Statistical Process Control Activity
Resistance Measurement
Instructor Guide

Note to Instructor

This activity provides participants with the opportunity to apply their knowledge of controls charts, how to construct and how to interpret them. Participants will collect real data and then use that data to set up a control chart, plot data, and determine is a process is in or out of control.

This activity is part of the *Statistical Process Control Learning Module*, which covers the following:

- Statistical Process Control Knowledge Probe (KP) Pre-test
- Introduction to Statistical Process Control (PK)
- Control Chart Basics (PK)
- **SPC Resistance Measurement Activity**
- Activity (Advanced) – An MEMS Process Problem (Found in the SCME Systematic Approach to Problem Solving Learning Problem)
- Final Assessment

This companion Instructor Guide (IG) contains all of the information in the Participant Guide (PG) as well as answers to the coaching and review questions at the end of the unit.

Activity Description

Statistical Process Control or SPC is a set of tools used for continuous improvement and the assurance of quality in an active manufacturing process. This quality control method uses statistical techniques to monitor a process by providing tools to determine when a process is running correctly or has begun to produce undesired results.

The purpose of this activity is to apply your knowledge of SPC to determine whether or not your process is operating as it should. You use historical data to construct a control chart with the statistically appropriate parameters. You then take resistance measurements of process samples, plot them on your chart and analyze the results.

Objectives

- Use historical data to construct a control chart.
- Measure resistance values of process samples and plot the resistance values on your control chart.
- Using the Shewhart Rules (Western Electric Rules), determine if your process is in control.

Introduction

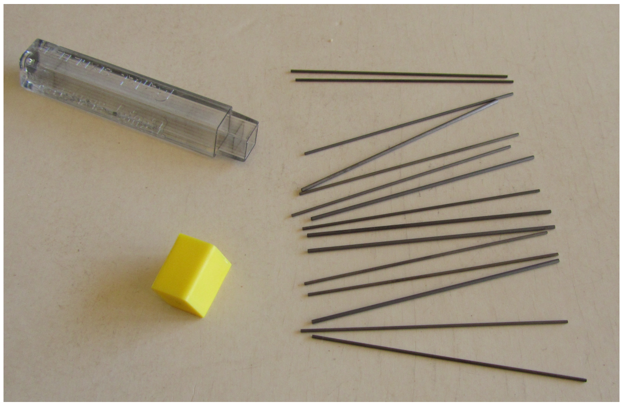
Activity Scenario: You work in a factory that produces small conductive rods, 6 cm in length, approximately 0.7 mm in diameter. The rods are packaged in batches of 15 rods. The material used to manufacture the rods is graphene. Graphene is a conductive material, thus it carries electrical properties.

It is your job to determine if the process is producing rods within a specified range of resistance values based on the historical data (previous production results). SPC charts are used to monitor these resistance values.

However, before determining is the current process is “in-control”, you must first use historical data to construct the control charts. You are given a set of historical resistance measurements for 20 different batches of rods from which you design the control charts for rod processing.

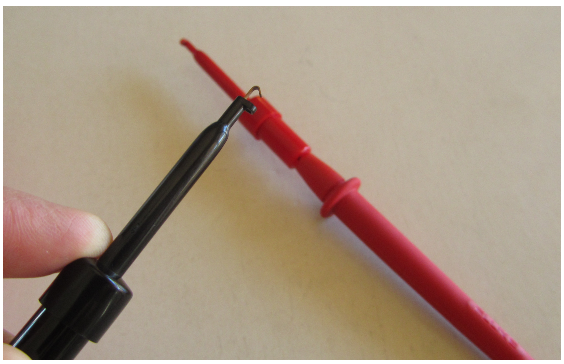
Supplies / Equipment

- A batch of 6 cm long graphene rods. (Each batch contains 15 individual rods)
- A voltmeter with mini test clip adapters
- A sample set of historical data to calculate SPC chart parameters (included)
- SPC chart template (attached)
- Data collection template (attached)

