Control Chart for Mean using Standard Deviation

SESSION 3

Structure

3.1 INTRODUCTION

In Lab Session 2, you have learnt how to construct the control chart for mean in MS Excel 2007 when process variability is unknown. We have used sample range to estimate the process standard deviation (σ) in Lab Session 2. You have studied in Unit 2 of MSTE-001 (Industrial Statistics-I) that sample standard deviation can also be used for estimating the process standard deviation.

In this lab session, you will learn about the construction of control chart for mean in MS Excel 2007 **when process variability is unknown**. We shall consider the **sample standard deviation** as an estimator of process standard deviation to develop the control chart for mean using a specific problem.

Prerequisite

- Lab Sessions 1, 3 and 6 of MSTL-001 (Basic Statistics Lab).
- Lab Sessions 1 and 2 of MSTL-002 (Industrial Statistics Lab).
- Unit 2 of MSTE-001 (Industrial Statistics-I).

Objectives

After performing the activities of this session, you should be able to:

- prepare the spreadsheet in MS Excel 2007;
- determine the control limits for control chart for mean using sample standard deviation to estimate the unknown process variability;
- construct the control chart for mean using sample standard deviation;
- obtain the revised control limits for control charts for mean using standard deviation; and
- interpret the control chart.

3.2 PROBLEM DESCRIPTION

Once again, we consider the data given in Lab Session 1. Suppose the quality control inspector of the juice manufacturing company wishes to develop $\bar{X}$-chart using sample standard deviation to estimate the process standard deviation. He/she also wants to check whether the process of bottling is under control or out-of-control. If the process is out-of-control, he/she would like to compute the revised control limits.

Therefore, the problem for this session is to construct the control chart for mean using sample standard deviation to estimate the process variability.

3.3 PROCEDURE FOR THE CONSTRUCTION OF $\bar{X}$-CHART

You have already learnt all the formulae for calculating control limits for control chart for mean when process variability is unknown and estimated by sample standard deviation in Sec. 2.4 of Unit 2 of MSTE-001.

The main steps involved in the construction of $\bar{X}$-chart using sample standard deviation to estimate the process standard deviation are as follows:

Steps 1-3: The first three steps are the same as explained in Sec. 1.3 of Lab Session 1.

Step 4: We calculate the sample standard deviation for each sample (subgroup), say, $S_1, S_2, \ldots, S_k$ where S_i is the sample standard deviation for i^{th} sample given by

$$S_i = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(X_{ij} - \bar{X}_i\right)^2} \qquad \ldots(1)$$

Step 5: We find the mean of all sample standard deviations given by

$$\bar{S} = \frac{1}{k}\left(S_1 + S_2 \ldots, S_k\right) = \frac{1}{k}\sum_{i=1}^{k} S_i \qquad \ldots(2)$$

Step 6: The control limits for $\bar{X}$-chart when σ is estimated by $\bar{S}/c_4$ are given by

- ✓ Centre line $(CL) = \bar{\bar{X}}$ …(3)
- ✓ Upper control limit (UCL) $= \bar{\bar{X}} + A_3\bar{S}$ …(4)
- ✓ Lower control limit (LCL) $= \bar{\bar{X}} - A_3\bar{S}$ …(5)

where $A_3 = \dfrac{3}{\sqrt{n}\, c_4}$ is a constant and depends on the size of the sample. It is tabulated for various sample sizes in the Appendix given at the end of this lab course.

Step 7: Interpretation of the $\bar{X}$-chart.

3.4 STEPS INVOLVED IN THE CONSTRUCTION OF $\bar{X}$-CHART IN EXCEL 2007

In order to calculate the control limits of $\bar{X}$-chart and to plot the control chart when σ is estimated by $\bar{S}/c_4$ in Excel 2007 for the given data, we follow the steps given below:

Step 1: We repeat the Steps 1-5 of Sec. 1.4 of Lab Session 1 to compute the sample mean of the 25 samples given in Table 1 of Lab Session 1. To compute the grand sample mean ($\bar{\bar{X}}$) of these samples, we repeat Step 6 of Sec. 1.4. The output is given in Fig. 3.1.

	A	B	C	D	E	F
1		Juice Volume (in ml)				
2	Sample No.	Obs 1	Obs 2	Obs 3	Obs 4	Sample Mean
3	1	497.32	500.62	498.68	497.82	498.610
4	2	504.76	500.00	498.32	500.32	500.850
5	3	499.24	497.18	498.12	498.68	498.305
6	4	499.26	496.32	498.88	497.82	498.070
7	5	502.32	503.62	504.56	503.12	503.405
8	6	502.12	500.32	501.38	500.94	501.190
9	7	499.34	498.32	497.32	497.62	498.150
10	8	499.38	498.12	500.62	498.12	499.060
11	9	501.26	502.38	500.68	501.38	501.425
12	10	498.60	497.62	499.25	498.56	498.508
13	11	502.44	500.00	501.32	499.38	500.785
14	12	501.26	502.32	500.76	502.68	501.755
15	13	497.32	498.50	497.18	499.38	498.095
16	14	499.56	498.00	498.76	501.12	499.360
17	15	502.24	500.32	503.12	501.25	501.733
18	16	501.76	500.50	502.68	501.12	501.515
19	17	500.65	497.82	494.06	496.25	497.195
20	18	501.12	501.26	500.44	502.76	501.395
21	19	501.00	500.50	501.56	501.76	501.205
22	20	497.50	498.82	499.76	497.82	498.475
23	21	503.44	500.62	500.00	501.26	501.330
24	22	499.38	498.38	497.56	498.56	498.470
25	23	501.56	499.56	498.00	499.82	499.735

X Bar Chart

F28 =AVERAGE(F3:F27)

	A	B	C	D	E	F
25	23	501.56	499.56	498.00	499.82	499.735
26	24	498.32	497.32	499.56	498.62	498.455
27	25	499.50	501.12	502.50	500.38	500.875
28					Average	499.918
29						

Fig. 3.1: Partial screenshot of the spreadsheet for the given data.

Step 2: We calculate standard deviation for each sample. For this, we type "=Stdev(B3:E3)" in Cell G3 as shown in Fig. 3.2 and click on the ***Enter*** key. We get the value of the standard deviation in the Cell G3.

AVERAGE | =STDEV(B3:E3)

	A	B	C	D	E	F	G	H
1				Juice Volume (in ml)				
2	Sample No.	Obs 1	Obs 2	Obs 3	Obs 4	Sample Mean	SD	
3	1	497.32	500.62	498.68	497.82	498.610	=STDEV(B3:E3)	
4	2	504.76	500.00	498.32	500.32	500.850		

	A	B	C	D	E	F	G	H
1				Juice Volume (in ml)				
2	Sample No.	Obs 1	Obs 2	Obs 3	Obs 4	Sample Mean	SD	
3	1	497.32	500.62	498.68	497.82	498.610	1.453	
4	2	504.76	500.00	498.32	500.32	500.850		
5	3	499.24	497.18	498.12	498.68	498.305		

Fig. 3.2

Step 3: We drag down Cell G3 up to Cell G27 to get the standard deviations for all 25 samples (see Fig. 3.3).

