SPC Fundamentals

DataNet Quality Systems

SPC Fundamentals Course Agenda

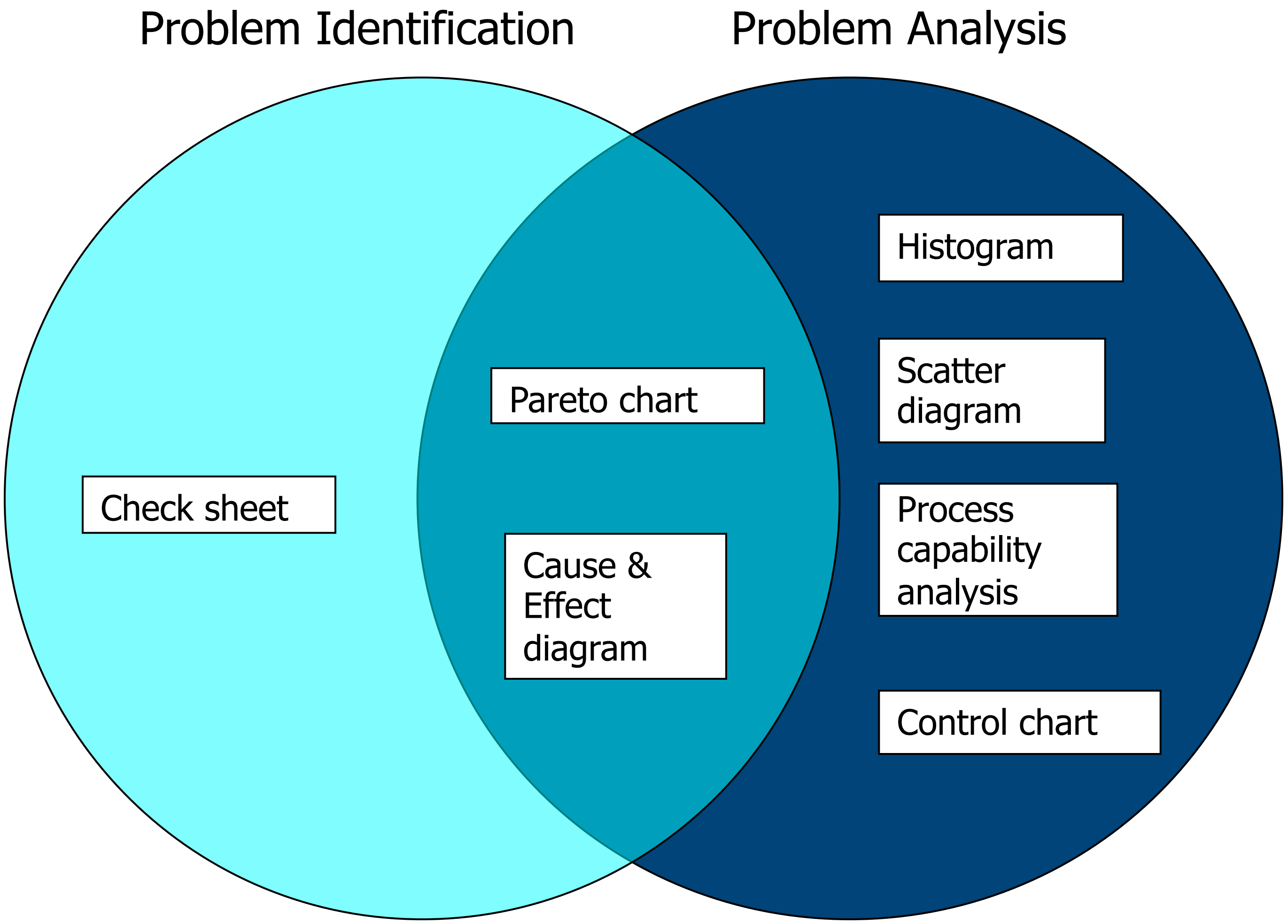
- **Introduction to SPC**
- **The Seven SPC Tools**
  - **Check Sheet** - Purpose and uses
  - **Pareto Charts**
    - What is the Pareto Principle?
    - Exercise
  - **Cause and Effect Diagram**
    - Brainstorming, creating the C&E diagram
    - Exercise
  - **Control Charts**
    - Variable : Xbar-R, Xbar-S, X-MR
    - Attribute : p, np, c, u
    - Exercises : Xbar-R, X-MR, p
  - **Histogram** - Purpose and uses
  - **Process Capability Studies**
    - What are capability and performance indices?
    - How to calculate and interpret Cp, Cpk, Pp, Ppk values?
    - Exercise
  - **Scatter Diagram** - Purpose and uses
- What SPC tool(s) should you use during process improvements?
- How can WinSPC help with your SPC needs?

What is SPC?

- SPC or Statistical Process Control: Is a method for achieving quality control in a manufacturing environment

- There are a core set of 7 tools
- Used for improving processes
- Monitoring and controlling ongoing processes
- Moves from a detection (reactive) model to a prevention (proactive) model
- Reduces the cost of producing, finding and repairing non conforming parts

The 7 SPC tools



Check Sheet

Check Sheet

- A simple, user friendly form for collecting data for a period of time

<u>Example</u>: A Pencil manufacturer collects data for the different types of defects found in one week.

Sr. No.	**Defect Types**	**2/13**	**2/14**	**2/15**	**2/16**	**2/17**
1	Broken leads	𝍸 𝍸	|||	𝍸	𝍸	||||
2	Bent	|||	||||	||	𝍸 𝍸	||
3	Eraser – Pencil assembly loose	𝍸	𝍸 |	|	𝍸 ||	|
4	Other		|		|	|

Check Sheet

Advantages

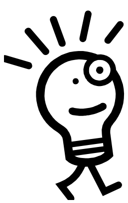
• Simple and easy to construct

• Very useful for data collection for an improvement project

Disadvantages

• Manage many papers for check sheets

• Inspection reports used in place of check sheets



Useful Tips

✓ Construct a separate check sheet for each project

Pareto Chart

Pareto Chart - History

- Vilfredo Pareto, an Italian economist studied the wealth distribution in Italy and found that 80% of the wealth is concentrated with 20% people

- In the 1940s, Juran applied this principle to Quality

- The name Pareto is from the founder of the 80/20 rule

What is the Pareto Principle?

What is the 80/20 rule?

80% of the problems are due to 20% causes.

Also, known as the Pareto principle.

Other examples:

- 80% of the product cost is due to 20% raw material
- 80% of the sales is due to 20% customers

What is a Pareto Chart?

A pareto chart is a combination chart…

- Bar chart for the % frequency
- Curve for the cumulative frequency

Uses of the Pareto Chart

- Prioritizes the problems or causes of a problem
- Separates the vital few from the trivial many

Pareto Chart - Example

Pareto Chart

Example:

Part: Pencil

Project: A process improvement team wants to prioritize the types of defects found in pencils. They have collected data about the defects for the last week.

Pareto Chart

The data for defects found in one week.

