Statistical Process Control

A Unit for Tech Prep Mathematics Courses

Produced by the Mathematics Education Development
Center at Indiana University

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Statistical Process Control

Unit Overview

Students will develop understanding of quality assurance in industry, which includes working with upper and lower control limits for product length. They will exercise skill in rounding, measuring, finding means, looking for patterns, and collecting data, as well as representing and interpreting data through the use of coordinate graphing. You might wish to spend more time on prerequisite skills than is included in this unit.

It is important to include the teacher's parts of this unit in teaching it, and it is suggested that students work in small groups for most or all of the activities. In some cases answer keys provide *sample* answers—other reasonable answers should be considered. Individual activities are not intended to be accomplished in one class period. Each may take up to several class periods to complete. Key objectives addressed the previous day or two should be reviewed in some manner at the beginning of each class period.

This unit involves finding the length of wire coils but can be adapted for use with other manufactured items. An attribute other than length (e.g., weight) might replace or be added to the attribute under investigation. Local industries may be helpful in determining such details.

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Materials

precision measuring devices—see second bullet under Introduction [optional]

Activity Summary: A framework for the unit will be laid by having students discuss quality assurance in industry, precision measurement and measuring devices, and the use of metric units for some measurement. Students will exercise the prerequisite skills of rounding decimals, measuring length in tenths of centimeters, and finding the mean of decimals in tenths. Use with S1.

Objectives

- To become familiar with the role of quality assurance in industry.
- To list items that would be measured in small units or precise measures involving small units or partial units, and to name appropriate devices for making such measurements.
- To name items that might be measured in metric units, and to give reasons why some items might be manufactured in metric units.
- To round a decimal to the nearest tenth or hundredth.
- To measure length to the nearest tenth of a centimeter.
- To find the mean of several decimals in tenths to the nearest tenth.

Introduction

Ask students if they can describe and/or give examples of the use of quality assurance in industry. Discuss the importance of quality assurance. Note that quality assurance, also called quality control, is intended to monitor production so that problem areas can be addressed *before* bad parts are made (i.e., it is a preventive measure). Tell students that they will work with one example of quality assurance (called statistical process control, or SPC, in this unit) in industry during this unit—the production of metal coils used in electrical devices in such items as cars, radios, and hairdryers (show or pass around some coils). In the unit, students will determine if the coils fall within the acceptable length limits set by a company, graph coil lengths, interpret their graphs, and determine an appropriate course of action based on their interpretations.

Have students (as a class or first in small groups):

- give examples of industrially produced items that would be measured in small units of length and/or to a very precise degree of measurement (*nails, bolts, tongue-and-groove hardwood flooring ["close tolerance" required], computer chips, ball bearings, etc.*)
- name measuring devices that can be used for finding the length of items in very small units or fractional parts of units (*rulers/yardsticks/meter sticks/tape measures ruled in fractions of an inch or in centimeters or*

millimeters, micrometers, calipers, measuring pins, devices that use sonar/radio waves or laser beams); if possible, have some on hand for students to examine and, perhaps, to use to measure some items
• tell why the length of some items might be given in metric measurements, for example, centimeters, millimeters, or fractional parts of these given as decimals (*for items that will be exported to countries that use the metric system, replacement parts for items made overseas, etc.*)
• name some items that are likely to be or might be measured in small metric units (*examples: metric bolts, used in the auto industry and in some electronics equipment; medical supplies—catheters, wire guides, needles*)

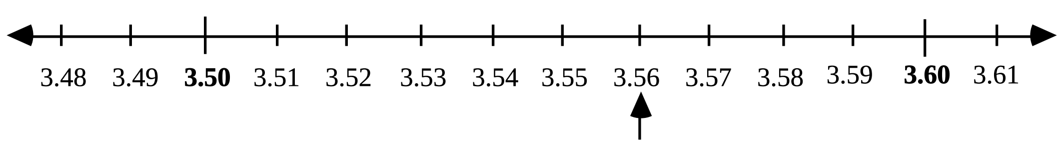
[You might also want to discuss why the United States has not converted from the English or customary measurement system to the metric system in light of its minority status in using its traditional system, the importance of a standardized system for international trade in an increasingly "shrinking globe," and the greater ease of using the metric system (you might also want to compare the relative ease of using the two systems where pertinent in this unit). (*Reasons might include adherence to tradition and difficulty in effecting change among people in such an entrenched and familiar way of doing things in everyday life, and historical self sufficiency because of the size of the nation as well as its physical/geographical separation from others*.)]

Tell students that the worksheet they will do will give them review practice in some of the skills that they will need for completing this unit successfully—rounding decimals and finding the mean of several decimals.