	A	B	C	D	E	F	G
1			Juice Volume (in ml)				
2	Sample No.	Obs 1	Obs 2	Obs 3	Obs 4	Sample Mean	SD
3	1	497.32	500.62	498.68	497.82	498.610	1.453
4	2	504.76	500.00	498.32	500.32	500.850	2.750
5	3	499.24	497.18	498.12	498.68	498.305	0.878
6	4	499.26	496.32	498.88	497.82	498.070	1.316
7	5	502.32	503.62	504.56	503.12	503.405	0.938
8	6	502.12	500.32	501.38	500.94	501.190	0.757
9	7	499.34	498.32	497.32	497.62	498.150	0.897
10	8	499.38	498.12	500.62	498.12	499.060	1.198
11	9	501.26	502.38	500.68	501.38	501.425	0.706
12	10	498.60	497.62	499.25	498.56	498.508	0.671
13	11	502.44	500.00	501.32	499.38	500.785	1.368
14	12	501.26	502.32	500.76	502.68	501.755	0.896
15	13	497.32	498.50	497.18	499.38	498.095	1.041
16	14	499.56	498.00	498.76	501.12	499.360	1.335
17	15	502.24	500.32	503.12	501.25	501.733	1.213
18	16	501.76	500.50	502.68	501.12	501.515	0.932
19	17	500.65	497.82	494.06	496.25	497.195	2.772
20	18	501.12	501.26	500.44	502.76	501.395	0.978
21	19	501.00	500.50	501.56	501.76	501.205	0.570
22	20	497.50	498.82	499.76	497.82	498.475	1.025
23	21	503.44	500.62	500.00	501.26	501.330	1.498
24	22	499.38	498.38	497.56	498.56	498.470	0.747
25	23	501.56	499.56	498.00	499.82	499.735	1.458

X Bar Chart

Fig. 3.3

Step 4: To obtain the average standard deviation ($\bar{S}$), we type "=Average(G3:G27)" in Cell G28 as shown in Fig. 3.4.

G28 | =AVERAGE(G3:G27)

	A	B	C	D	E	F	G
25	23	501.56	499.56	498.00	499.82	499.735	1.458
26	24	498.32	497.32	499.56	498.62	498.455	0.923
27	25	499.50	501.12	502.50	500.38	500.875	1.270
28					Average	499.918	1.184
29							

Fig. 3.4

Step 5: We type the values of k and n in Cells F31 and F32, respectively, as shown in Fig. 3.5. Note that we have also typed the value of A_3 for n = 4 in Cell F33 from the Appendix given at the end of this lab course.

	C	D	E	F
31			k	25
32			n	4
33		A_3 Value from Table (for n=4)		1.628

Fig. 3.5

Step 6: We recall the method for computing centre line and both control limits described in Step 5, Sec. 2.4 of Lab Session 2. Here we use Columns H, I and J for putting the values of the centre line, upper and lower control limits, respectively. We compute the centre line, upper and lower control limits as follows:

i) The centre line is $CL = \overline{\overline{X}}$ and $\overline{\overline{X}}$ is given in Cell F28 (see Fig. 3.4). So in Excel, we type "=$F$28" in Cell H3 to find the centre line as shown in Fig. 3.6a.

ii) The upper control limit is $UCL = \overline{\overline{X}} + A_3\overline{S}$. The values of $\overline{\overline{X}}$, A_3 and $\overline{S}$ are given in Cells F28, F33 and G28, respectively (see Figs. 3.4 and 3.5). So we type "=$F$28+$F$33*$G$28" in Cell I3 as shown in Fig. 3.6b.

iii) Similarly, we calculate the lower control limit $LCL = \overline{\overline{X}} - A_3\overline{S}$ by typing "=$F$28-$F$33*$G$28" in Cell J3 as shown in Fig. 3.6c.

The formula with dollar sign ($) is used for an absolute reference.

H3 =$F$28

	H	I	J	K
1		Control Limits		
2	Centre Line	UCL	LCL	
3	499.918			
4				

(a)

I3 =$F$28+$F$33*$G$28

	I	J	K	L
1	Control Limits			
2	UCL	LCL		
3	501.845			
4				

(b)

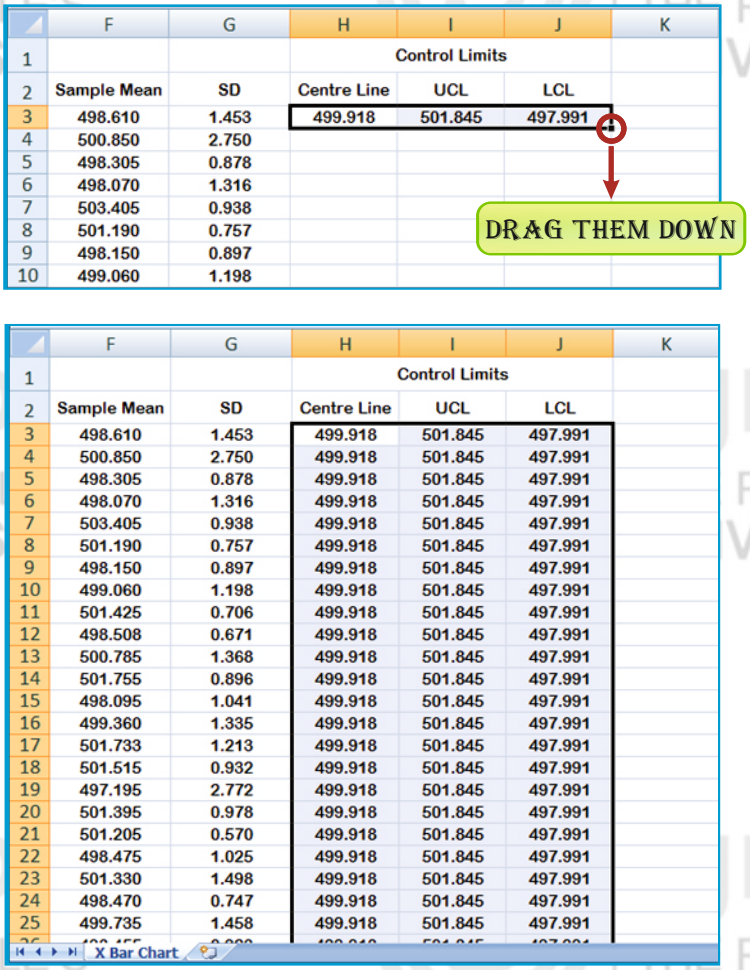
J3 =$F$28-$F$33*$G$28

	J	K	L	M
1				
2	LCL			
3	497.991			
4				

(c)

Fig. 3.6

Step 7: For plotting the control limits using Excel, we first select Cells H3:J3 and drag them down up to Row 27. We get the output shown in Fig. 3.7.



	F	G	H	I	J	K
1			Control Limits			
2	Sample Mean	SD	Centre Line	UCL	LCL	
3	498.610	1.453	499.918	501.845	497.991	
4	500.850	2.750				
5	498.305	0.878				
6	498.070	1.316				
7	503.405	0.938				
8	501.190	0.757				
9	498.150	0.897				
10	499.060	1.198				