Sr. No.	Defect Types	2/13	2/14	2/15	2/16	2/17	Total
1	Broken leads	𝍸 𝍸	𝍷𝍷𝍷	𝍸	𝍸	𝍷𝍷𝍷𝍷	27
2	Bent	𝍷𝍷𝍷	𝍷𝍷𝍷	𝍷	𝍸	𝍷𝍷	14
3	Eraser – Pencil assembly loose	𝍸	𝍷	𝍷	𝍸 𝍷	𝍷𝍷𝍷	16
4	Aesthetic problems	𝍸	𝍷𝍷𝍷𝍷	𝍷	𝍷	𝍷𝍷	13
5	Other		𝍷		𝍷	𝍷	3

Construct a Pareto chart.

Pareto Chart

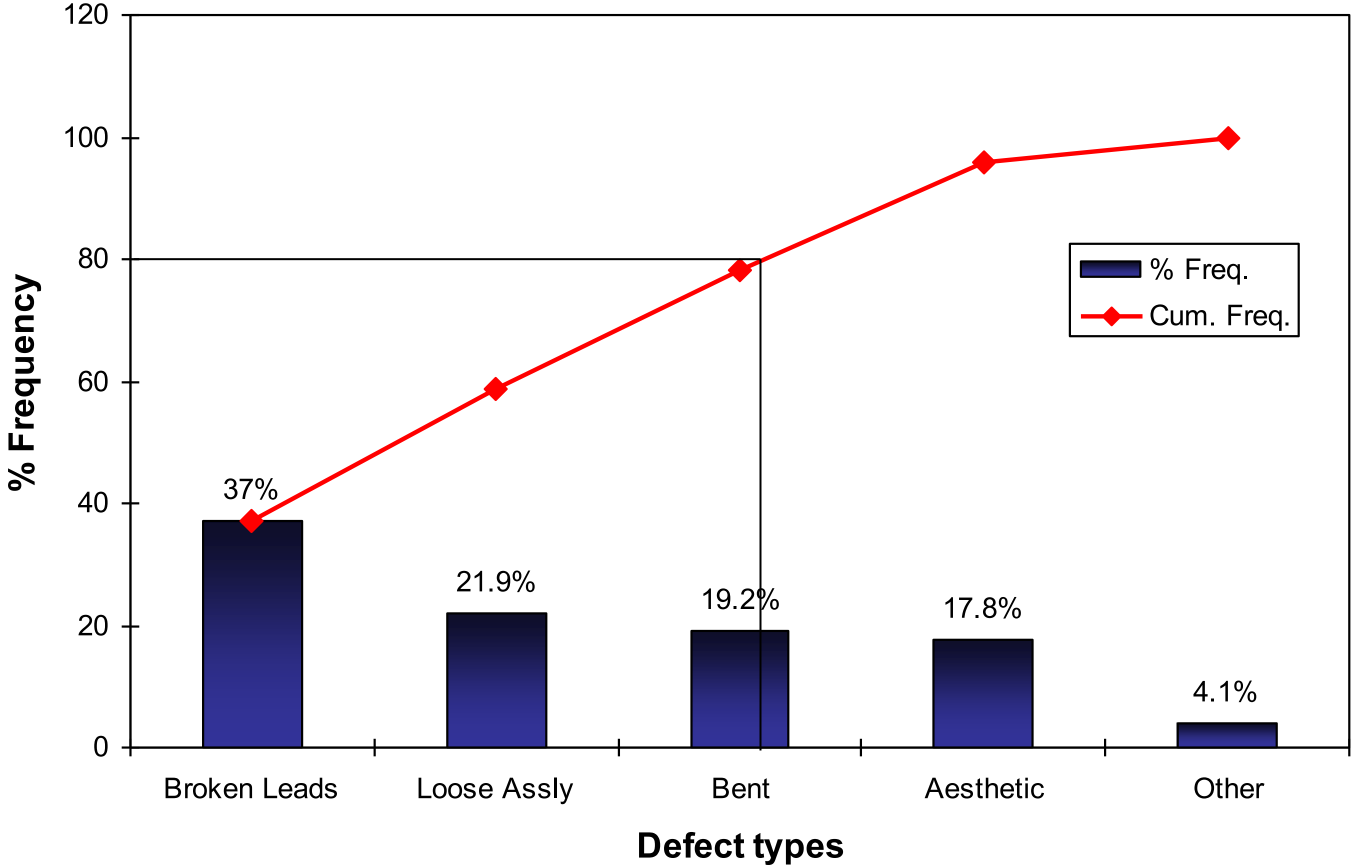
Step 1: Arrange the data in descending order

Step 2: Calculate % frequency and cumulative frequency

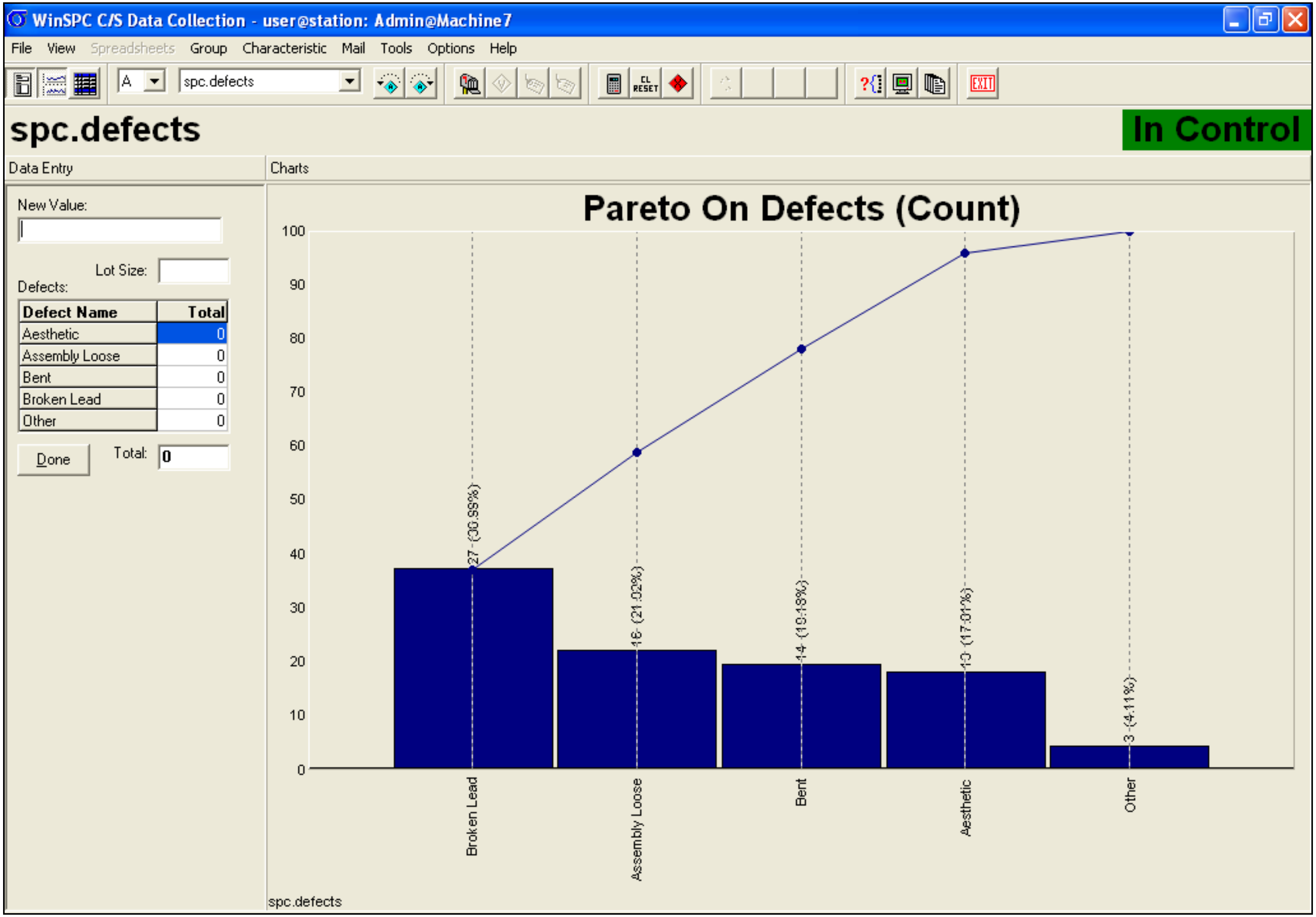
Sr. No.	Defect Types	Count	% Freq.	% Cum. Freq.
1	Broken leads	27	(27/73)x100= 37	37
2	Assembly loose	16	(16/73)x100= 21.9	58.9
3	Bent	14	(14/73)x100= 19.2	78.1
4	Aesthetic	13	(13/73)x100= 17.8	95.9
5	Other	3	(3/73)x100= 4.1	100
	TOTAL	**73**		