Answer Key

Part A

1. *3.6 (mean). The first drawing uses a number line to show that 3.56 is closer to 3.6 (3.60) than to 3.5 (3.50). The second shows the same by examining the fourth box in which each row represents one tenth (note that the first three boxes are optional because the wholes may be assumed).*



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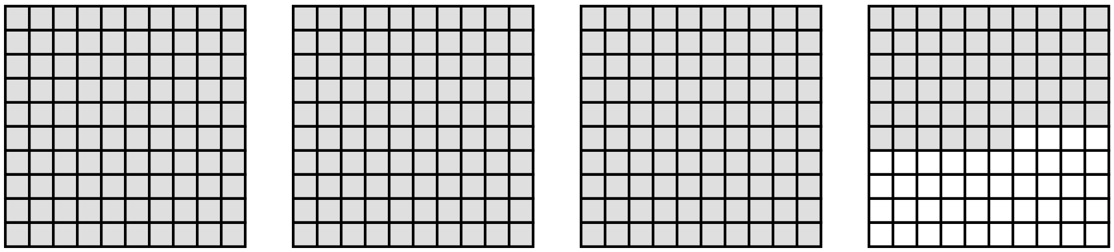
(#1 continued)



2. A. *12.7 cm* D. *8.0 cm*
   B. *1.0 cm* E. *7.0 cm*
   C. *6.9 cm* F. *0.6 cm*

3. A. *0.10 cm* C. *0.19 cm*
   B. *4.64 cm* D. *15.68 cm*

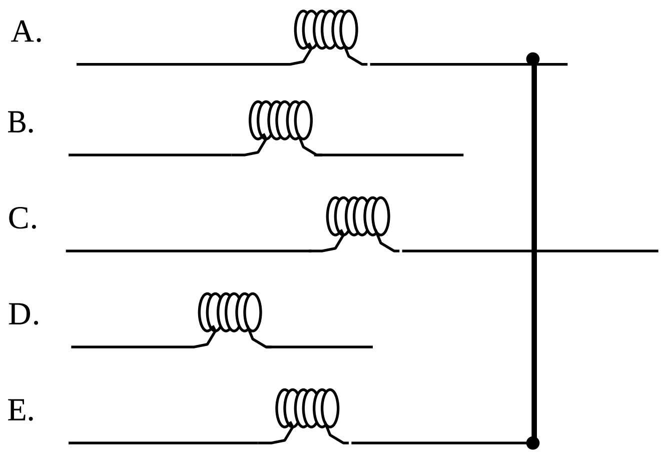
4. *Find the place value to which you are rounding (e.g., tenths). Look at the next place value to the right (hundredths) to determine whether to round the tenths digit up one or to keep it the same. If the hundredths digit is 5-9, the tenths digit is raised one; if the hundredths digit is 0-4, the tenths digit stays the same. All digits after the place to which you are rounding are dropped, but there should be a number in each place up through the place value to which you are rounding, even if the last few digits are zeros.*

Part B

1. (*You might want to allow answers that are off by one-tenth of a centimeter. Also, photocopy machines often reduce images slightly. This could change the answers given below.*)
   A. *6.5 cm*
   B. *5.3 cm*
   C. *7.8 cm*
   D. *4.2 cm*
   E. *6.0 cm*

2. *For the five numbers used above, the mean is 6.0 cm.*

3.



A. *coils longer than the mean—A, C; shorter—B, D; close/same—E*

B. *All coils would extend exactly (or, almost exactly, because of the possibility of rounding error) to the vertical line.*

4. A. • *estimated mean: 6 to 7 cm; reasons will vary but might include finding a point where total points above and below it are about the same*
• *actual mean: 6.4 cm (rounded from 6.425)*
• *lengths longer than the mean—7.0, 8.3; shorter—4.9, 5.5; closest— 7.0 [You might also want to ask which length is next closest—5.5, and if the two closest numbers to the mean must always include one above and one below the mean (no) and have students support their answers.]*

B. • *estimated mean: 6 to 6.5 cm*
• *actual mean: 6.2 cm (rounded from 6.24)*
• *lengths longer than the mean—6.6, 9.1; shorter—3.6, 5.7 (might include 6.2 because mean rounded down); closest/same—6.2*

Extensions/Discussion Questions

[These items (used in their entirety or selected from to suit your students' needs) may be used for all students or only for those who finish their work early. Students might be asked to discuss them or to write answers on the back of the page or on separate paper.]

1. *See drawings in Part A #1 for examples.*
2. *If the measurement falls between two of the designated units or partial units to which you are finding a measurement, the measurement used*

is the one to which the actual measurement falls closest (rounding up if halfway).

3. *Two (e.g., see the previous item).*
4. *Because we have to agree on a procedure that is universal/standard among people performing mathematics everywhere for better communication and exchange, and there are probably more cases in which it is practical to round up and have too much/too many than to round down and have too little/too few.*
5. • *To reduce the possibility of error in reading written decimals.*
   • *To reduce the possibility of error/interpretation—for example, combining other numbers written too closely to the whole number or being uncertain that a number had been rounded to the tenths place (rather than to the nearest whole number).*

   The zero could be omitted in both cases, and the numbers are still correct. However, chances of accuracy are raised through the enhanced clarity provided by using the zeros (important to precise fields such as math and science).

