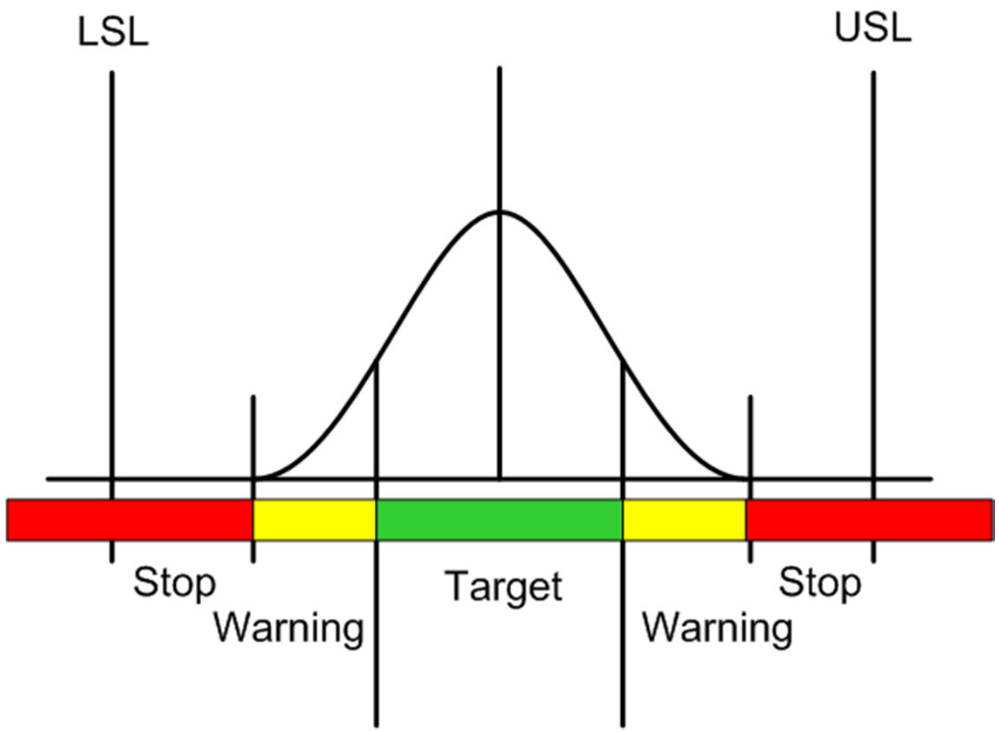
- Stoplight Control

- Pre-Control



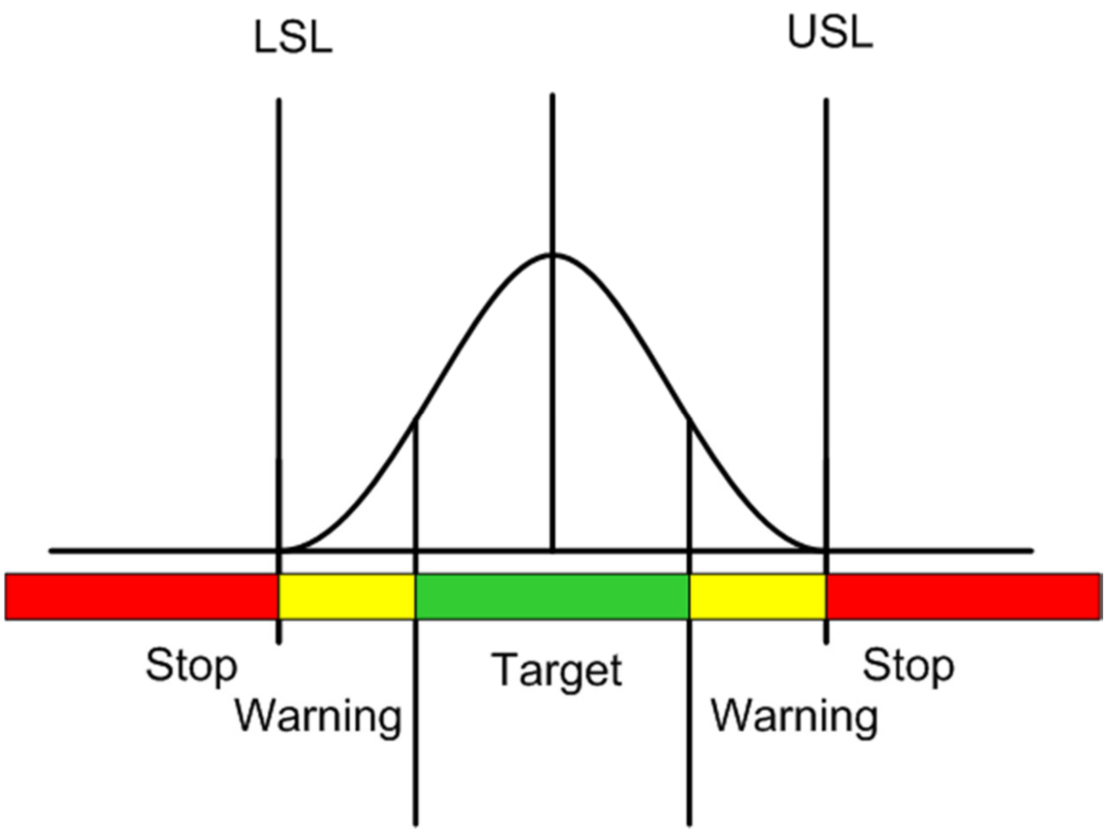
Stoplight Control

- With stoplight control, the red, yellow, and green zones are determined from the natural variation inherent in the process. It is simply a form of process control that is based on random occurrence from a stable process.



Pre-Control

- Pre-Control is a technique that sets the limits of the red zones at the upper and lower specifications.



Understanding Process Capability

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Three Questions to be Taken in Order

Dr. Hans Bajaria claimed that these three questions could identify three unique sets of causes.

1. Is the process stable?

2. Is there too much variation?

3. Is the process off-target?

Impact of Instability

- It makes no sense to talk of the capability of the system when that system is unstable, because it is unpredictable.
- The process must be brought in to a state of statistical control, for then and only then, does it have a definable capability.

Three Questions to be Taken in Order

Dr. Hans Bajaria claimed that these three questions could identify three unique sets of causes.

1. Is the process stable?

   Method to know: **Control Chart**

2. Is there too much variation?

   Method to know: **Cp or Pp**

3. Is the process off-target?

   Method to know: **Cpk or Ppk**

Summary and Closure

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Course Goals

1. To provide a fundamental understanding of the relationship between SPC and continuous improvement.

2. To use SPC to achieve a state of statistical process control for special characteristics.

3. To assess process capability and process performance for special characteristics.

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Questions and Answers

Please type your questions in the panel box

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Thank You For Attending

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