Pareto Chart

Step 3: Plot the chart and Identify the vital few



Pareto Chart from WinSPC



Pareto By Cost

Pareto By Cost

If there is a cost associated with each defect type, then a Pareto based on cost can be done. This cost may be the time/effort required to correct the defect.

Sr. No.	Defect Types	Count	Cost (¢/defect)
1	Broken leads	27	60
2	Assembly loose	16	50
3	Bent	14	80
4	Aesthetic	13	20
5	Other	3	20

Pareto By Cost

For a Pareto by cost, calculate the total cost for each defect type and construct a Pareto chart of this data.

Sr. No.	Defect Types	Count	Cost (¢/ defect)	Cost (¢)
1	Broken leads	27	60	1620
2	Assembly loose	16	50	800
3	Bent	14	80	1120
4	Aesthetic	13	20	260
5	Other	3	20	60

Pareto By Cost

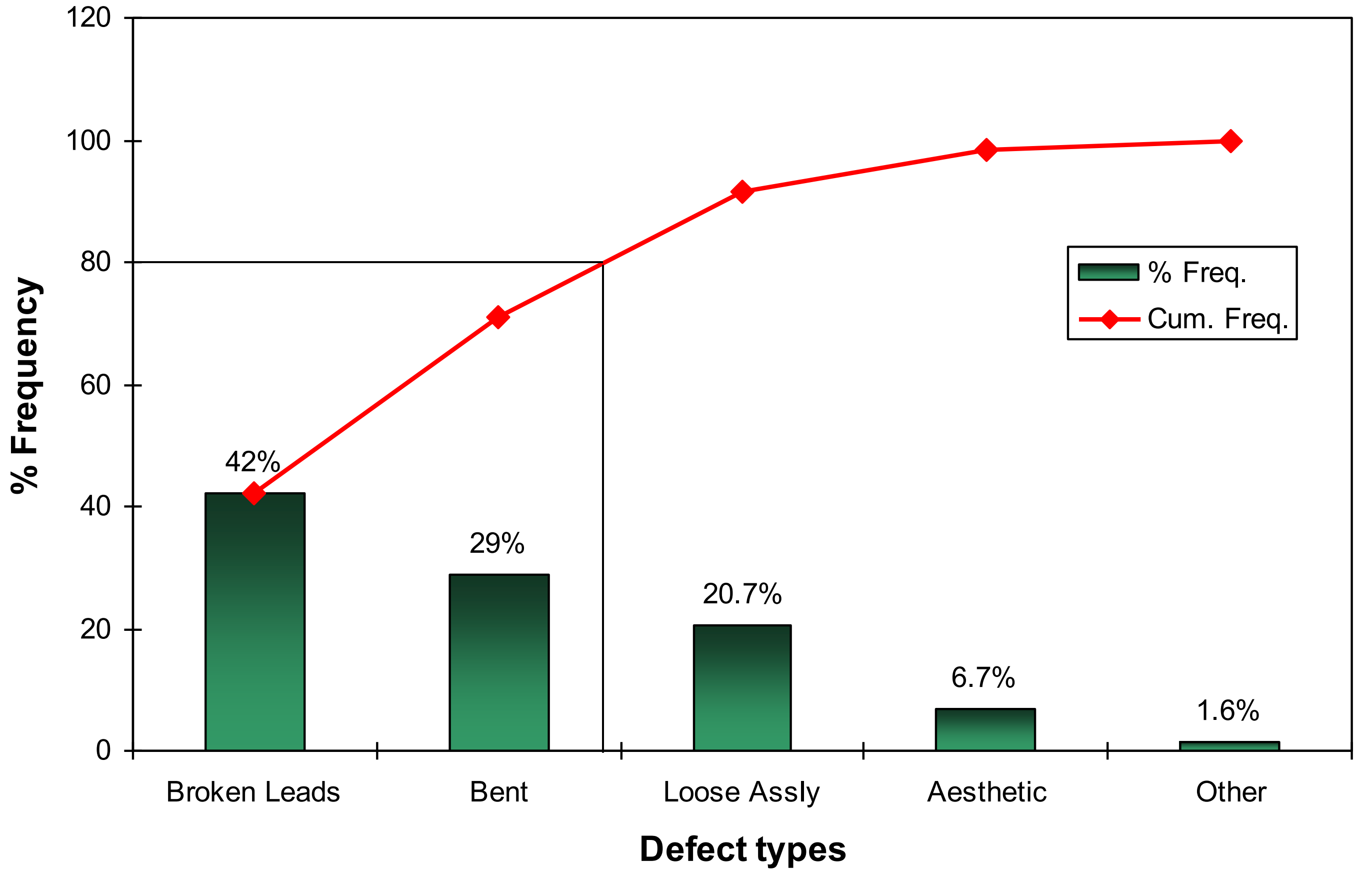
Step 1: Arrange data in descending order

