Creating Control Charts (Using X̄ and R Charts as an Example)
Excel 2010 Tutorial

Introduction:

Purpose: Control Charts provide a method for assessing the stability of a process. Constructing Control Charts using Excel follows the same approach as constructing a Run Chart (with additional lines added. This tutorial uses a very small number of subgroups (smaller than would be used in practice) from data that would be used to construct X̄ and R charts to illustrate the process for constructing the charts. The Control Charts will consist of dots (usually plotted in time order) representing the characteristic that is being studied, lines connecting the dots, and horizontal lines showing the Upper Control Limit, Center Line, and Lower Control Limit (if one exist). Additional lines will show the zones needed to conduct the Runs Tests.

X̄ and R charts are usually constructed so that both charts are on the same page—with the X̄ chart at the top of the page and the R chart at the bottom of the same page. In addition, they are usually sized to be approximately the same size.

Making the Charts

1. Enter the data so that all of the data for one subgroup in in the same row. For this tutorial, we will use the data in the following figure.

	A	B	C	D
1	Subgroup	Obs. 1	Obs. 2	Obs. 3
2	1	53	39	46
3	2	46	53	43
4	3	50	61	53
5	4	52	51	55
6	5	56	52	49
7	6	51	49	58
8	7	49	48	36

2. Calculate the subgroup averages (the X̄s) and the subgroup ranges (the Rs). To do this create a column for the X-bars and a column for the Rs. I'll use F and G. For the first subgroup (the data in Row 2, Columns B, C, and D), the formulas will be:

=average(B2:D2) to find X-bar
=max(B2:D2)-min(B2:D2) to find R

Then fill down the columns to find the other X-bars and Rs. These values will be used to create the points on the charts. The resulting spreadsheet will look like the following:

	B	C	D	E	F	G
1	Obs. 1	Obs. 2	Obs. 3		X-Bar	R
2	53	39	46		46	14
3	46	53	43		47.33333	10
4	50	61	53		54.66667	11
5	52	51	55		52.66667	4
6	56	52	49		52.33333	7
7	51	49	58		52.66667	9
8	49	48	36		44.33333	13

3. Calculate the value of the Center Line on each chart ($\bar{\bar{X}}$ pronounced X double bar and $\bar{R}$). Since these are simply the average of the values to be plotted, type the following formulas in cells F10 and G10: $\bar{\bar{X}}$ =average(F2:F8) and $\bar{R}$ =average(G2:G8) to get the following:

E	F	G
	X-Bar	R
	46	14
	47.33333	10
	54.66667	11
	52.66667	4
	52.33333	7
	52.66667	9
	44.33333	13
Center line	50	9.714286

4. Determine the control limits using the appropriate formulas. For $\bar{X}$/R charts, this involves using the table of Control Chart Constants where the row is selected based on the number of observations in each subgroup. The R chart should be completed first and any signals of instability should be addressed prior to moving to the $\bar{X}$ chart. When there are more subgroups involved in calculating the control limits, this means that the Runs Tests on the R chart should be completed (and none of them failed) prior to moving to the $\bar{X}$ chart. Since this tutorial concentrates on constructing the charts, we will progress with constructing the charts.

Using the Table of Control Chart Constants at the back of the textbook, we find that for subgroups of size 3, we enter the values in our spreadsheet. In this example, the constants are entered in cells B12 – B15.

	A	B	C
10			
11	Control Chart Constants for n = 3		
12	A2	1.023	
13	D3	no LCL	
14	D4	2.574	
15	d2	1.693	

$$LCL_R = D_3\bar{R}$$
$$CL_R = \bar{R}$$
$$UCL_R = D_4\bar{R}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R}$$
$$CL_{\bar{X}} = \bar{\bar{X}}$$
$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}$$

We will use rows 11 and 12 of columns F and G to show the control limits. To have Excel calculate the Upper Control Limit for the R chart, click on cell G12. Then enter the formula by typing = followed by clicking on cell B14 (to use D_4); then * (for multiply); then click on cell G10 (to use $\bar{R}$); and finally hit enter. Since the there is no value for D_3 when the subgroup size is 3, we will not calculate a LCL for the R chart. Calculate the Upper Control Limit and the Lower Control Limit for the $\bar{X}$ chart in a similar way (=click on the cell with $\bar{\bar{X}}$, click on the + (or the –) sign, click on the cell with A2, click on *, and then click on the cell with $\bar{R}$. Put the UCL in cell F12 and the LCL in cell F13. When you finish your spreadsheet should look like the following:

E	F	G
	X-Bar	R
	46	14
	47.33333	10
	54.66667	11
	52.66667	4
	52.33333	7
	52.66667	9
	44.33333	13
Center line	50	9.714286
UCL	59.93771	25.00457
LCL	40.06229	