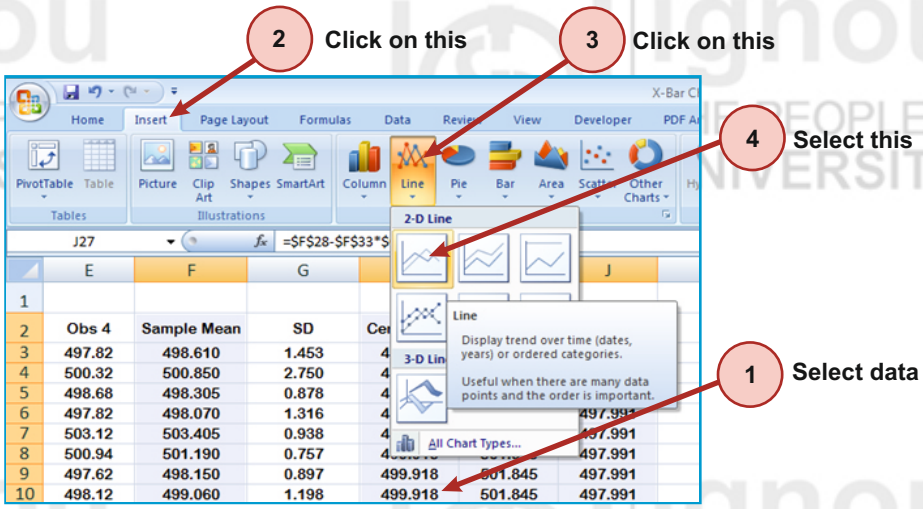
	F	G	H	I	J	K
1			Control Limits			
2	Sample Mean	SD	Centre Line	UCL	LCL	
3	498.610	1.453	499.918	501.845	497.991	
4	500.850	2.750	499.918	501.845	497.991	
5	498.305	0.878	499.918	501.845	497.991	
6	498.070	1.316	499.918	501.845	497.991	
7	503.405	0.938	499.918	501.845	497.991	
8	501.190	0.757	499.918	501.845	497.991	
9	498.150	0.897	499.918	501.845	497.991	
10	499.060	1.198	499.918	501.845	497.991	
11	501.425	0.706	499.918	501.845	497.991	
12	498.508	0.671	499.918	501.845	497.991	
13	500.785	1.368	499.918	501.845	497.991	
14	501.755	0.896	499.918	501.845	497.991	
15	498.095	1.041	499.918	501.845	497.991	
16	499.360	1.335	499.918	501.845	497.991	
17	501.733	1.213	499.918	501.845	497.991	
18	501.515	0.932	499.918	501.845	497.991	
19	497.195	2.772	499.918	501.845	497.991	
20	501.395	0.978	499.918	501.845	497.991	
21	501.205	0.570	499.918	501.845	497.991	
22	498.475	1.025	499.918	501.845	497.991	
23	501.330	1.498	499.918	501.845	497.991	
24	498.470	0.747	499.918	501.845	497.991	
25	499.735	1.458	499.918	501.845	497.991	

X Bar Chart

Fig. 3.7

Step 8: To obtain the $\bar{X}$-chart, we follow the procedure explained in Step 10 of Sec. 1.4, Lab Session 1 (see Fig. 3.8). It means that we

1. select Cells F2:F27 and H2:J27 by holding ***Ctrl*** key,
2. click on the ***Insert*** tab,
3. select the ***Line*** option, and
4. choose the chart subtype.



	E	F	G	J
1				
2	Obs 4	Sample Mean	SD	
3	497.82	498.610	1.453	
4	500.32	500.850	2.750	
5	498.68	498.305	0.878	
6	497.82	498.070	1.316	
7	503.12	503.405	0.938	
8	500.94	501.190	0.757	
9	497.62	498.150	0.897	497.991
10	498.12	499.060	1.198	497.991

Fig. 3.8

Step 9: We find that the values in Columns H, I and J provide the horizontal lines on the chart representing the centre line, UCL and LCL, respectively. The values in Column F represent the averages for 25 samples We format the chart in the way explained in Sec. 1.4 of Lab Session 1 and obtain the control chart shown in Fig. 3.9.

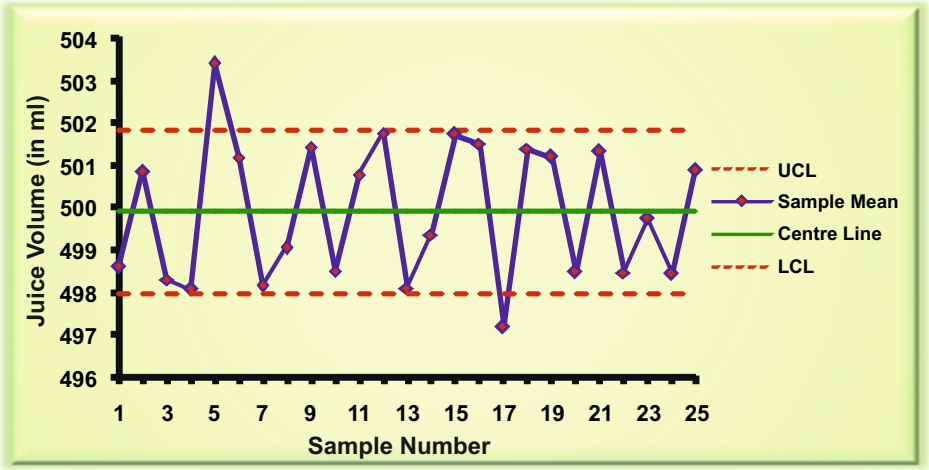


Fig. 3.9

Interpretation

Fig. 3.9 reveals that two points corresponding to Samples 5 and 17 lie outside the UCL and LCL, respectively. So the control chart indicates that the process is **not under statistical control**. Some **assignable causes** are present in the process. To bring the process under statistical control, it is necessary to investigate the assignable causes and take corrective action to eliminate them.

3.5 REVISED $\bar{X}$-CHART

After eliminating the assignable causes from the process, we delete the out-of-control samples and calculate the revised centre line and control limits for the $\bar{X}$-chart using the remaining samples. These limits are known as the **revised control limits** which can be computed from the following equations:

Step 1: For revised limits for $\bar{X}$-chart using sample standard deviation, we first calculate the new $\bar{\bar{X}}$ and new $\bar{S}$ as follows:

$$\bar{\bar{X}}_{new} = \frac{\sum_{i=1}^{k} \bar{X}_i - \sum_{j=1}^{d} \bar{X}_j}{k - d} \quad \ldots(6)$$

and $$\bar{S}_{new} = \frac{\sum_{i=1}^{k} S_i - \sum_{j=1}^{d} S_j}{k - d} \quad \ldots(7)$$

where $\sum_{j=1}^{d} \bar{X}_j$ – sum of the averages of discarded samples,

d – number of discarded samples, and

$\sum_{j=1}^{d} S_j$ – sum of the standard deviations of discarded samples.

Step 2: After determining the new $\bar{\bar{X}}$ and new $\bar{S}$, we reconstruct the centre line, upper and lower control limits by replacing $\bar{\bar{X}}$ by $\bar{\bar{X}}_{new}$ and $\bar{S}$ by $\bar{S}_{new}$ as follows:

- ✓ Centre line = $\bar{S}_{new}$ ...(8)
- ✓ Upper control limit (UCL) = $\bar{\bar{X}}_{new} + A_3\bar{S}_{new}$ ...(9)
- ✓ Lower control limit (LCL) = $\bar{\bar{X}}_{new} - A_3\bar{S}_{new}$ ...(10)

Step 3: Interpretation of the $\bar{X}$-chart.

Steps in Excel

The main steps for calculating the revised centre line and control limits for the $\bar{X}$-chart in Excel 2007 using the remaining samples are as follows:

Step 1: We highlight the samples outside the control limits, i.e., the 5th and 17th samples, with light orange colour as shown in Fig. 3.10.

	A	B	C	D	E	F	G	H	I	J
1		Juice Volume (in ml)						Control Limits		
2	Sample No.	Obs 1	Obs 2	Obs 3	Obs 4	Sample Mean	SD	Centre Line	UCL	LCL
3	1	497.32	500.62	498.68	497.82	498.610	1.453	499.918	501.845	497.991
4	2	504.76	500.00	498.32	500.32	500.850	2.750	499.918	501.845	497.991
5	3	499.24	497.18	498.12	498.68	498.305	0.878	499.918	501.845	497.991
6	4	499.26	496.32	498.88	497.82	498.070	1.316	499.918	501.845	497.991
7	5	502.32	503.62	504.56	503.12	503.405	0.938	499.918	501.845	497.991
8	6	502.12	500.32	501.38	500.94	501.190	0.757	499.918	501.845	497.991
9	7	499.34	498.32	497.32	497.62	498.150	0.897	499.918	501.845	497.991
10	8	499.38	498.12	500.62	498.12	499.060	1.198	499.918	501.845	497.991
11	9	501.26	502.38	500.68	501.38	501.425	0.706	499.918	501.845	497.991
12	10	498.60	497.62	499.25	498.56	498.508	0.671	499.918	501.845	497.991
13	11	502.44	500.00	501.32	499.38	500.785	1.368	499.918	501.845	497.991
14	12	501.26	502.32	500.76	502.68	501.755	0.896	499.918	501.845	497.991
15	13	497.32	498.50	497.18	499.38	498.095	1.041	499.918	501.845	497.991
16	14	499.56	498.00	498.76	501.12	499.360	1.335	499.918	501.845	497.991
17	15	502.24	500.32	503.12	501.25	501.733	1.213	499.918	501.845	497.991
18	16	501.76	500.50	502.68	501.12	501.515	0.932	499.918	501.845	497.991
19	17	500.65	497.82	494.06	496.25	497.195	2.772	499.918	501.845	497.991
20	18	501.12	501.26	500.44	502.76	501.395	0.978	499.918	501.845	497.991
21	19	501.00	500.50	501.56	501.76	501.205	0.570	499.918	501.845	497.991
22	20	497.50	498.82	499.76	497.82	498.475	1.025	499.918	501.845	497.991

Fig. 3.10

Step 2: We put the value of d = 2 in Cell F34 in addition to the values of k, n and A_3 as shown in Fig. 3.11.