Step 2: Calculate % frequency and cumulative frequency

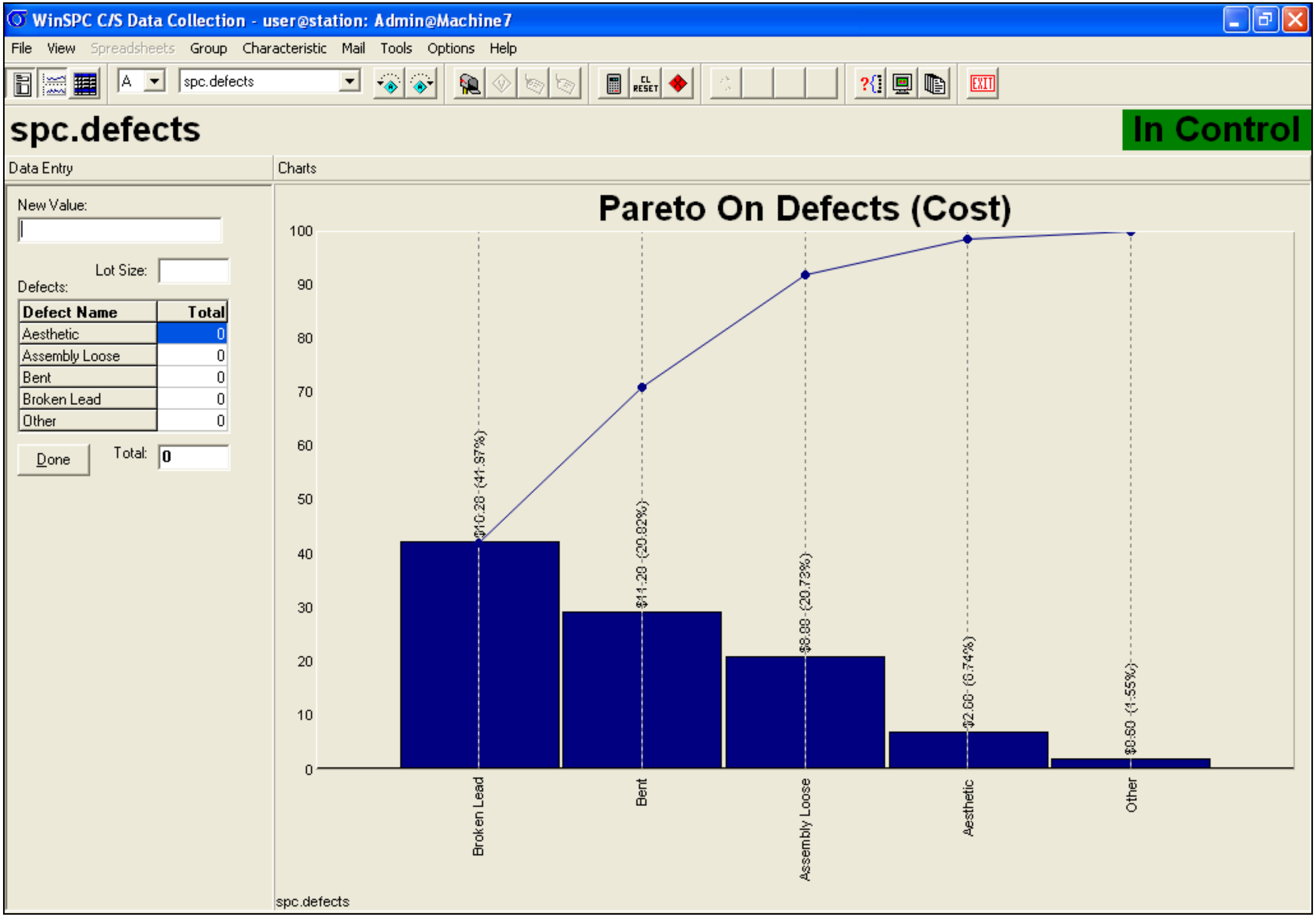
Sr. No.	Defect Types	Cost (¢)	% Freq.	% Cum. Freq.
1	Broken leads	1620	42	42
2	Bent	1120	29	71
3	Assembly loose	800	20.7	91.7
4	Aesthetic	260	6.7	98.4
5	Other	60	1.6	100
	TOTAL	3860		

Pareto by Cost

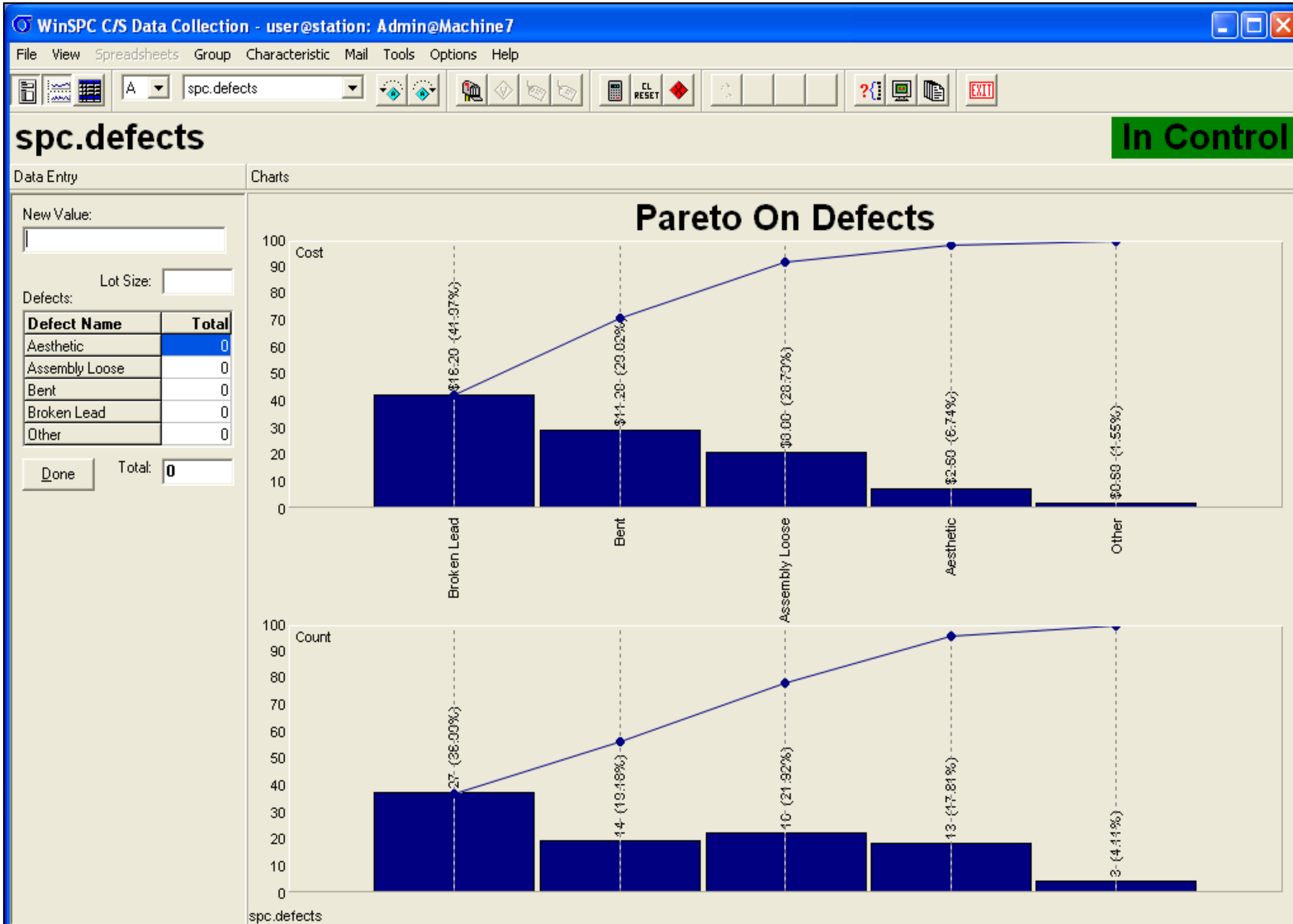
Step 3: Plot the chart and Identify the vital few