5. Calculate the values that correspond to the heights of the lines that will separate the zones. The zone lines are set so that there are three equal width bands between the Center Line and the Upper Control Limit and the same width bands below the Center Line. We will put these in Columns F and G, with our work in Rows 15-21. The first step is to calculate the width of the zones as (UCL – CL)/3. This is done in cells F14 and G14. Then we place the value of the UCLs in Row 15. To find each of the other lines we subtract the width of the zone from the height of the line above it. By using a combination of relative references and absolute references, we can type in the formula for cell F16 and then copy down (and across) to find the other entries. Notice that the last two values in the G column are negative. Since these are not observable values for a R [It is mathematically impossible for R to be negative.] we will delete these

width	=(F11-F10)/3	=(G11-G10)/3
UCL	=F11	=G11
Upper AB	=F15-F$14	=G15-G$14
Upper BC	=F16-F$14	=G16-G$14
CL	=F17-F$14	=G17-G$14
Lower BC	=F18-F$14	=G18-G$14
Lower AB	=F19-F$14	=G19-G$14
LCL	=F20-F$14	=G20-G$14

	D	E	F	G
13				
14		width	3.312571	5.096762
15		UCL	59.93771	25.00457
16		Upper AB	56.62514	19.90781
17		Upper BC	53.31257	14.81105
18		CL	50	9.714286
19		Lower BC	46.68743	4.617524
20		Lower AB	43.37486	-0.47924
21		LCL	40.06229	-5.576
22				

6. Organize the data so that you will be able to plot all of the dots and lines at the same time. You will need one column for the data for the dots on the chart and one column for each of the lines to be drawn (control limits and zone lines). For this example, the data for the $\overline{X}$ chart is placed at the top of the spreadsheet and the data for the R chart is placed below this.

	K	L	M	N	O	P	Q	R
1	X-Bar	UCL	Upper AB	Upper BC	CL	Lower BC	Lower AB	LCL

And

	K	L	M	N	O	P
11	R	UCL	Upper AB	Upper BC	CL	Lower BC

7. Link to the $\overline{X}$ values into the rows just below the heading X-Bar (starting in K2 in this example—so K2 is entered as =F2). Do the same with the R values just below the R heading (starting in K12 for this problem—so K12 is entered as =G2). Be careful that you have the same values listed here as were in your original calculations—if you try to copy and past the data, the formulas may recalculate! When you finish the data in K2 – K8 and K12 – K18 should look as follows.

| X-Bar		R	
46		14	
47.33333		10	
54.66667		11	
52.66667		4	
52.33333		7	
52.66667		9	
44.33333		13	

8. Set up the entries in the first row of each table using absolute references to the values calculated in steps 5. The formulas should look like the following:

| K	L	M	N	O	P	Q	R
X-Bar	UCL	Upper AB	Upper BC	CL	Lower BC	Lower AB	LCL
=F2	=$F$15	=$F$16	=$F$17	=$F$18	=$F$19	=$F$20	=$F$21
=F3							
=F4							
=F5							
=F6							
=F7							
=F8							
R	UCL	Upper AB	Upper BC	CL	Lower BC		
=G2	=$G$15	=$G$16	=$G$17	=$G$18	=$G$19		
=G3							
=G4							
=G5							
=G6							
=G7							
=G8							

9. Copy the formulas for all but the first column down the columns so that each row has the same value as the one above it. This needs to be done for the data for the $\overline{X}$ chart and then again for the R Chart. The resulting data will look as follows:

K	L	M	N	O	P	Q	R
X-Bar	UCL	Upper AB	Upper BC	CL	Lower BC	Lower AB	LCL
46	59.93771	56.62514	53.31257	50	46.68743	43.37486	40.06229
47.33333	59.93771	56.62514	53.31257	50	46.68743	43.37486	40.06229
54.66667	59.93771	56.62514	53.31257	50	46.68743	43.37486	40.06229
52.66667	59.93771	56.62514	53.31257	50	46.68743	43.37486	40.06229
52.33333	59.93771	56.62514	53.31257	50	46.68743	43.37486	40.06229
52.66667	59.93771	56.62514	53.31257	50	46.68743	43.37486	40.06229
44.33333	59.93771	56.62514	53.31257	50	46.68743	43.37486	40.06229
R	UCL	Upper AB	Upper BC	CL	Lower BC		
14	25.00457	19.90781	14.81105	9.714286	4.617524		
10	25.00457	19.90781	14.81105	9.714286	4.617524		
11	25.00457	19.90781	14.81105	9.714286	4.617524		
4	25.00457	19.90781	14.81105	9.714286	4.617524		
7	25.00457	19.90781	14.81105	9.714286	4.617524		
9	25.00457	19.90781	14.81105	9.714286	4.617524		
13	25.00457	19.90781	14.81105	9.714286	4.617524		