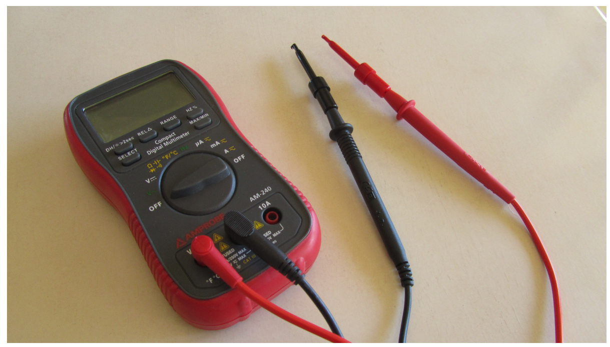


One batch of 15 conductive rods

Voltmeter with probes and mini test clips



Close up of mini test clips



Voltmeter with mini test clips attached

Documentation

Write a report to include the following:

- Describe how to calculate the SPC limits, show equations and sample calculations.
- Describe which type of SPC chart you used for the individual measurements in your batch and show this chart with its control limits and the data points from your individual measurements from your batch.
- Describe which Shewhart rules you applied to your individual measurements chart.
- Discuss the variation and possible causes of variation between individual rod measurements in each given batch.
- Describe which SPC chart(s) you used for the classroom batch measurements.
- Describe which Shewhart rules you applied to your classroom measurements chart.
- Discuss possible causes of variation between the batch measurements in the classroom.
- Discuss the differences between your SPC chart for individual rod measurements, and the X-bar chart for the classroom batch measurements. Which one is more accurate?

- Describe what additional information the Range chart for the classroom batches gives you and how the X-bar and Range chart can work together.
- Answers to the Post-Activity questions.

Expectations

This activity allows you to put into practice the concepts of Statistical Process Control (SPC) by taking you through the steps of building a SPC chart. You measure and plot resistance values on your SPC chart and use the Shewart/Western Electric Rules to determine if your process is in control. This exercise also helps you to gain insight into causes of process variation.

Preparation / Setup

Gather all of the supplies for this activity. Set up a workspace on a flat table large enough to lay out each piece of lead in your batch. Keep in mind that you will be using a voltmeter to measure the resistance of each graphene rod. You will also need to keep track of the order of each piece of rod that you measure; therefore, consider that when you are setting up your workspace.

Activity: Part I – Calculate the individual SPC chart parameters using historical data & create an SPC Chart with Control Limits

1. You are given a sample set of historical resistance measurement data for 20 different *batches* of 6 cm long conductive, graphene rods. This data for each *batch* (x_n) is actually the mean or $\bar{X}$ (X-bar) of the individual resistance measurements of each individual rod in a batch.

Historical Mean Resistance values ($\bar{X}$) for 20 different *batches* of 6mm graphene rods.

$\bar{X} = x_n$ Resistance (Ω)
1.6
1.6
1.7
1.4
1.9
1.6
1.9
1.4
1.6
1.7
2.0
1.3
2.0
1.8
1.7
2.0
1.6
1.4
1.7
1.9

2. Use this set of historical $\bar{X}$ (X-bar) data given above to calculate the mean of the batch means or $\bar{\bar{X}}$ (X-bar-bar). This will be the centerline or target value for your SPC chart. We will call this $\bar{\bar{X}}$ value, μ. Recall the equation for μ:

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

3. Use this set of historical $\bar{X}$ data and the $\bar{\bar{X}}$ you have just calculated to calculate the standard deviation for your historical data. Recall the equation for standard deviation, σ:

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

$$x_i = \bar{X} \; and \; \mu = \bar{\bar{X}}$$

4. Use the mean of the batch means or $\bar{\bar{X}}$ value and the standard deviation value to find the control limits: μ±1σ, μ±2σ, and μ±3σ.