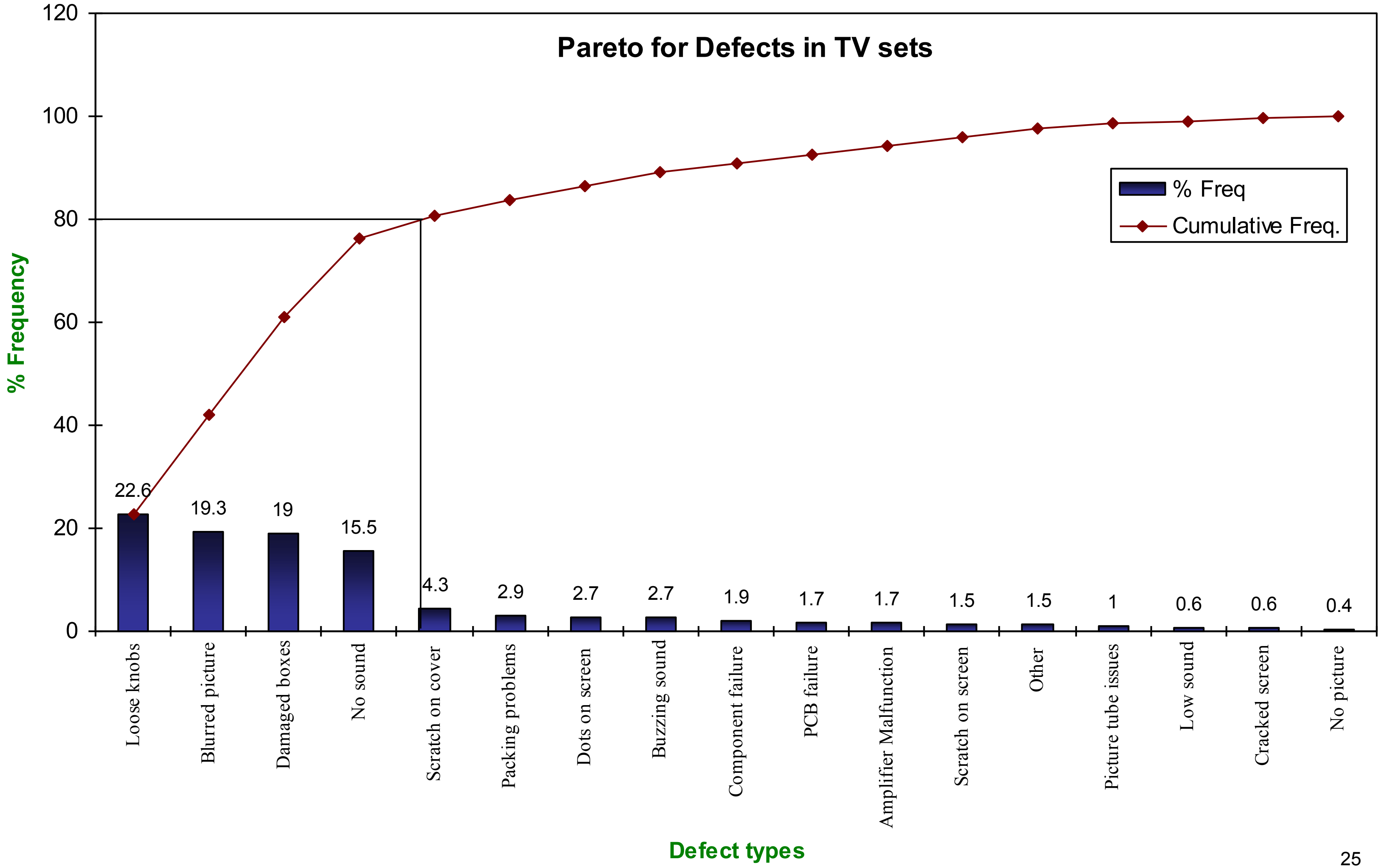
Pareto by Cost from WinSPC



Pareto by Count and Cost from WinSPC



Pareto Chart – Practical Example



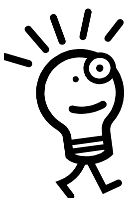
Pareto Chart

Advantages

- Helps prioritize
- Enables you to focus on the vital few

Disadvantages

- A snapshot of the process at a given time



Useful Tips

✓ Compare Pareto based on counts and cost for prioritization

✓ To monitor progress, do a Pareto analysis before and after process improvement

Pareto Chart - Exercise

Exercise: Pareto Chart

Part: Radio

Project: A process improvement team wants to prioritize the types of defects found in radios. They have collected the defect data for the past month.

Pareto Chart

Data for the type of defects found in a radio

Sr. No.	Defect Types	Count	Cost ($/defect)	Cost ($)
1	Amplifier problems	50	15	
2	Assembly loose	60	20	
3	Speaker output	20	15	
4	Scratches on the cover	30	2	
5	Loose knobs	10	10	
6	Packaging issues	40	5	

Construct a Pareto chart for the count and cost of defects.

Pareto Chart

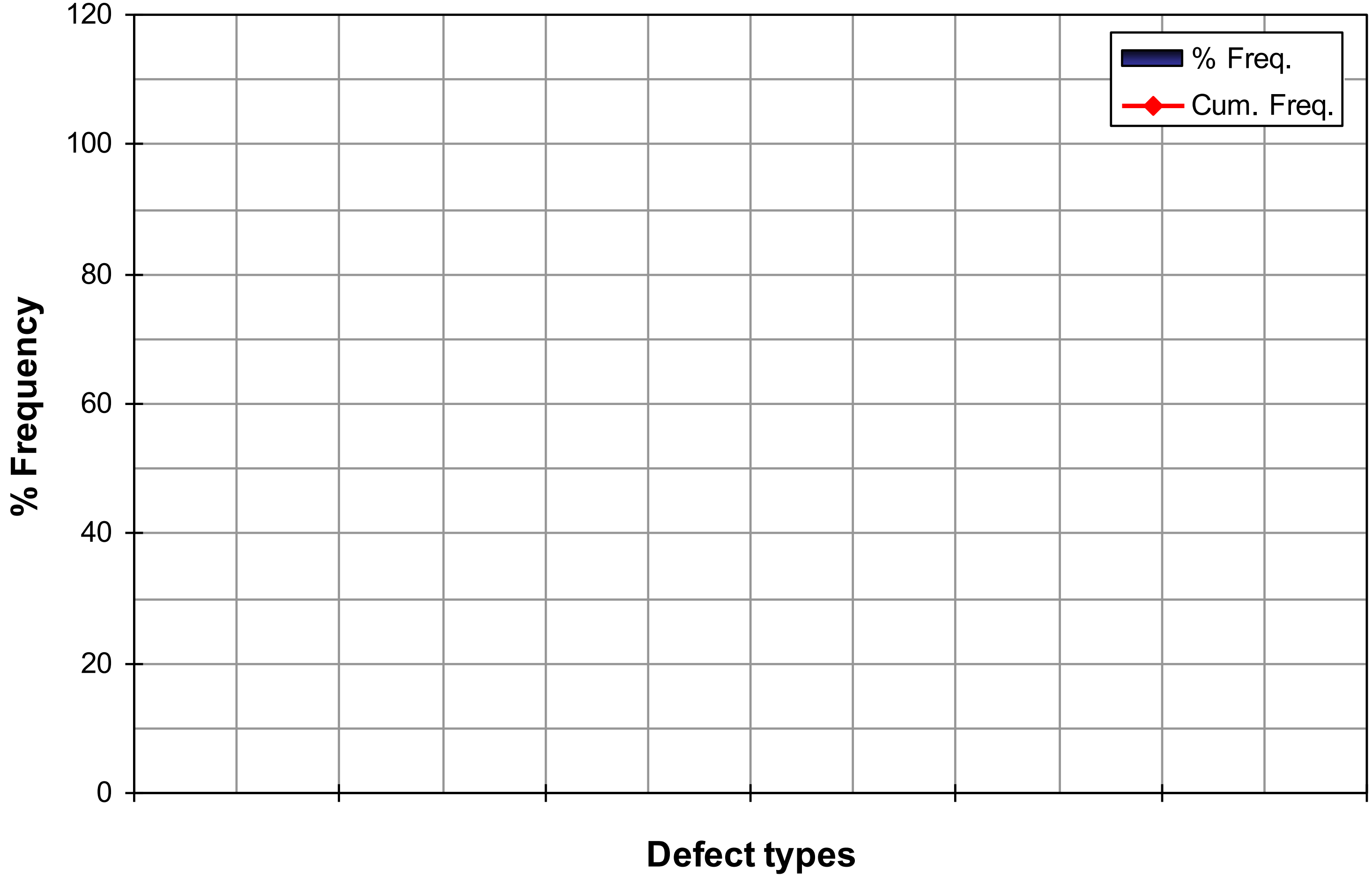
Step 1: Arrange data in descending order