The process of revising control limits will continue until the process comes under control.

	C	D	E	F
31			k	25
32			n	4
33		A_3 Value from Table (for n=4)		1.628
34			d	2

Fig. 3.11

Step 3: In Cell F29, we type "=(Sum(F3:F27)-F7-F19)/(F31-F34)" to get $\bar{\bar{X}}_{new}$ using equation (6) and then press ***Enter*** as shown in Fig. 3.12. We get the value of the revised average.

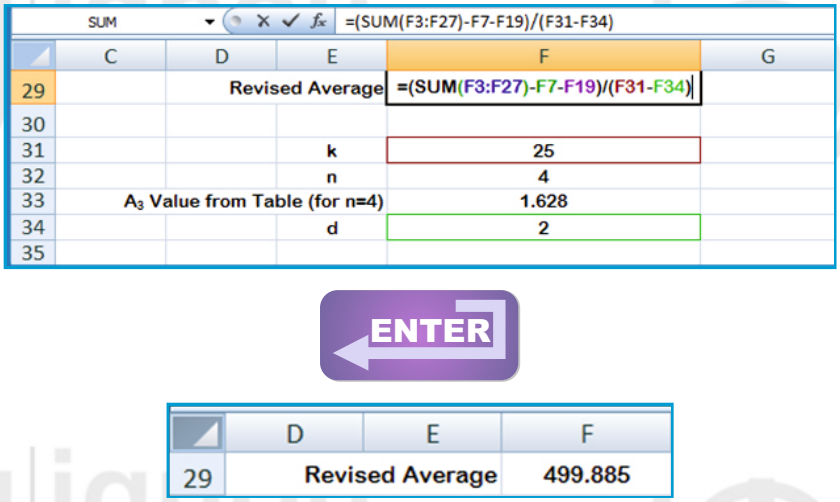


Fig. 3.12

Step 4: Similarly, for calculating $\bar{S}_{new}$, we use equation (7) and type "=(Sum(G3:G27)-G7-G19)/(F31-F34)" in Cell G29. To get the result, we press ***Enter*** as shown in Fig. 3.13.

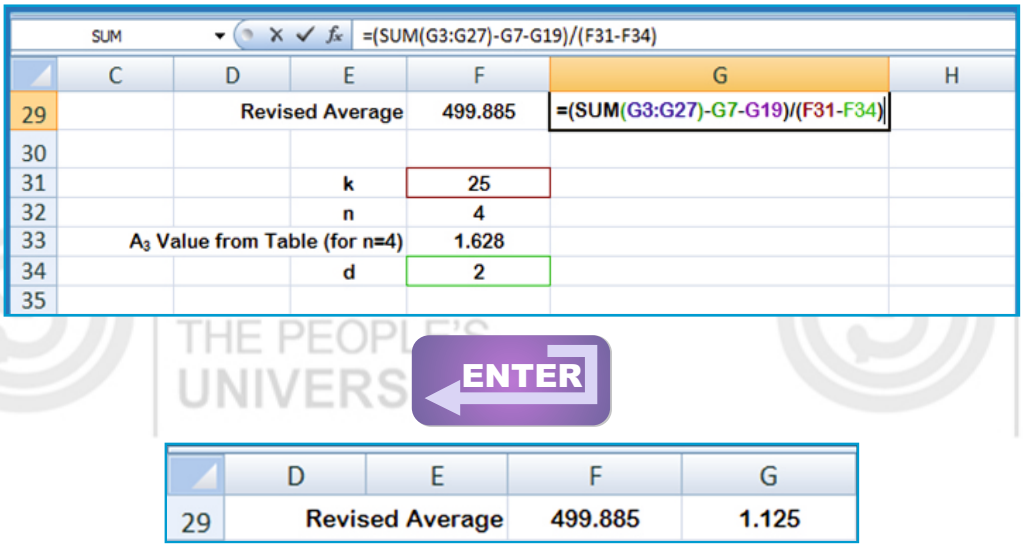


Fig. 3.13

Step 5: We follow Step 5 of Sec. 2.5 and use Columns K, L and M for putting the values of revised centre line, upper and lower control limits, respectively. We compute the centre line, upper and lower control limits as follows:

i) The revised centre line is given by (CL) = $\bar{\bar{X}}_{new}$ and $\bar{\bar{X}}_{new}$ is given in F29 (see Fig. 3.13). So in Excel, we type "=$F$29" in Cell K3 to find the centre line as shown in Fig. 3.14a.

ii) The upper control limit is given by $UCL = \bar{\bar{X}}_{new} + A_3\bar{S}_{new}$ and $\bar{\bar{X}}$, A_3 and $\bar{S}_{new}$ are given in Cells F29, F33 and G29, respectively (see Fig. 3.13). So we type "=$F$29+$F$33*$G$29" in Cell L3 as shown in Fig. 3.14b.

iii) Similarly, we calculate the lower control limit $LCL = \bar{\bar{X}}_{new} - A_3\bar{S}_{new}$ by typing "=$F$29-$F$33*$G$29" in Cell M3 as shown in Fig. 3.14c.

The formula with dollar sign ($) is used for an absolute reference.

(a)

K3 | =$F$29

	K	L	M	N
1	Revised Control Limits			
2	Centre Line	UCL	LCL	
3	499.885			
4				

(b)

L3 | =$F$29+$F$33*$G$29

	L	M	N	O
1	sed Control Limits			
2	UCL	LCL		
3	501.717			
4				

(c)

M3 | =$F$29-$F$33*$G$29

	M	N	O	P
1	imits			
2	LCL			
3	498.053			
4				

Fig. 3.14

Step 6: For plotting control limits on the chart using Excel, we first select Cells K3:M3 and drag them down up to Row 27 as shown in Fig. 3.15.

	H	I	J	K	L	M	N
1	Control Limits			Revised Control Limits			
2	Centre Line	UCL	LCL	Centre Line	UCL	LCL	
3	499.918	501.845	497.991	499.885	501.717	498.053	
4	499.918	501.845	497.991				
5	499.918	501.845	497.991				
6	499.918	501.845	497.991				
7	499.918	501.845	497.991				
8	499.918	501.845	497.991				