5. Using the SPC chart template on the following page, set up your SPC chart by plotting your calculated values: $\bar{\bar{X}}$, μ±1σ, μ±2σ, and μ±3σ. Make sure to label the chart values and remember, these 7 values should be shown as Control Limits, or lines across your chart. It is a good idea to use colors to distinguish between $\bar{\bar{X}}$, μ±1σ, μ±2σ, and μ±3σ.

Mean (μ) $\bar{\bar{X}}$	Std. Dev. (σ)	μ+1σ	μ-1σ	μ+2σ	μ-2σ	μ+3σ	μ-3σ
1.69	0.215	1.905	1.475	2.120	1.260	2.335	1.045

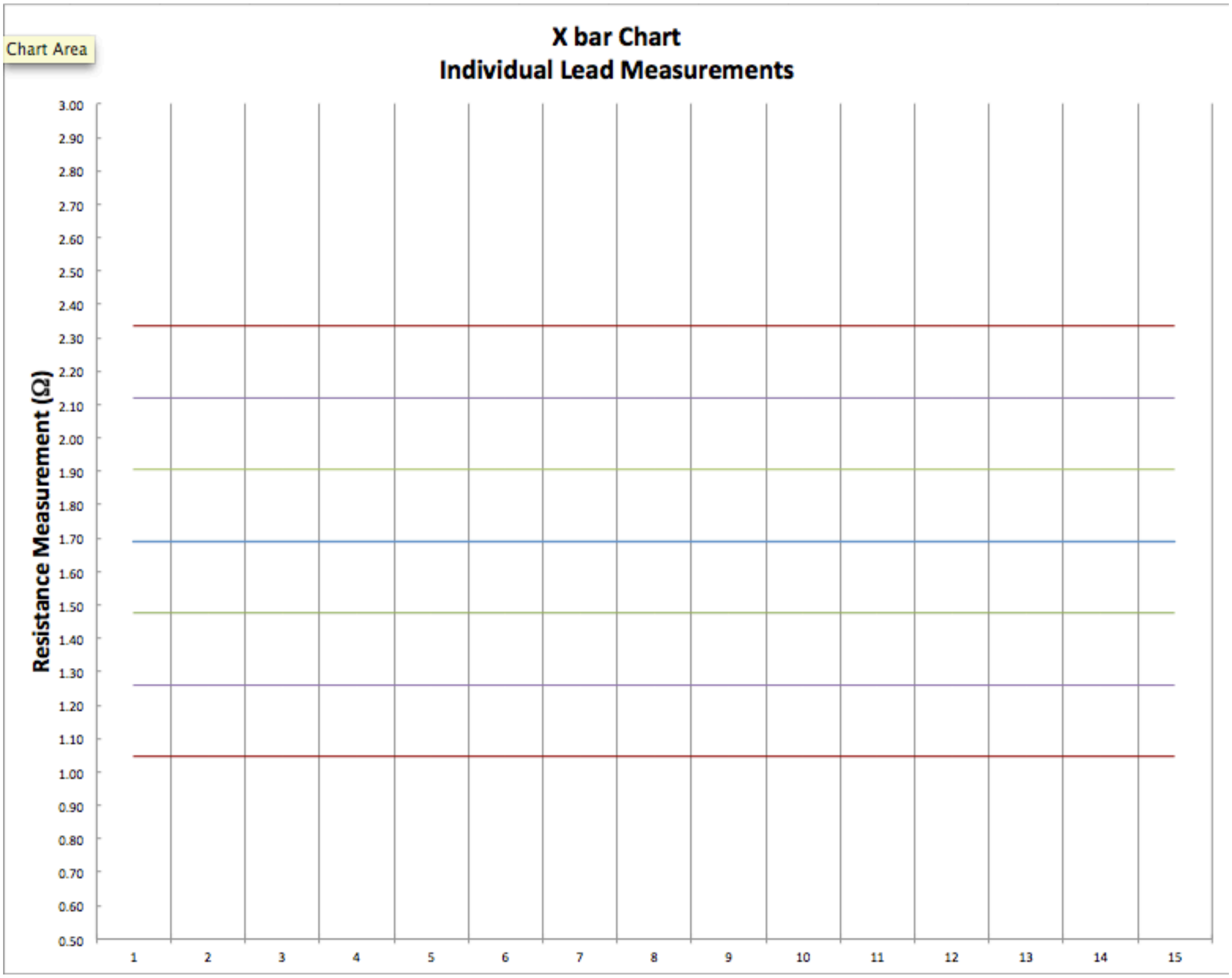


Chart Area
X bar Chart
Individual Lead Measurements
Resistance Measurement (Ω)
3.00
2.90
2.80
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
1
2
3
4
5
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11
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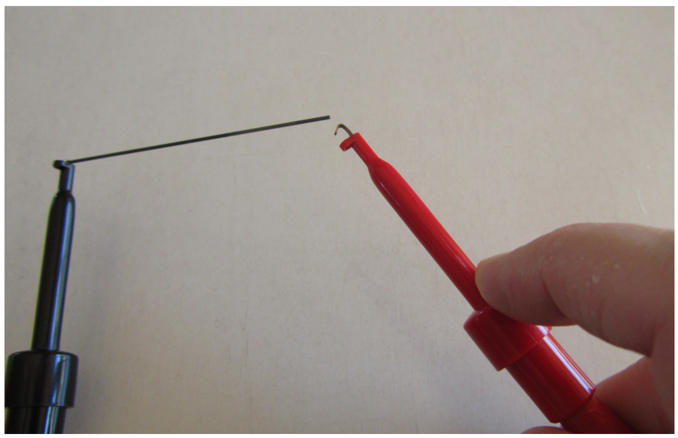
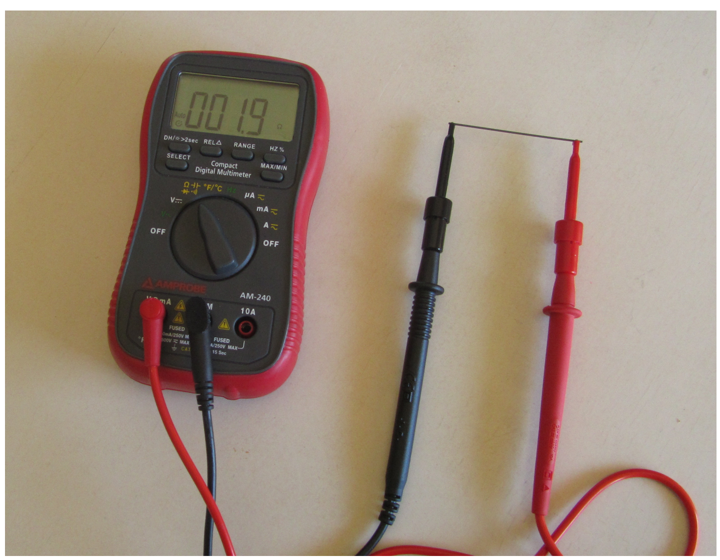
15

Part II – Use your given batch of lead to measure the resistance of each individual lead

1. Using the voltmeter, measure the resistance value (in Ω) of each individual piece of lead in your batch.
    a. Make sure that the voltmeter is set to measure Ω.
    b. Attach the mini test clips to the probes. Be very careful when attaching and detaching these mini test clips from the probes. They break easily.
    c. Attach a mini test clip to each end of the graphene rod. Be careful when attaching the clips to each end, you don't want to snap off the end of the rod.



    d. Once both mini test clips are attached, place the clips with the rod flat on the table and let the voltmeter reading stabilize.



    e. Record the resistance value in the table on the following page.
    f. Repeat for each of the 15 rods in your batch.

Measured Data Resistance (Ω) Individual lead

Answers may vary for measured data

Part III – Plot the individual resistance values on the SPC Chart.