Step 2: Calculate % frequency and cumulative frequency

Sr. No.	Defect Types	Count	% Freq.	% Cum. Freq.
1				
2				
3				
4				
5				
6				
	TOTAL			

Pareto Chart

Step 3: Plot the chart and apply the Pareto principle



Pareto by Cost

Pareto by Cost

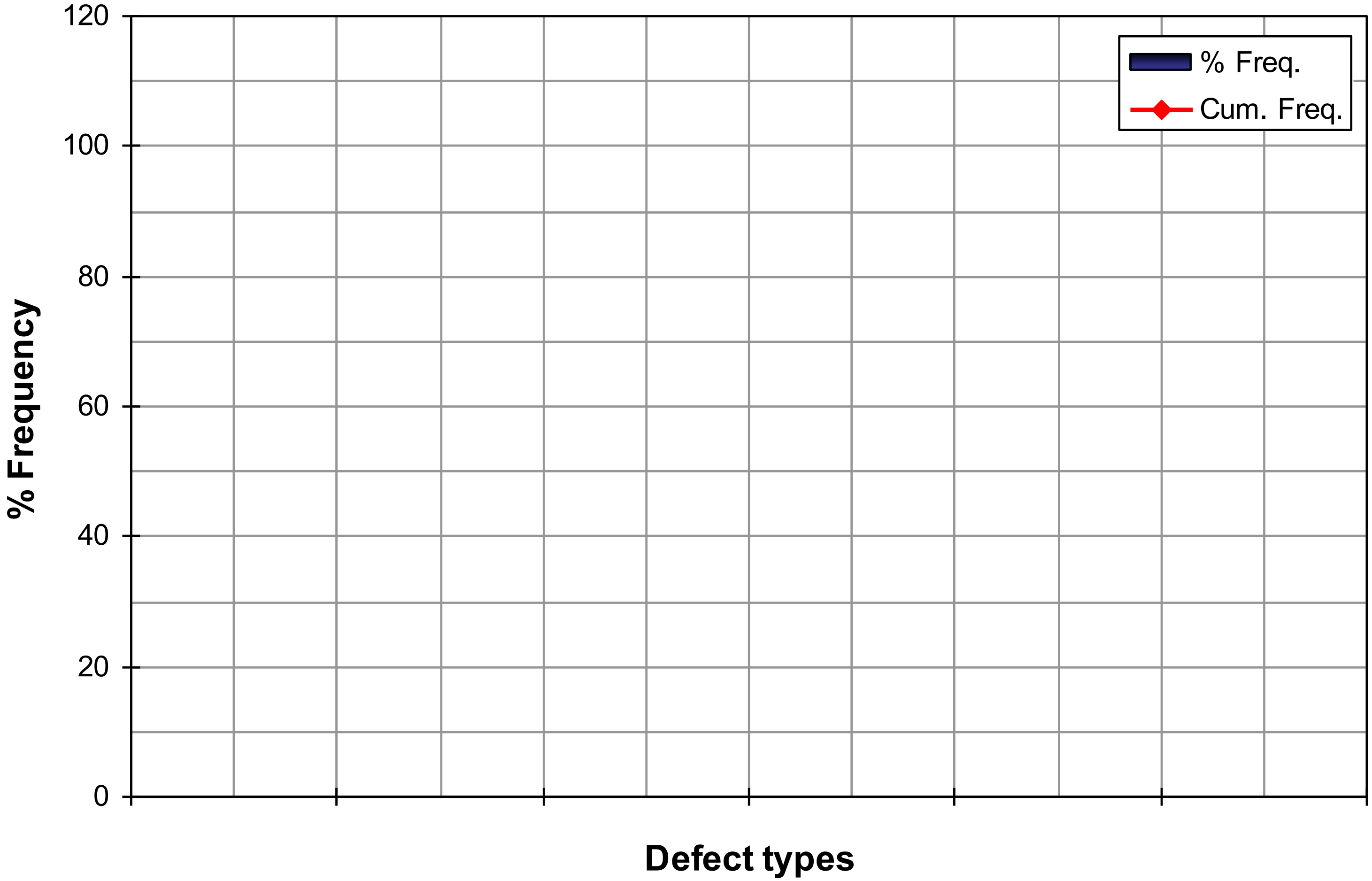
Step 1: Arrange data in descending order

Step 2: Calculate % frequency and cumulative frequency

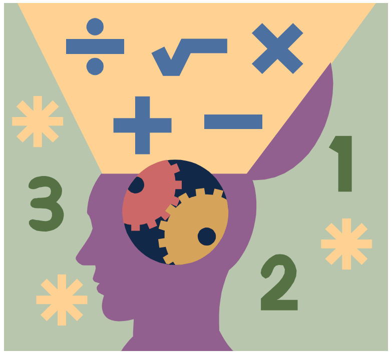
Sr. No.	Defect Types	Cost	% Freq.	% Cum. Freq.
1				
2				
3				
4				
5				
6				
	TOTAL			