DRAG THEM DOWN

	H	I	J	K	L	M	N
1	Control Limits			Revised Control Limits			
2	Centre Line	UCL	LCL	Centre Line	UCL	LCL	
3	499.918	501.845	497.991	499.885	501.717	498.053	
4	499.918	501.845	497.991	499.885	501.717	498.053	
5	499.918	501.845	497.991	499.885	501.717	498.053	
6	499.918	501.845	497.991	499.885	501.717	498.053	
7	499.918	501.845	497.991	499.885	501.717	498.053	
8	499.918	501.845	497.991	499.885	501.717	498.053	
9	499.918	501.845	497.991	499.885	501.717	498.053	
10	499.918	501.845	497.991	499.885	501.717	498.053	
11	499.918	501.845	497.991	499.885	501.717	498.053	
12	499.918	501.845	497.991	499.885	501.717	498.053	
13	499.918	501.845	497.991	499.885	501.717	498.053	
14	499.918	501.845	497.991	499.885	501.717	498.053	
15	499.918	501.845	497.991	499.885	501.717	498.053	
16	499.918	501.845	497.991	499.885	501.717	498.053	
17	499.918	501.845	497.991	499.885	501.717	498.053	
18	499.918	501.845	497.991	499.885	501.717	498.053	
19	499.918	501.845	497.991	499.885	501.717	498.053	
20	499.918	501.845	497.991	499.885	501.717	498.053	
21	499.918	501.845	497.991	499.885	501.717	498.053	
22	499.918	501.845	497.991	499.885	501.717	498.053	
23	499.918	501.845	497.991	499.885	501.717	498.053	
24	499.918	501.845	497.991	499.885	501.717	498.053	
25	499.918	501.845	497.991	499.885	501.717	498.053	

X Bar Chart

Fig. 3.15

Step 7: For plotting the $\bar{X}$-chart in Excel 2007, we refer to Fig. 3.16. It means that we

1. select Cells F2:F6, F8:F18, F20:F27, K2:M6, K8:M18 and K20:M27 by holding ***Ctrl*** key,
2. click on the ***Insert*** tab,
3. select the ***Line*** option, and
4. choose the chart subtype.

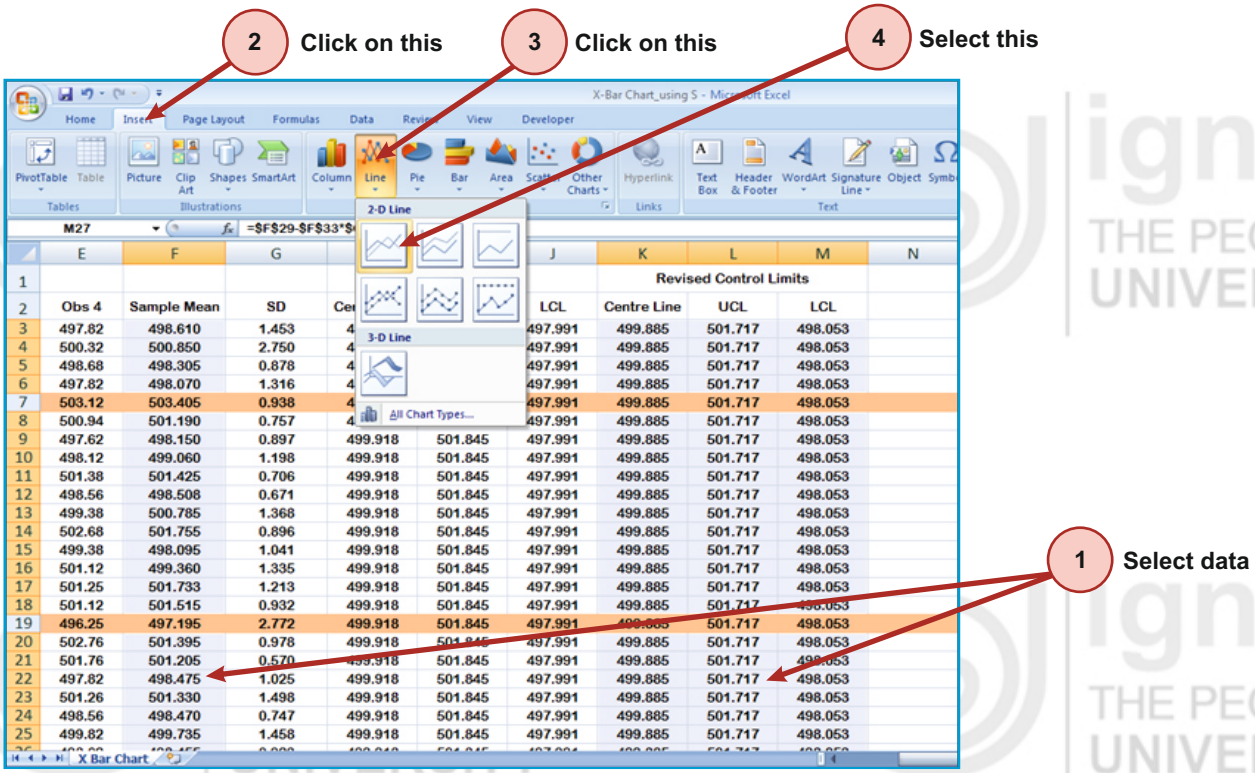


Fig. 3.16

Step 8: We find that the values in Columns K, L and M provide the horizontal lines on the chart representing the revised centre line, UCL and LCL, respectively.

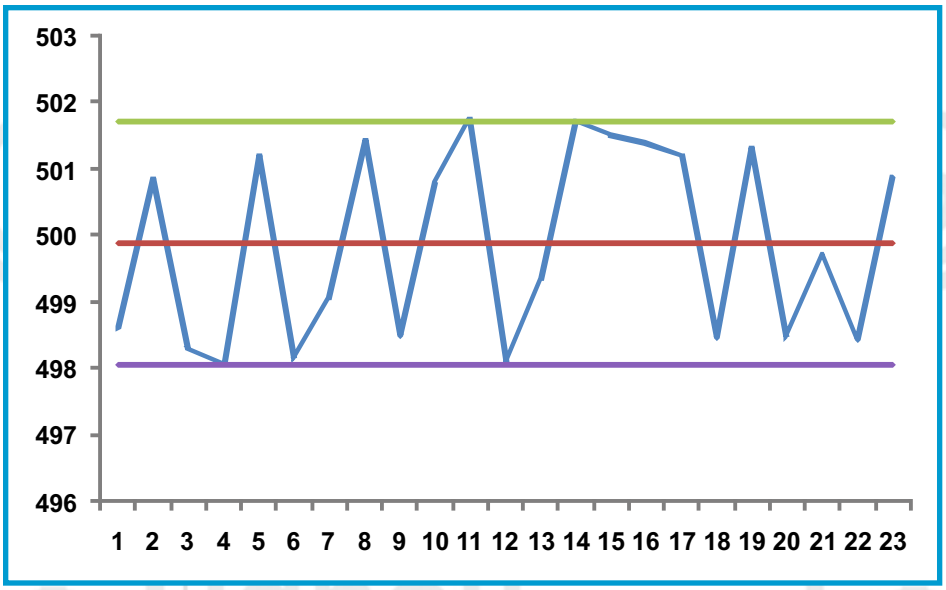


Fig. 3.17

Step 9: We note that the horizontal axis shown in Fig. 3.17 includes the 5th and 17th sample points. We need to eliminate these points from the horizontal axis. For this, we follow Steps 9 and 10 of Sec. 2.5 of Lab Session 2 as shown in Fig. 3.18.