Materials

rulers (cm)
calculators

Part A

1. When a precision measuring device gives a more specific measurement than that which is needed or the mean of several measurements results in a greater level of specificity than is needed, a measurement might be rounded to an acceptable larger unit or partial unit. Suppose you want to round 3.56 to the nearest tenth. Give your answer, and make any reasonable drawing that shows why your answer makes sense. Also explain in words why your answer is correct and how your drawing demonstrates this.

2. Round the following decimals to the nearest tenth.

A.	12.719 cm	_____________	D.	8.02 cm	_____________
B.	0.97 cm	_____________	E.	7 cm	_____________
C.	6.9 cm	_____________	F.	0.6239 cm	_____________

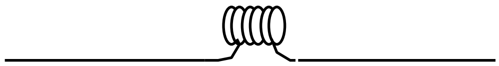
3. Round the following decimals to the nearest hundredth.

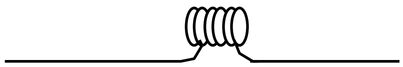
A.	0.098 cm	_____________	C.	0.19 cm	_____________
B.	4.63501 cm	_____________	D.	15.6827 cm	_____________

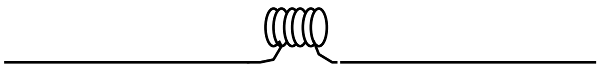
4. Describe the procedure for rounding a decimal to a given place value (i.e., a "rounding rule"). ____
____
____

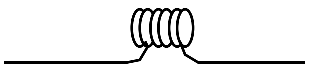
Part B

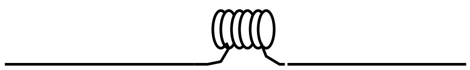
1. Measure each coil to the nearest tenth of a centimeter.

A.  ____________________

B.  ____________________

C.  ____________________

D.  ____________________

E.  ____________________

2. Use a calculator to find the mean length of the five coils to the nearest tenth of a centimeter. ________________

3. Measuring from the left side of coil A and then from the left side of coil E, place a dot at the point that shows where the mean length of the five coils would fall. Use a straightedge to connect the two dots to create a vertical line extending from the top to the bottom coil.

   A. • Use the vertical line, which represents the mean, to tell which coils are longer than the mean. ________________________

   • shorter: ________________________

   • close to the mean: ________________________

   B. What could happen if you would "break off" the parts of coils that fall on the right side of your vertical line and place the pieces (breaking them further if needed) on the right ends of coils that are shorter than the mean (vertical line)? ________________________

   ____

   ____

   ____

4. Use a calculator to find the mean lengths of each of the following sets of coils to the nearest tenth of a centimeter. First estimate what you think the mean will be and tell why.

   A. 4.9 cm, 7.0 cm, 8.3 cm, 5.5 cm
      - estimated mean _________________
      - reason for estimate ____
        ____• actual mean _________________
      - Which lengths are longer than the mean? _________________
        shorter? _________________
      - Which length is closest to the mean? _____________

   B. 3.6 cm, 6.6 cm, 9.1 cm, 6.2 cm, 5.7 cm
      - estimated mean _________________
      - reason for estimate ____
        ____
      - actual mean _________________
      - Which lengths are longer than the mean? _________________
        shorter? _________________
      - Which length is closest to the mean? _____________

Extensions/Discussion Questions

1. Try to find a different type of drawing from the one you used in Part A #1 to illustrate your answer.
2. What does it mean to say a measurement is given to the nearest unit or partial unit (centimeter, inch, tenth of a centimeter, half inch, etc.)?
3. When you round a number to a given place value or find a measurement to the nearest unit, between/among how many "closest" numbers must you choose? Explain.
4. Why do you think we round up numbers that represent half (e.g., the $^1/_2$ in 3 $^1/_2$ or the 5 in 6.5 when rounding to the nearest whole, or the 5 in 23.45 when rounding to tenths)?
5. Why do you suppose that we often use a 0:
   - in the whole number place in a decimal such as 0.654?
   - in the tenths place for a number such as 5.0 that has been rounded to the nearest tenth?

   Could the 0 be omitted in each of these cases?

Activity Summary: Students will learn some basics of quality assurance in industry—in particular, as applied to the dimension of length of produced items. They will look for patterns in graphed data and determine appropriate actions for detected problem areas, and they will exercise coordinate graphing skills. Students will become familiar with tolerances provided for product dimensions and how upper and lower control limits are derived using these. Use with S2 and R2.

Objectives

- To look for patterns in graphed data in order to determine problem areas and recommend appropriate courses of action.
- To make and interpret line graphs.
- To determine upper and lower control limits for a product dimension, given the nominal (ideal dimension) and tolerance.