1. Plot the resistance value of each individual measurement on your SPC chart you created in Part I.
2. Using the Shewhart/Western Electric Rules, are these resistance measurements "in control".
3. Do you notice any process changes such as shifting, trending, cycling?

8 Rules to Signal an Out of Control Process – Shewhart Rules or Western Electric Rules

Rule 1: A single point outside the $\mu \pm 3\sigma$ zone.
Rule 2: 2 out of 3 successive points outside $\mu \pm 2\sigma$ zone.
Rule 3: 4 out of 5 successive points outside $\mu \pm 1\sigma$ zone.
Rule 4: 8 or more successive numbers either strictly above or strictly below the mean (the center).
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.

Part IV – Set up and create a X-bar Chart for the classroom batches

1. Using the X-bar chart for batch resistance values on the following page, plot the control limits, $\bar{\bar{X}}$, μ±1σ, μ±2σ, and μ±3σ, that you calculated in Part I.
2. Calculate X-bar (mean) for your batch of rods.
3. Plot the X-bar resistance value for your batch on the X-bar SPC chart on the following page.
4. Calculate the Range for your batch of rods.
5. Given the Range Chart for Batch Resistance values, plot your batch range of resistance on the Range SPC chart.
6. If there are other groups in your class calculating the X-bar and Range for their batches, record their $\bar{X}$ and R values and plot them on your X-bar and R charts. If there are not other groups, obtain X-bar and R values from your instructor to plot on your X-bar and R charts.
7. Using the Shewhart/Western Electric Rules, are your plotted resistance measurements "in control".
8. Compare the X-bar and R charts, what do you notice?
9. Compare the Individual Measurements Chart you created in Part III to the X-bar chart of batch values created here, what are the differences?