Pareto by Cost

Step 3: Plot the chart and apply the Pareto Principle



Pareto Chart - Solution



Pareto Chart

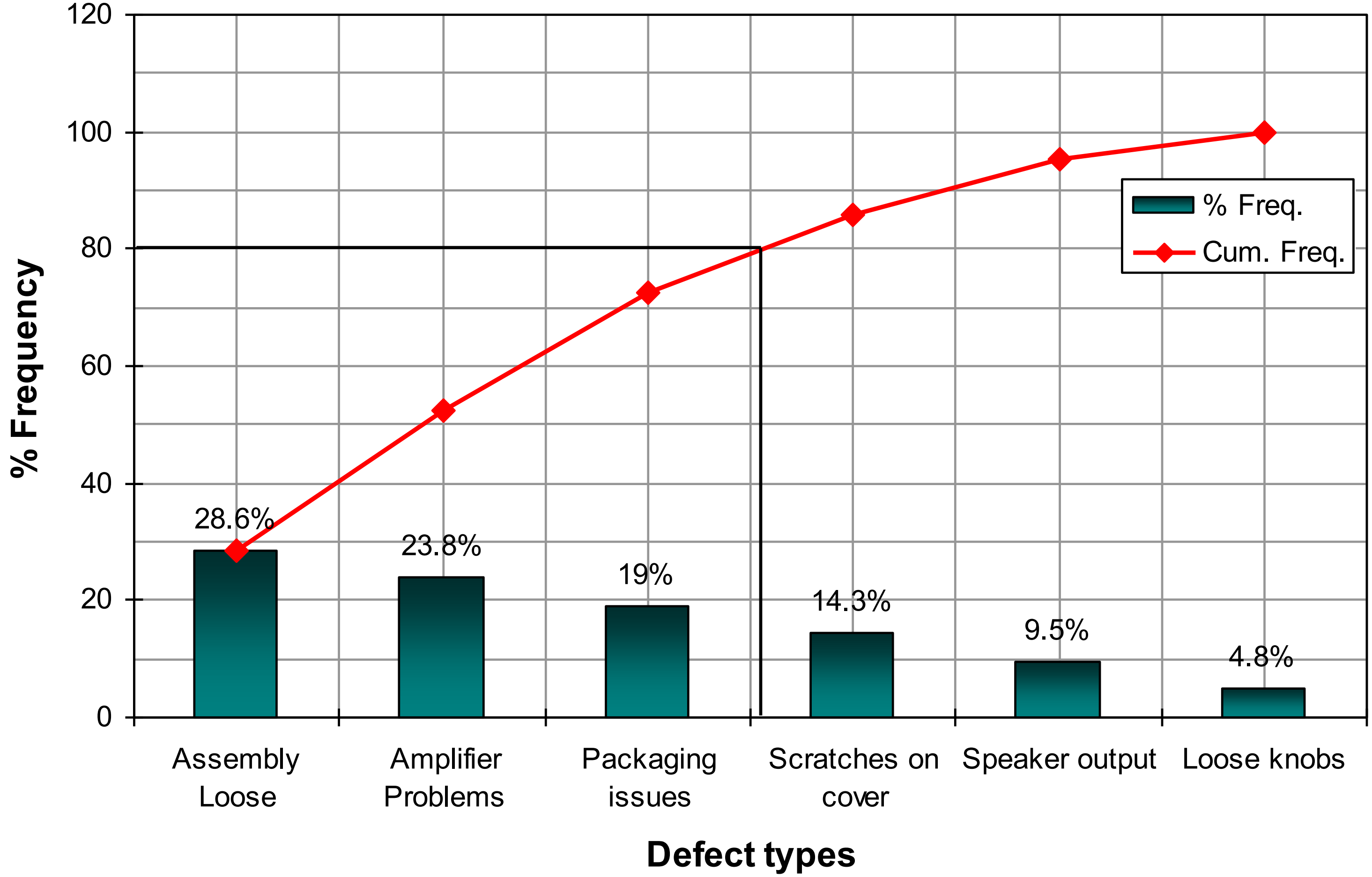
Step 1: Arrange data in descending order

Step 2: Calculate % frequency and cumulative frequency

Sr. No.	Defect Types	Count	% Freq.	% Cum. Freq.
1	Assembly loose	60	28.6%	28.6%
2	Amplifier problems	50	23.8%	52.4%
3	Packaging issues	40	19%	71.4%
4	Scratches on the cover	30	14.3%	85.7%
5	Speaker output	20	9.5%	95.2%
6	Loose knobs	10	4.8%	100%
	TOTAL	**210**		

Pareto Chart

Step 3: Plot the chart and apply the Pareto principle



Pareto by Cost

Pareto by Cost

Sr. No.	Defect Types	Count	Cost ($/defect)	Cost ($)
1	Amplifier problems	50	15	750
2	Assembly loose	60	20	1200
3	Speaker output	20	15	300
4	Scratches on the cover	30	2	60
5	Loose knobs	10	10	100
6	Packaging issues	40	5	200

Pareto by Cost

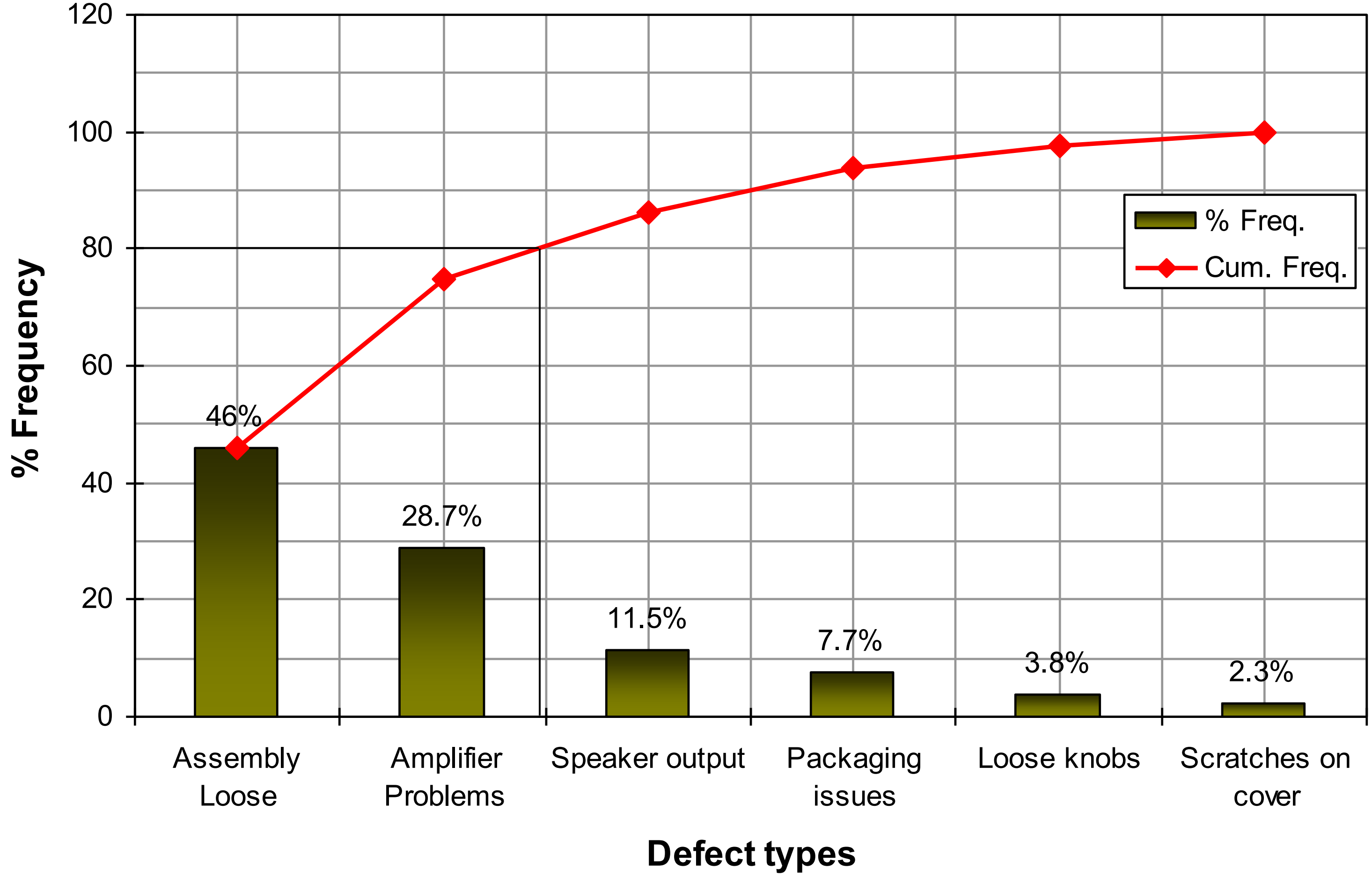
Step 1: Arrange data in descending order