Introduction

Have students look at the "SPC Run Rule Overview" sheet (page R2). Tell them that this sheet is provided by a coil company for its quality assurance employees to follow in monitoring and maintaining coil production by company standards. Each circle represents the mean length of a sample (set) of coils, and a graphed set of circles shows the mean length of the coil samples over a period of time. (You might first want to explain/show the format of the graphs in general and ask students to conjecture about problem patterns before they see those listed on R2.) Discuss questions such as the following with the class:

- What is a sample? (*set of items randomly drawn from the total number produced*) Why do quality assurance measures involve examining random samples of manufactured items? (*Because it is not practical/possible to check all items, and because a mean found for a random sample has been shown to approximate the mean for the population [total set of items] from which it comes. Therefore, it is reasonable in quality assurance to spot-check samples of a company's product.*)
- The middle horizontal line for each graph shows the ideal length of the coils, called the *nominal.* The upper line, marked UCL, is the upper control limit, and the lower line—LCL—is the lower control limit. What do you think these terms mean? (*The upper and lower control limits designate the range within which coil length must fall—maximum and minimum lengths—to meet company standards.*)
- Have students read over the sheet on their own and raise questions or points for discussion. Include the following question if students do not: Why is action called for in the case of "overcontrol," which shows that coils are consistently falling close to their ideal length? (*Employees might be*

putting too much effort into producing coils that fall closer to their ideal length than is necessary for the coils to be acceptable [for example, by adjusting machines often],thereby resulting in excessive time expenditure which means extra cost for the company.)

- Before students begin the worksheet, ask if they know what symbol is used to represent the mean of a set of numbers (X *bar*). Then discuss the meaning of X double bar. See if a student can tell what it represents (*mean of the means*) and explain it in terms of its use on the graph shown in #1. (*Ideally, a mean found for the coil length means represented by points on the graph should fall at the thick horizontal bar labeled X double bar, also called "X bar average." Note that X double bar could differ somewhat from the ideal length for a product ordered by a customer, because a company's machine might not be capable of being set at the ideal length. [The ideal length is termed the nominal and is the midpoint of the range of length that will be accepted by the customer for the desired product. This range—consisting of the nominal plus total "tolerance" (a term explained later in this activity)—is known as the customer's specifications, usually referred to as specs (pronounced "speks").]*)
- You might want to review/teach any necessary skills for constructing and interpreting line graphs (which students use beginning with #2 in this activity).

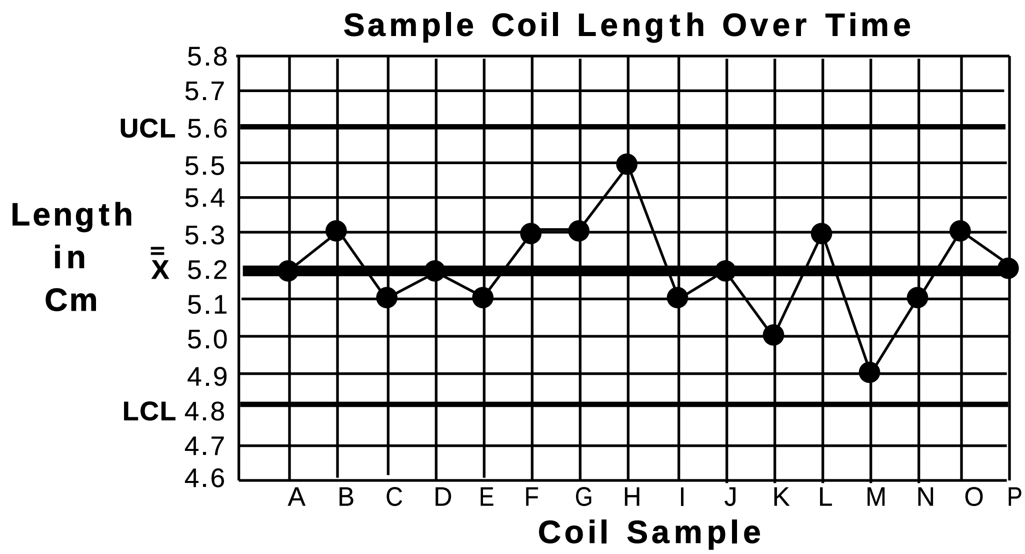
Answer Key

Part A

[*#'s 1 & 2: patterns should also be circled/labeled on graphs.*]

1. - *Coil samples A-I (other letter groupings, such as A-J, might be chosen) show a natural pattern, which calls for no action.*
   - *F-L show a trend. Notify supervisor*.
   - *L indicates out of control. Adjust machine*.
   - *M-S (or some other combination starting with J, K, or L) show an unusual pattern. Notify supervisor.*

2.



A-G: Overcontrol—notify supervisor.
H-P (or starting sooner): Natural Pattern—no action required.