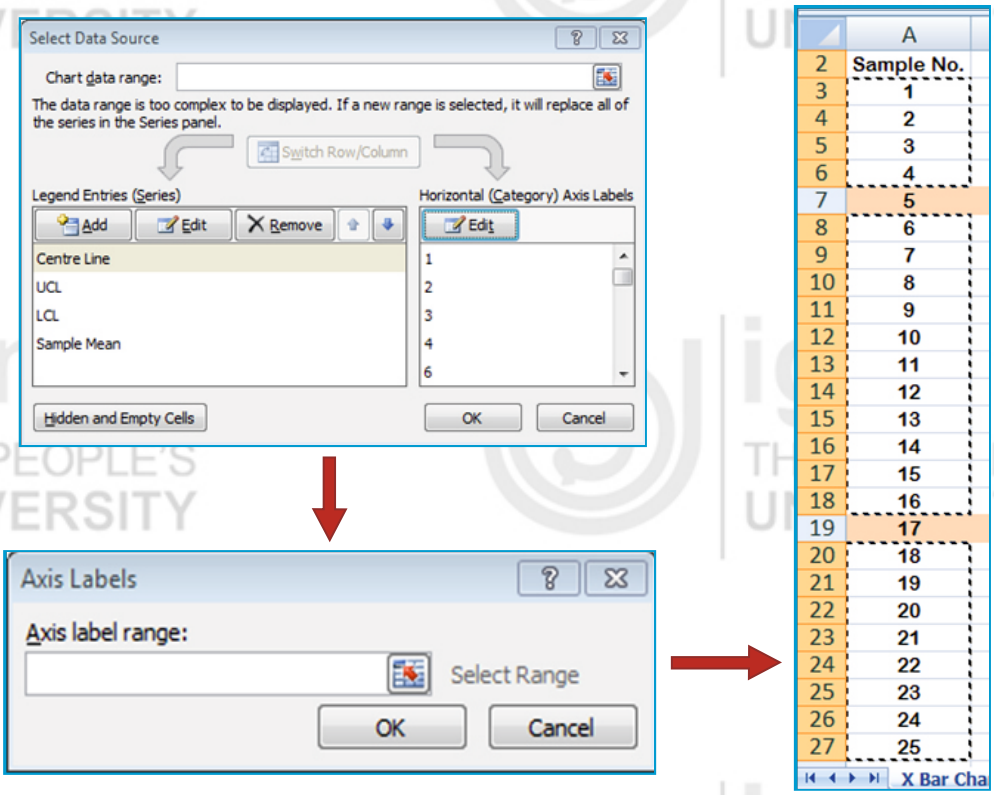


Fig. 3.18

Step 10: We format the chart as explained in Sec. 1.4 of Lab Session 1. The resulting control chart is shown in Fig. 3.19.

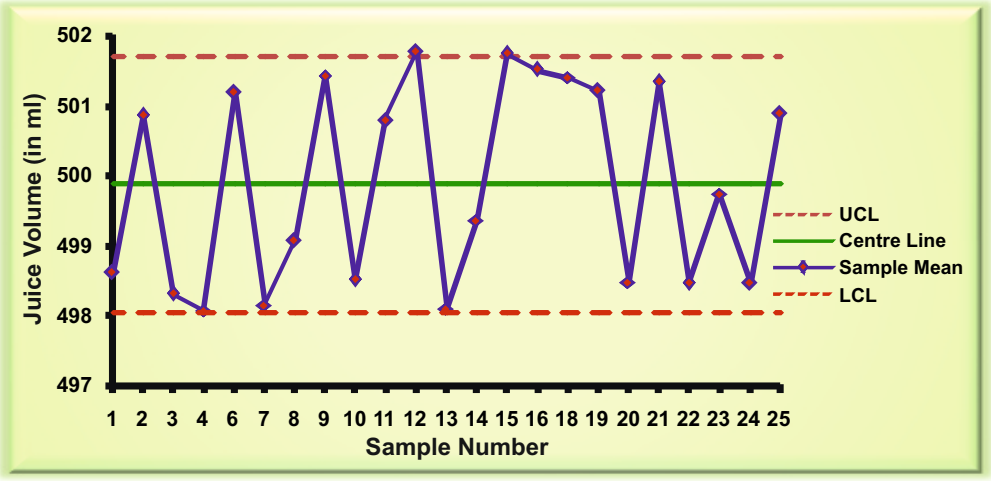


Fig. 3.19

Interpretation

Note from Fig. 3.19 that two points corresponding to Samples 12 and 15 lie outside the UCL and LCL, respectively, in the revised control chart. This control chart indicates that the process is **still not under statistical control**. Some assignable causes are still present in the process. To bring the process under statistical control, it is necessary to investigate the assignable causes and take corrective action to eliminate them. After that, we delete the out-of-control points. In the next section, you will learn how to calculate the revised centre line and control limits again for the $\bar{X}$-chart for the remaining samples.

Activity 1

You can also determine the revised control limits using another approach. For this purpose, follow the steps given below:

- ✓ Select Cells A1:E6, A8:E18, and A20:E27.
- ✓ Choose Cell A35 or any other cell and paste the values. You can also use a separate Excel sheet where you can paste these values.
- ✓ Repeat all steps given in Sec. 3.4.

It will give you the same results as you have obtained in Sec. 3.5.

3.6 FURTHER REVISION OF $\bar{X}$-CHART

We can obtain the revised centre line and control limits for the $\bar{X}$-chart for the remaining samples as follows:

Step 1: We highlight the samples lying outside the revised control limits obtained in Sec. 3.5, i.e., the 12th and 15th samples, with purple colour as shown in Fig. 3.20.

	A	B	C	D	E	F	G	H	I	J
1		Juice Volume (in ml)						Control Limits		
2	Sample No.	Obs 1	Obs 2	Obs 3	Obs 4	Sample Mean	SD	Centre Line	UCL	LCL
3	1	497.32	500.62	498.68	497.82	498.610	1.453	499.918	501.845	497.991
4	2	504.76	500.00	498.32	500.32	500.850	2.750	499.918	501.845	497.991
5	3	499.24	497.18	498.12	498.68	498.305	0.878	499.918	501.845	497.991
6	4	499.26	496.32	498.88	497.82	498.070	1.316	499.918	501.845	497.991
7	5	502.32	503.62	504.56	503.12	503.405	0.938	499.918	501.845	497.991
8	6	502.12	500.32	501.38	500.94	501.190	0.757	499.918	501.845	497.991
9	7	499.34	498.32	497.32	497.62	498.150	0.897	499.918	501.845	497.991
10	8	499.38	498.12	500.62	498.12	499.060	1.198	499.918	501.845	497.991
11	9	501.26	502.38	500.68	501.38	501.425	0.706	499.918	501.845	497.991
12	10	498.60	497.62	499.25	498.56	498.508	0.671	499.918	501.845	497.991
13	11	502.44	500.00	501.32	499.38	500.785	1.368	499.918	501.845	497.991
14	12	501.26	502.32	500.76	502.68	501.755	0.896	499.918	501.845	497.991
15	13	497.32	498.50	497.18	499.38	498.095	1.041	499.918	501.845	497.991
16	14	499.56	498.00	498.76	501.12	499.360	1.335	499.918	501.845	497.991
17	15	502.24	500.32	503.12	501.25	501.733	1.213	499.918	501.845	497.991
18	16	501.76	500.50	502.68	501.12	501.515	0.932	499.918	501.845	497.991
19	17	500.65	497.82	494.06	496.25	497.195	2.772	499.918	501.845	497.991
20	18	501.12	501.26	500.44	502.76	501.395	0.978	499.918	501.845	497.991
21	19	501.00	500.50	501.56	501.76	501.205	0.570	499.918	501.845	497.991
22	20	497.50	498.82	499.76	497.82	498.475	1.025	499.918	501.845	497.991
23	21	503.44	500.62	500.00	501.26	501.330	1.498	499.918	501.845	497.991
24	22	499.38	498.38	497.56	498.56	498.470	0.747	499.918	501.845	497.991
25	23	501.56	499.56	498.00	499.82	499.735	1.458	499.918	501.845	497.991

X Bar Chart

Fig. 3.20

Step 2: Two points were outside the control limits as shown in Fig. 3.9 and two points are outside the revised control limits again as shown in Fig. 3.19. Thus, we need to eliminate a total of 4 samples. So we put the value of d′ (= 2 + 2 = 4) in Cell F35 as shown in Fig. 3.21.

	C	D	E	F
31			k	25
32			n	4
33		A_3 Value from Table (for n=4)		1.628
34			d	2
35			d'	4

Fig. 3.21

Step 3: We repeat Step 3 of Sec. 3.5 and compute the revised average $\bar{\bar{X}}'_{new}$ for this data as shown in Fig. 3.22.