10. Create a graph for each chart. Note: The initial graph will be messy and need lots of help to be make "presentable." To create the initial $\overline{X}$ Chart, highlight the data in K2 – R8 and insert a Line Chart (from the Insert tab at the top) with <u>no</u> dots on the lines. With most data set we will use, Excel will recognize that the data are in columns, but with fewer observations than columns, we need to help Excel! Once you get the chart on the left below, select Switch Row/Column at the top of the screen to get the chart on the right:
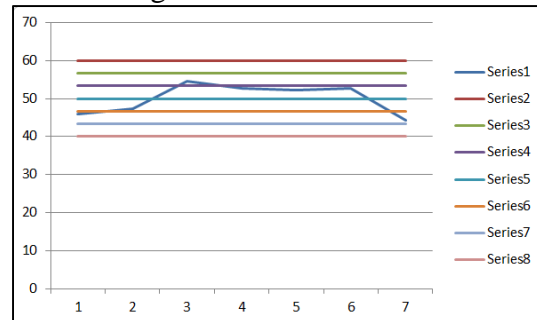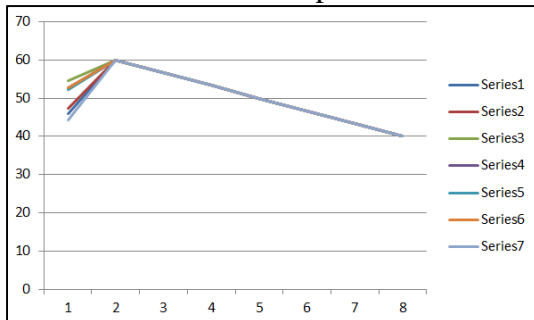
Follow the same approach for the R Chart, highlighting the data for the R values and the heights of the lines (K11 – P19). This time Excel recognizes that the data are in columns:
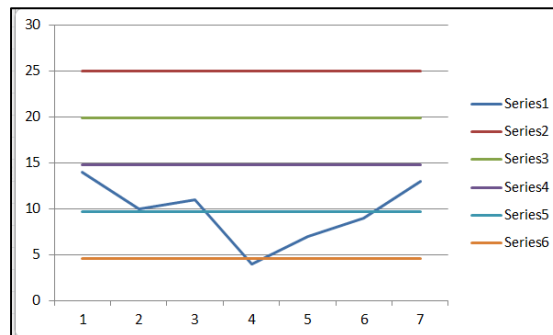

11. Clean up the charts. To do this, you need to
    - Remove the extra gridlines (click on one and delete)

- Remove the legend (click on the legend and delete)
- Add dots to on the jagged line connecting the observations (right click on the place a dot should go and select Format Data Series and then Marker Options and Built In)
- Adjust the vertical axis to focus on the data (right click on the axis and Format Axis to adjust the min and max values)
- Get rid of the extra color on the lines and change the style (right click on a horizontal line and select Format Data Series and then use the Line Color and Line Style to make adjustments; repeat for each line)
- Add axis labels (from the Layout Tab)
- Add a chart title (from the Layout Tab)

12. Position the charts on a single page with the $\overline{X}$ at the top and the R chart at the bottom. The resulting charts are shown on the next page.
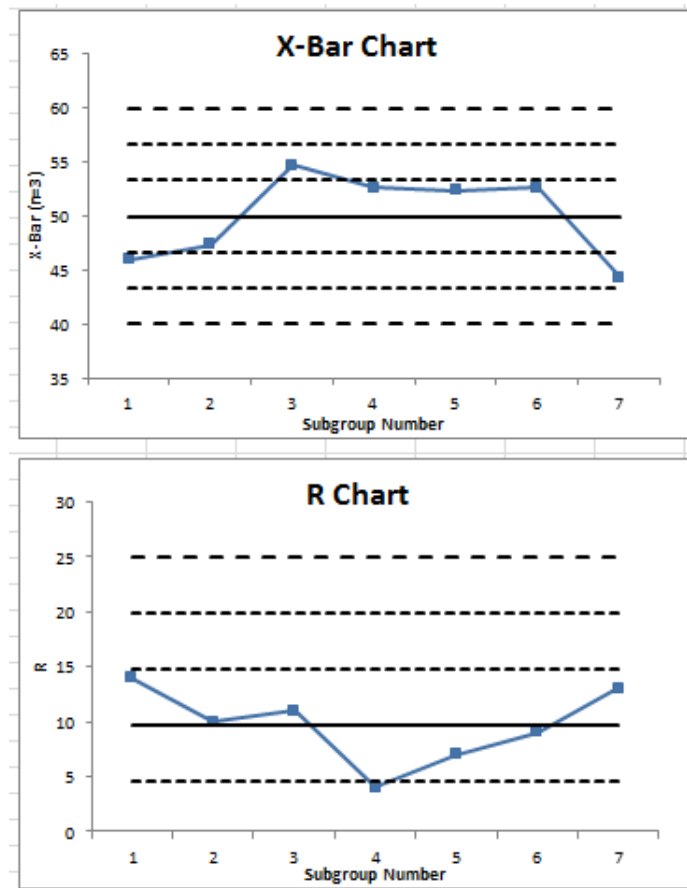
13. Click in a blank cell on the spreadsheet (to make sure that Excel does show the chart as active) before you try to print. Otherwise, you will get one chart that occupies the whole page.