Part B

1. A. *Moderately close tolerance would be okay for a pencil, because it does not have to fit into a particular, rather precise space in most cases. The tolerance for a 7 $^1/_2$" pencil might be ± $^1/_{16}$".* (*You might want to work through with students what the upper—7 $^9/_{16}$"—and lower—7 $^7/_{16}$"—control limits would be for such a pencil.*)

   B. *The tolerance would not have to be particularly close for the gate, because it can be adjusted with hinges, etc. (although it can depend on the type of gate/fence). An example of a gate width might be 36" with a 1" tolerance, for an acceptable range of 35-37".*

   C. *Because each tongue must fit into the groove of an adjoining piece, tongue-and-groove flooring requires close tolerance. For example, tongue-and-groove hardwood flooring used for a gymnasium floor has very close tolerance, such as ± $^1/_{64}$" (about half the thickness of a sheet of paper) for a width of 2 $^1/_2$". The length of each plank is about 2-3'. The small plank size is necessary to minimize the movement—expanding and contracting—that is caused by humidity changes.*

2. • *No. The lower control limit is $^{15}/_{16}$", which is equivalent to $^{60}/_{64}$", and $^{57}/_{64}$" falls below that and thus outside of the acceptable range.*
   • *The LCL is 3 $^7/_8$" and the UCL is 4 $^1/_8$" (the width is the smaller of two sides that comprise a rectangle); length—7 $^3/_4$" (LCL) and 8 $^1/_4$" (UCL).*

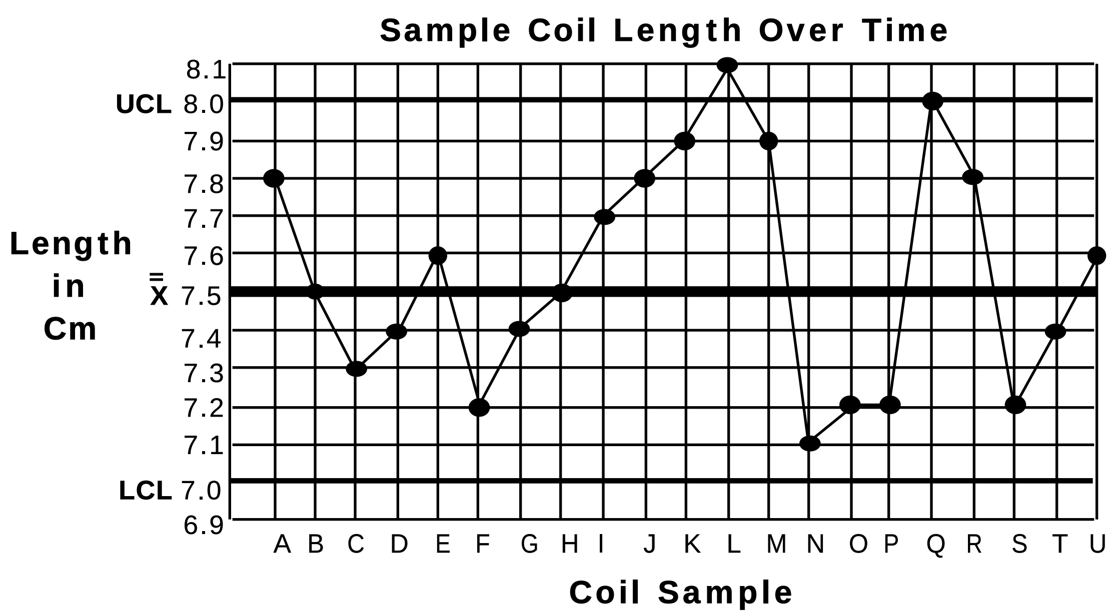
3. *metal washer (diameter): 968/1000" (LCL), 1 32/1000" (UCL)*
   metal washer (thickness): 50/1000" (LCL), 70/1000" (UCL)
   catheter: 52 cm (LCL), 58 cm (UCL)
   hypodermic needle: 14.7 cm (LCL), 15.3 cm (UCL)
   - *The two dimensions for the metal washer, and perhaps the hypodermic needle.*
   - *No, because the preciseness indicated by the tolerance might be relative to the length of the item. For example, a tolerance of ± $^{1}/_{32}$" for a 82" item can have different meaning than the same tolerance for a 3" item.*