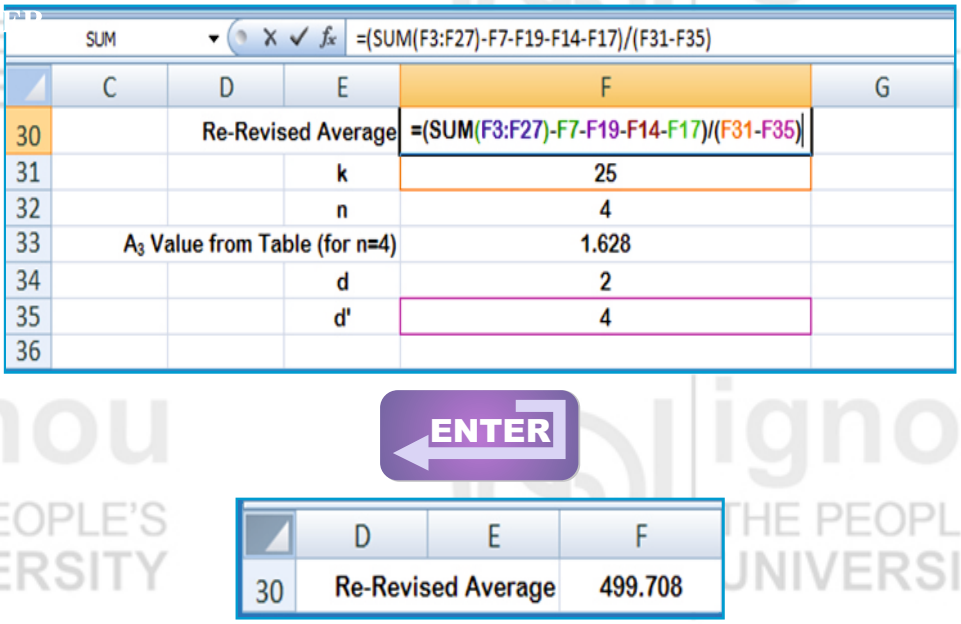


Fig. 3.22

Step 4: We repeat Step 4 of Sec. 3.5 and compute the revised average sample standard deviation $\bar{S}'_{new}$ for this data (see Fig. 3.23).

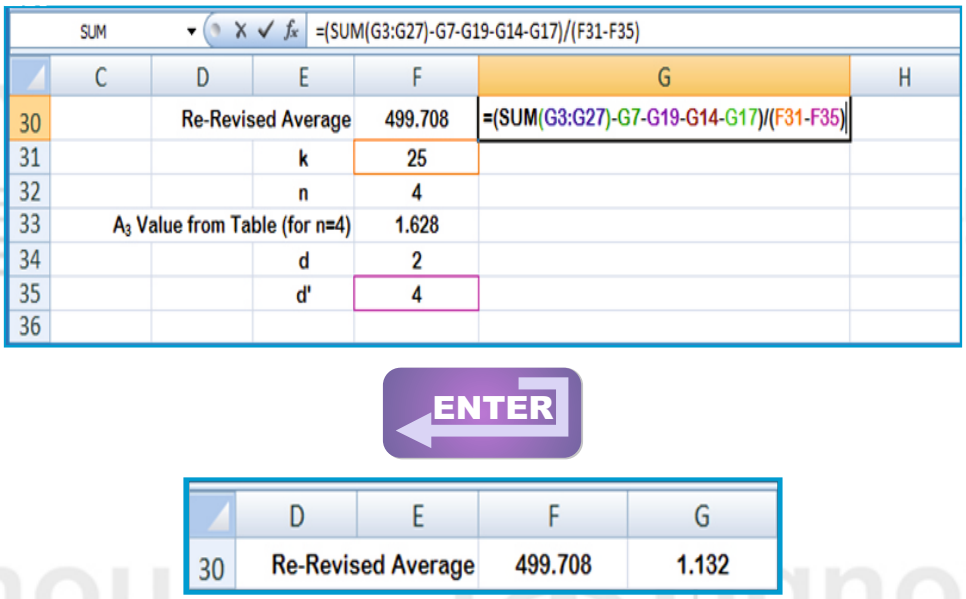


Fig. 3.23

Step 5: We follow Step 5 of Sec. 3.5 and compute the revised centre, upper and lower control limits, respectively:

i) The revised centre line is $(CL) = \bar{\bar{X}}'_{new}$. So we type "=$F$30" in Cell N3 to find the centre line as shown in Fig. 3.24a.

ii) We calculate the upper control limit $UCL = \bar{\bar{X}}'_{new} + A_3\bar{S}'_{new}$ by typing "=$F$30+$F$33*$G$30" in Cell O3 as shown in Fig. 3.24b.

iii) Similarly, we calculate the lower control limit $LCL = \bar{\bar{X}}'_{new} - A_3\bar{S}'_{new}$ by typing "=$F$30-$F$33*$G$30" in Cell P3 as shown in Fig. 3.24c.

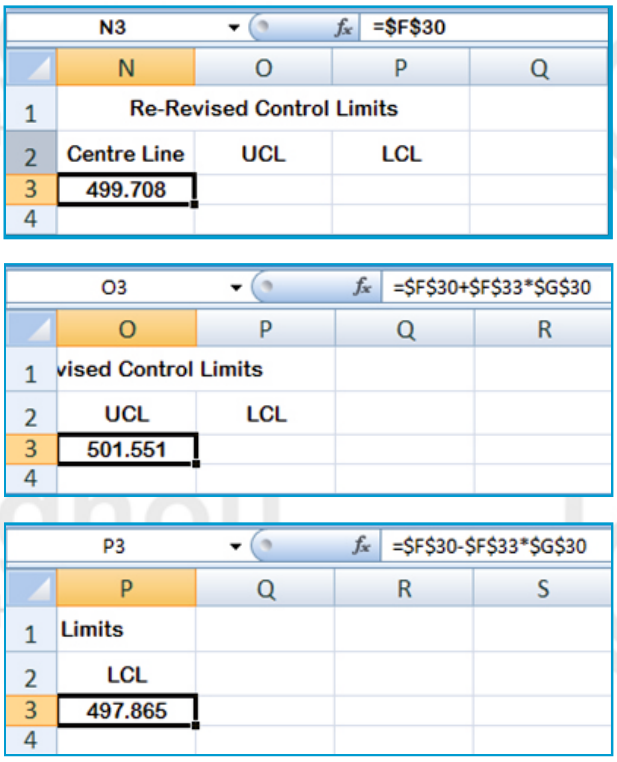


Fig. 3.24

Step 6: We follow Steps 6 and 7 of Sec. 3.5 and calculate the centre line, upper and lower control limits in Cells N3, O3 and P3, respectively, for the first sample. Then we select Cells N3:P3 and drag them up to Row 27. The output is shown in Fig. 3.25.

	K	L	M	N	O	P	Q
1	Revised Control Limits			Re-Revised Control Limits			
2	Centre Line	UCL	LCL	Centre Line	UCL	LCL	
3	499.885	501.717	498.053	499.708	501.551	497.865	
4	499.885	501.717	498.053	499.708	501.551	497.865	
5	499.885	501.717	498.053	499.708	501.551	497.865	
6	499.885	501.717	498.053	499.708	501.551	497.865	
7	499.885	501.717	498.053	499.708	501.551	497.865	
8	499.885	501.717	498.053	499.708	501.551	497.865	
9	499.885	501.717	498.053	499.708	501.551	497.865	
10	499.885	501.717	498.053	499.708	501.551	497.865	
11	499.885	501.717	498.053	499.708	501.551	497.865	
12	499.885	501.717	498.053	499.708	501.551	497.865	
13	499.885	501.717	498.053	499.708	501.551	497.865	
14	499.885	501.717	498.053	499.708	501.551	497.865	
15	499.885	501.717	498.053	499.708	501.551	497.865	
16	499.885	501.717	498.053	499.708	501.551	497.865	
17	499.885	501.717	498.053	499.708	501.551	497.865	
18	499.885	501.717	498.053	499.708	501.551	497.865	
19	499.885	501.717	498.053	499.708	501.551	497.865	
20	499.885	501.717	498.053	499.708	501.551	497.865	
21	499.885	501.717	498.053	499.708	501.551	497.865	

Fig. 3.25

Step 7: For plotting the $\bar{X}$-chart in Excel 2007, we refer to Fig. 3.26. It means that we

1. select Cells F2:F6, F8:F13, F15:F16, F18, F20:F27, N2:P6, N8:P13, N15:P16, N18:P18 and N20:P27 by holding ***Ctrl*** key,
2. click on the ***Insert*** tab,
3. select the ***Line*** option, and
4. choose the chart subtype.