Your Batch Mean and Range Values

Batch Mean $\bar{X}$	Range
Answer will vary	***Answer will vary***

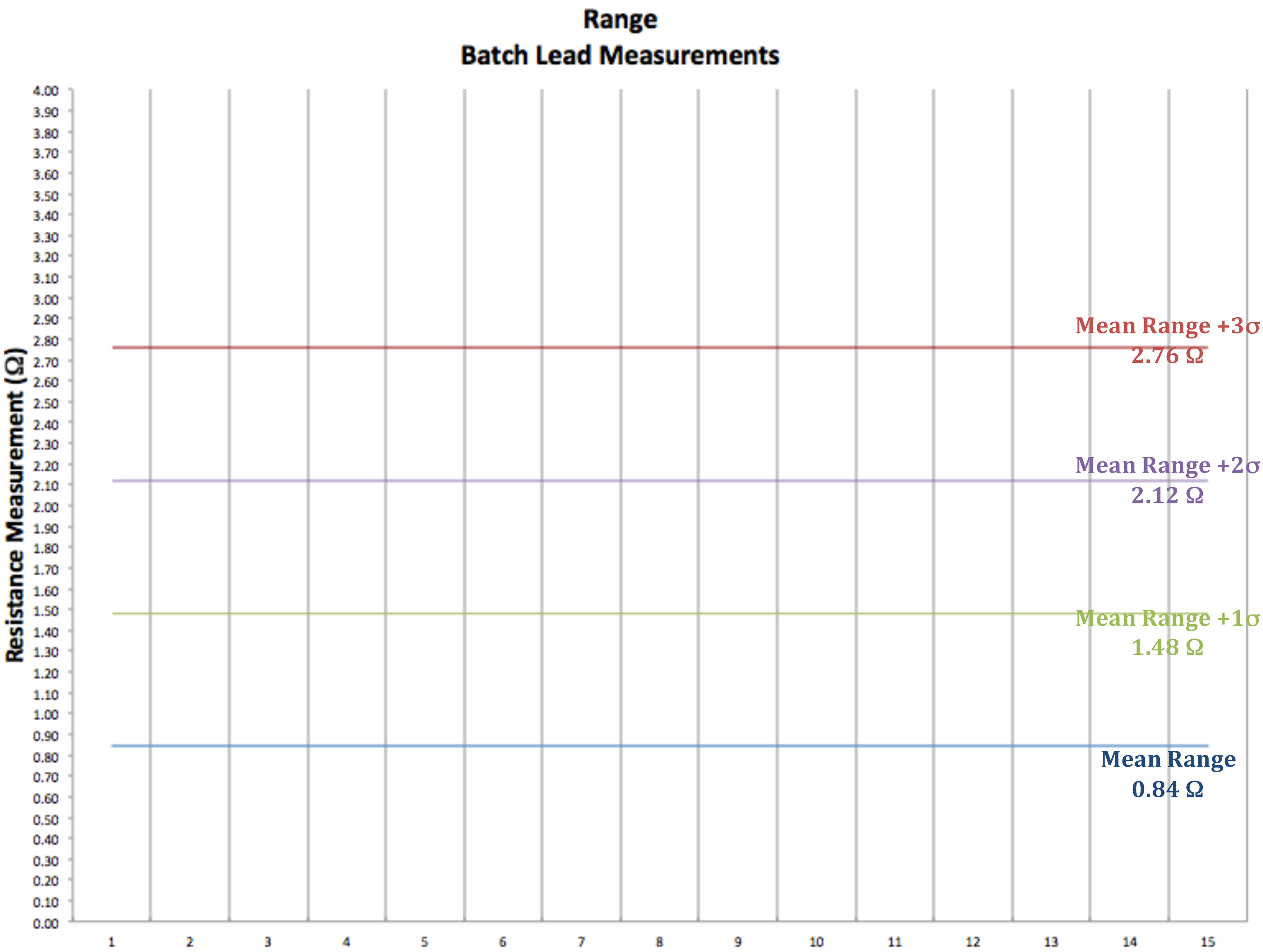
Other Class Batch Mean and Range Values

Here is a sample of Batch Mean values if you do not have 15 teams to take data

Batch Mean $\bar{X}$	Range
1.89	1.8
2.13	3.2
1.79	2.1
1.51	2.2
1.7	1.7
2.11	1.6
1.87	1.23
1.22	2.99
1.51	2.45
1.79	2.91
2.11	2.88

1.11	3.14
1.88	2.5
2.01	2.75

Answers for the X-bar Chart



Answers may vary for calculated ranges.

Post Activity Questions

1. Discuss the possible causes of variation in measurements *within* each batch.

   Answers may vary but may include a discussion on measurement techniques, variation in the measurement conditions between measurement, different diameters of rods, different lengths of rods.

2. Discuss the possible causes of variation between the X-bar values for each batch in the classroom.

   Answers may vary but may include discussion on measurement techniques between groups, variation in the voltmeters between groups, variation in the measurement conditions, variation in the technicians doing the measuring.

3. Compare the Individual Measurements Chart you created in Part III to the X-bar chart of batch values created here. What are the differences?

   The X-bar chart shows values that are much more "in control" or closer to the X-bar value than the individuals chart. There is a difference between plotting an individual measurement versus plotting the batch mean. It is not always feasible to plot nor record measurements of all manufactured products. Most often, sample measurements are taken within a batch, and also, most often a mean of these samples is plotted on a control chart. If you noticed in your individual measurement chart, not all of the measurements obeyed the Western Electric rules. You should have experienced several out of control conditions.

4. Discuss the difference between the X-bar, and R charts, what do you notice?

   Since the individual measurement chart most likely showed resistance values "out of control", you know there is a possible process problem. When you plotted the X-bar values of the class batches, these values should have obeyed the rules a bit more readily. But how do you recognize the problem with the process? That is where the R-chart comes in, when the Range values appear to have an "out of control" condition, that is where you recognize there is a problem in the variation of your process. The mean of the batches appears fine, but it is the Range in this case that poses the problem.

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