Materials

rulers (or other straight-edge tools)
Reference Sheet R2

Part A

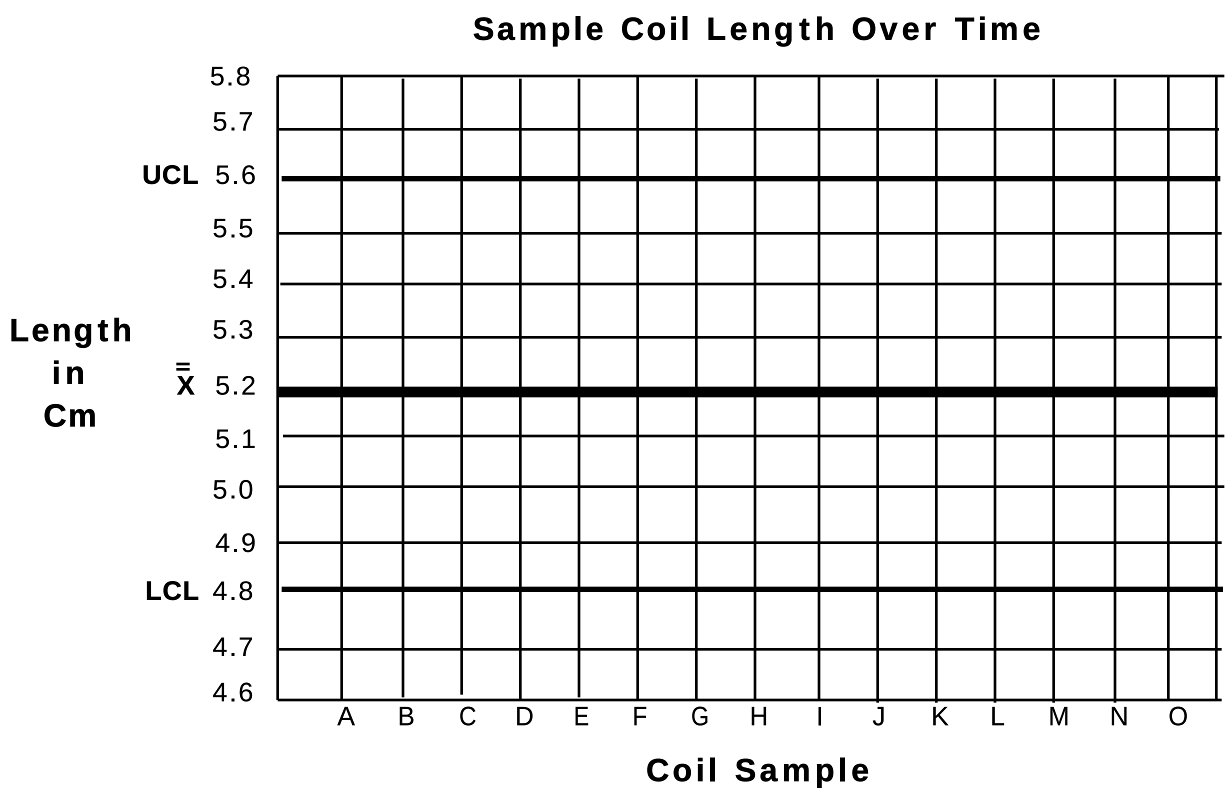
1. The graph below shows the plotted means for samples of coils over a period of time. The thickest horizontal line (center) shows where the average of the means should ideally fall, and the other two thick horizontal lines represent the upper and lower control limits. Use your "Run Rule Overview" (Reference Sheet R2) to name any situations that you detect and any action called for. (Note that the tolerance is unrealistic in that the actual range allowed for coil length would not be nearly as broad as that shown. Also, it would probably be uncommon to find such an irregular pattern of data as that shown on the graph. However, practice in the basic concepts and needed skills for the task of monitoring quality assurance in this manner can be gained through this exercise.)



On the graph, circle any situations that you identified and write the "run rule" term that names it (out of control, run, unusual pattern, etc.) by the circle. Then complete the following information.

"Run Rule" Situation Noted | Action Required (if any)

2. Using a ruler or other straightedge, graph the following samples below (letters name samples and numbers give mean lengths in centimeters): A—5.2, B—5.3, C—5.1, D—5.2, E—5.1, F—5.3, G—5.3, H—5.5, I—5.1, J—5.2, K—5.0, L—5.3, M—4.9, N—5.1, O—5.3, P—5.2.



Do you see any situations that compare to those found on your "Run Rule Overview" sheet? If so, circle and label them on the graph; also list them below (name them and tell any necessary action to be taken).

Part B

1. An ideal length, or *nominal*, is set for manufactured items, and a margin of error, or *tolerance*, is allowed, which results in upper and lower control limits. How "close" the tolerance is—close tolerance means a narrow margin of deviation from the specification—depends on the type of item. Tell how close you think the tolerance would need to be for each of the following items (in general terms, such as "very close," etc.), and explain why.