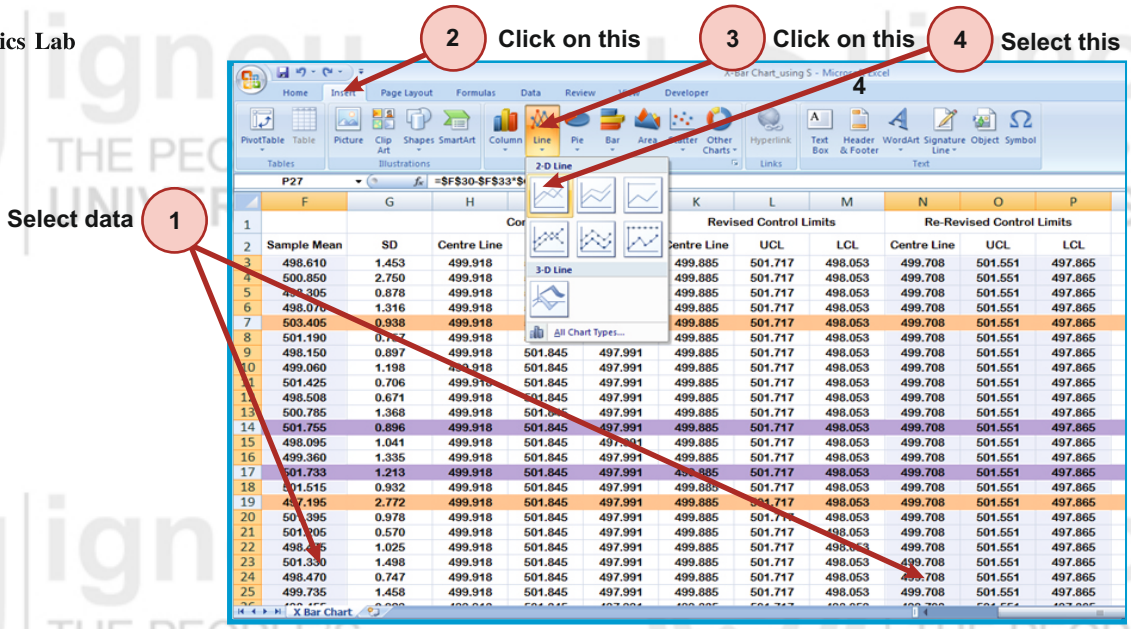


Fig. 3.26

Step 7: We can change the horizontal axis label as explained in Step 9 of Sec. 2.5. We select Cells A2:A6, A8:A13, A15:A16, A18 and A20:A27 by holding ***Ctrl*** key as shown in Fig. 3.27.

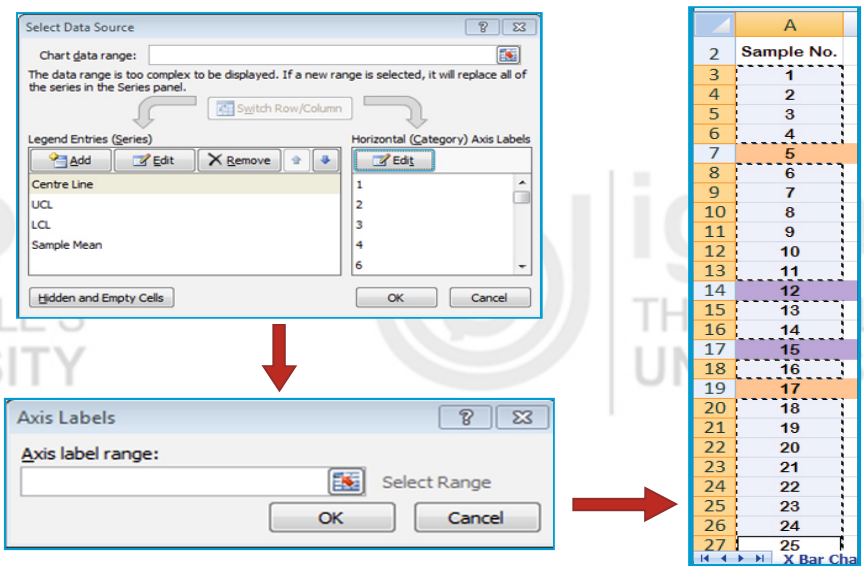


Fig. 3.27

Step 8: We format the chart as explained in Sec. 1.4 of Lab Session 1. The resulting control chart is shown in Fig. 3.28.

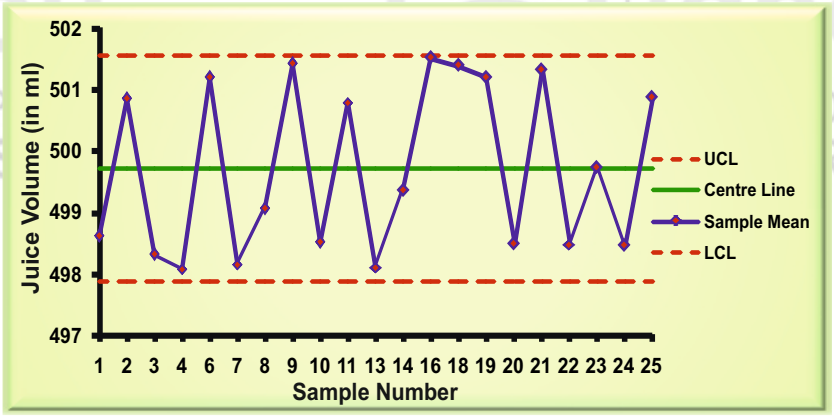


Fig. 3.28

Interpretation

The $\overline{X}$-chart revised further is shown in Fig. 3.28. It indicates that all points

lie within the control limits. So the process is under statistical control now with respect to mean.

Activity 2

You can also determine the revised control limits using another approach. For this purpose, follow the steps given below:

- ✓ Select Cells A1:E6, A8:E13, A15:E16, A18:E18 and A20:E27.
- ✓ Choose Cell A35 or any cell and paste the values. You can also use a separate Excel sheet where you can paste these values.
- ✓ Repeat all the steps given in Sec. 3.4.

It will give you the same results as you have obtained in Sec. 3.6.

You should now apply the method on other problems for practice.

Activity 3

Construct the control charts for mean when process variability is unknown and estimated by sample standard deviation with the help of MS Excel 2007 and interpret the results for

A1) Example 3 given in Unit 2 of MSTE-001.

A2) Exercise E6 given in Unit 2 of MSTE-001.

Match the results with the manual calculation done in Unit 2 of MSTE-001.

Continuous Assessment 3

Consider the data given in Continuous Assessment 1 and develop $\bar{X}$-chart to check whether the process of production of bulbs is under control or out-of-control when process variability is unknown. If it is out-of-control, compute the revised control limits. Use sample standard deviation to estimate the process standard deviation.

Home Work: Do It Yourself

1) Follow the steps explained in Sec. 3.4, 3.5 and 3.6 to construct the control chart for the data of Table 1 in Lab Session 1. Use a different format for the control chart. Take its screenshot and keep it in your record book.
2) Develop the spreadsheet for the exercise "Continuous Assessment 3" as explained in this lab session. Take screenshots of the final spreadsheet and the chart.
3) **Do not forget** to keep the screenshots in your record book as these will contribute in your continuous assessment in the Laboratory.