   A. pencil ____
   ____
   ____

   B. width of a gate to be attached to a fence by hinges _______________
   ____
   ____

   C. tongue-and-groove hardwood flooring (tongue on one end of each piece fits into groove on other end of an adjacent piece) _________
   ____
   ____

2. A "four by eight" (4 x 8) piece of Styrofoam with square edges (i.e., not tongue-and-groove) made by the Dow Chemical Company is 4 x 8 x 1" (the last dimension is thickness). The company allows a tolerance of ± $^{1}/_{16}$" for any thickness that is less than 2". Therefore, the thickness of the 4 x 8 x 1" Styrofoam must fall between $^{15}/_{16}$" and 1 $^{1}/_{16}$" (the lower and upper control limits).
   • Does Styrofoam with a thickness of $^{57}/_{64}$" thickness fall within the accepted range? Explain. _______________________________
   ____
   ____

   • What are the lower and upper control limits (UCL and LCL) for the
   width with a tolerance of ± $^{1}/_{8}$"? __________________________
   length with a tolerance of ± $^{1}/_{4}$"? __________________________

3. Give the upper and lower control limits for each of the following items.

Item	Basic Dimension	Tolerance	LCL	UCL
metal washer	1" (diameter)	± $^{32}/_{1000}$"	________	________
metal washer	$^{60}/_{1000}$" (thickness)	± $^{10}/_{1000}$"	________	________
catheter	55 cm (length)	± 3 cm	________	________
hypodermic needle	15 cm (length)	± 3 mm	________	________

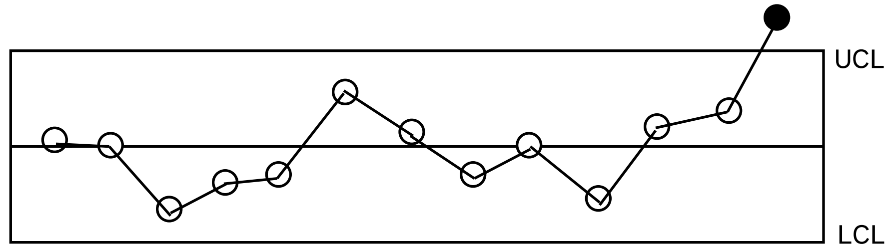
- Which of the previous items would you consider to have close or fairly close tolerance? ____
- Do you think a tolerance of ± $^{1}/_{64}$" is always closer (in terms of calling for a more precise measurement for an item) than a tolerance of $^{1}/_{8}$"? Explain. ____

  ____

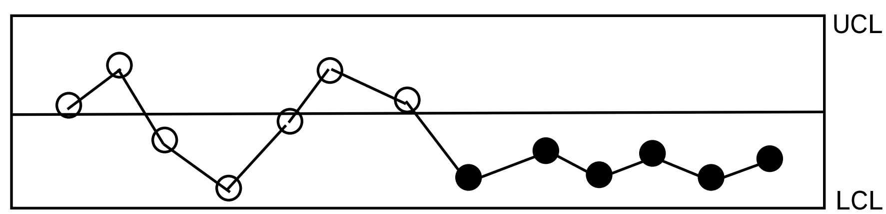
  ____

S P C
Run Rule Overview

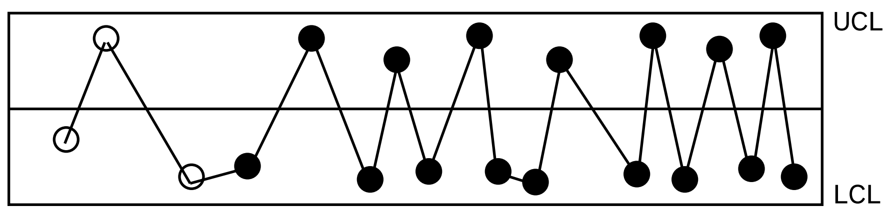
Out of Control:
1 point above the UCL or below the LCL. Adjust machine.



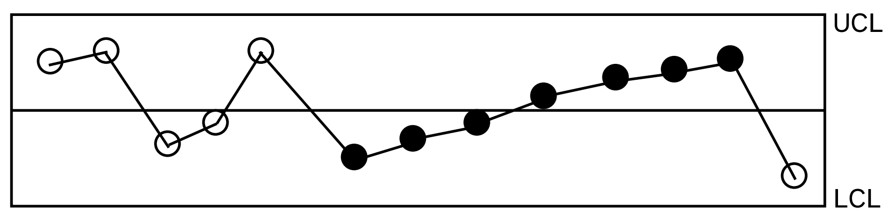
Run:
6 or 7 consecutive points above the center or 6 or 7 points below the center. Adjust machine.



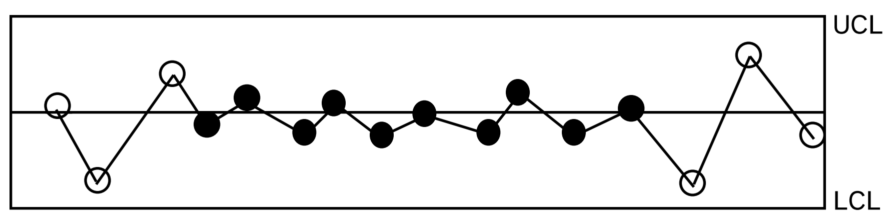
Unusual Pattern:
7 points—none of which fall near the center. Notify supervisor.



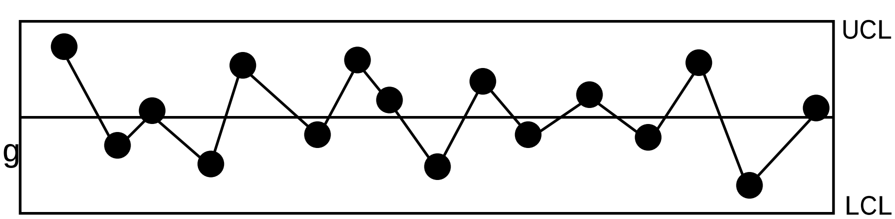
Trend:
7 consecutive increasing or decreasing points. Notify supervisor.



Overcontrol:
7 consecutive points are close to the center line. Notify supervisor.



Natural Pattern:
- No points outside the control limits
- Some points approaching both control limits
- Most points near the center line
- Points randomly cross center line



Activity Summary: Students will work in groups to measure coil samples, graph the means of the samples, and then look at their graphs to recommend any required action. Use with S3 and R3.

Objectives

- To gather data by measuring sets of coils to the nearest tenth of a centimeter and recording their lengths, mean length, and longest and shortest lengths.
- To make a line graph.
- To interpret data presented in the form of a line graph.

Introduction

About forty sets of five coils each, which might be obtained from the bad parts pile at a coil company, should be organized into a good storage system. For example, samples might be placed into small ziplock bags and numbered. Ends of the coils should be snipped so that the coil length varies from 6.8 - 8.2 cm.

Students should work in groups of about four, and each student should be assigned a role within the group. For example, two measurers would measure the coils in the sample, a recorder writes the information found for each sample, and a calculator/grapher finds the sample mean using a calculator then graphs the means. A system for rotating these roles should be devised.

If possible, it is helpful during this activity to have an "extra hand" (e.g., another teacher, a teacher's aide, or a parent or student aide) so that she/he can distribute and collect coil samples while the teacher moves about the classroom to student groups. Each group should only have one sample at a time, getting one from the distributor when needed and returning each when finished (to prevent samples from becoming mixed). One of the designated student roles (probably one of the measurers) might include getting and returning the samples.

Samples should be pre-measured and means determined, with an answer key for your use. Students should be provided with a slip of paper that lists the sample numbers that they should measure/record/graph (e.g., 5-14-10-21-8...) and these should be done in the order in which they are listed on the sheet (or each group can be given a Reference Sheet R3 that already has the sample numbers marked in the "date" spaces across the bottom of the graph). Different groups of students should receive different predetermined sample orders that have been arranged so that the graph of their mean lengths shows two or so of the patterns found on Reference Sheet R2. If the sample a group needs at a particular time is being used, they may temporarily skip ahead to the next sample, as long as they maintain the given sample order on the graph. You might want to have students first write the sample numbers in the "date" spaces across the bottom of the graph before beginning.

Answer Key

1 & 2. A key (graph) should be made for each of the different sample combinations given to groups (perhaps give each combination a number or letter for easy reference). Each key should have "run rule" patterns circled and labeled, as well as any action to be taken.

3. • *So that coil length can be monitored over time to look for patterns.*
   • *To see if some individual bad parts are being produced that might not show up when only looking at the mean.*
   • *Noting the average coil length for a group of coils gives a better sense of what coil lengths are being produced at that point in time than by looking at an individual coil length, which might not be typical of the overall set of coils being produced.*
   • *The extremes show the range of the coil lengths, indicating the variability in lengths of coils produced at a point in time.*

4. *Answers will vary. You might want to mention to students that a part that goes outside of the control limits is not always "bad." For example, a customer might set her/his UCL at 7.8 cm and the company might then set its UCL at 7.7 cm to be "safe" in monitoring ("controlling") quality according to the customer's specifications (in which case a 7.8 cm part goes above the company's UCL but is still a usable part for the customer).*

Materials

coil samples
rulers (cm)
calculators (one per group of four students)
Reference Sheet R3

1. For each coil sample, on Reference Sheet R3 list the number that identifies the sample in the "date" space (since the date and time categories are unnecessary for this activity). Measure each set of five coils, recording their lengths, mean length, and longest and shortest coil lengths (record all measurements to the nearest tenth of a centimeter). Graph the sample means as you work through different samples. (Note that the control limits used are unrealistic and have been expanded, for the purposes of this activity, beyond that which would be acceptable to the coil company and customer.)

2. Using Reference Sheet R2, name any patterns that you see on your graph and state any action that is required. Circle and label these patterns on your graph.

"Run Rule" Situation Noted	Action Required (if any)
______________________________	______________________________
______________________________	______________________________
______________________________	______________________________
______________________________	______________________________

3. Why do you think each of the following categories of information is recorded for each sample?
   - date and time: ____

     ____

     ____
   - individual coil lengths: ____

     ____

     ____
   - mean coil length: ____

     ____

     ____

• longest and shortest coil lengths: ________________________________

____

____

4. Were there any "bad parts" in your samples (i.e., individual coils that fell outside of the specified acceptable range for length)? ________________

____