Step 2: Calculate % frequency and cumulative frequency

Sr. No.	Defect Types	Cost	% Freq.	% Cum. Freq.
1	Assembly loose	1200	46%	46%
2	Amplifier problems	750	28.7%	74.7%
3	Speaker output	300	11.5%	86.2%
4	Packaging issues	200	7.7%	93.9%
5	Loose knobs	100	3.8%	97.7%
6	Scratches on the cover	60	2.3%	100%
	TOTAL	**2610**		

Pareto by Cost

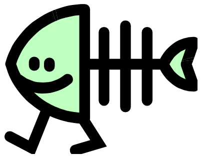
Step 3: Plot the chart and apply the Pareto Principle



Cause and Effect Diagram

Cause and Effect Diagram

- Uses brainstorming techniques to identify possible causes for a problem
- Also known as Ishikawa or the fishbone diagram



- The effect or the problem is placed on the right side of the bone and the causes are categorized on the left side under the 4Ms - Man, Method, Machine, Material

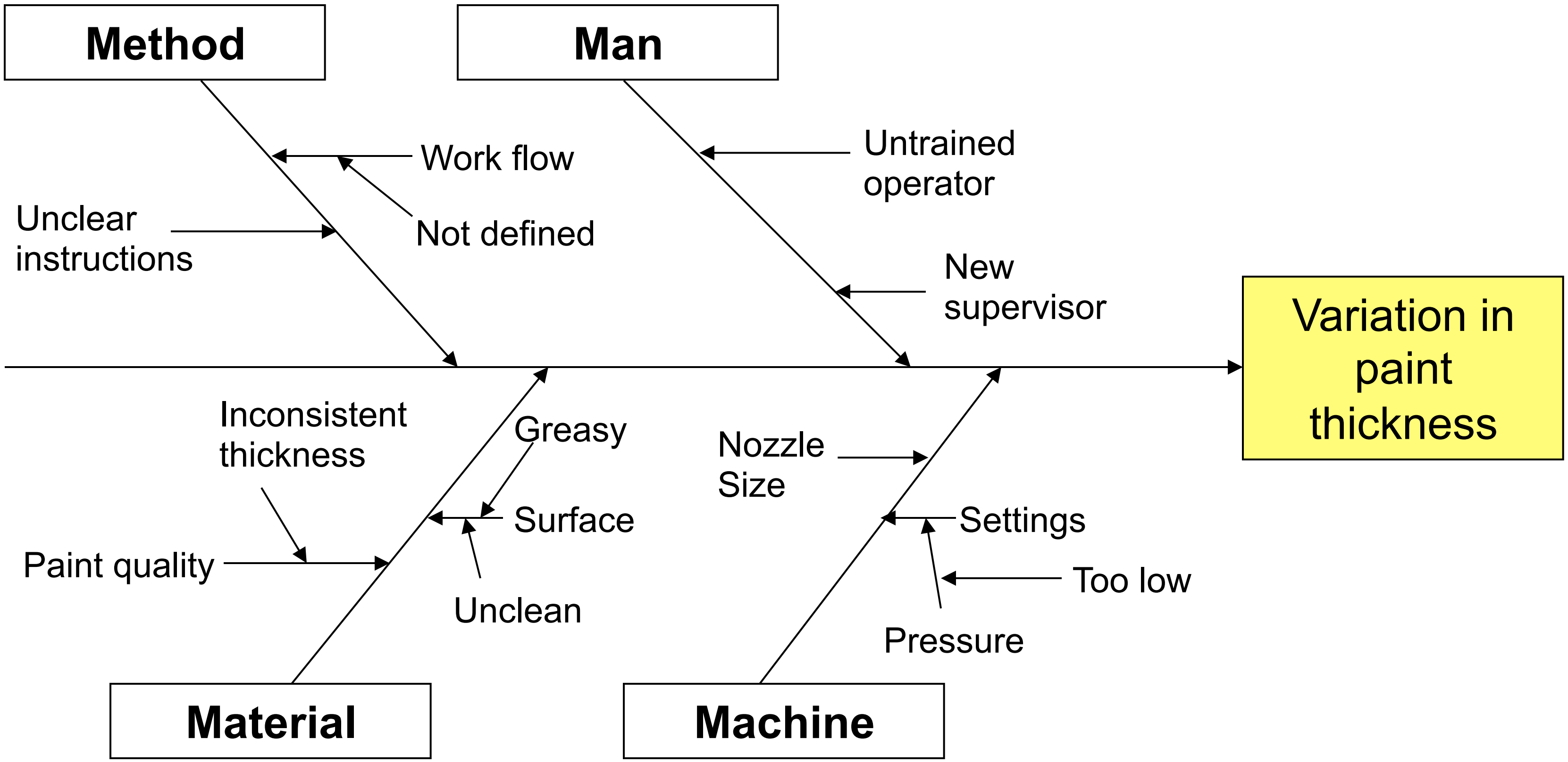
Cause and Effect Diagram

Steps for constructing a C&E diagram:

1. Form a team involving all people relevant to the problem
2. Brainstorm and list down all possible causes of the problem

3. Arrange the causes and sub causes under the 4Ms
4. Team members rank the causes
5. The top 3 causes are listed on the fishbone diagram

Cause and Effect Diagram



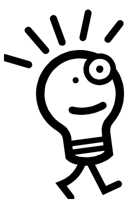
Cause and Effect Diagram

<u>Advantages</u>

- Useful for initial brainstorming
- Using the inputs from the team, helps list and categorize all possible causes of the problem

<u>Disadvantages</u>

- Tends to be too simplistic or too detailed



Useful Tips

✓ Update the fishbone diagram with new ideas even after it is constructed

✓ During brainstorming, encourage active participation from all team members

Cause and Effect Diagram: Exercise

Cause and Effect Diagram: Exercise

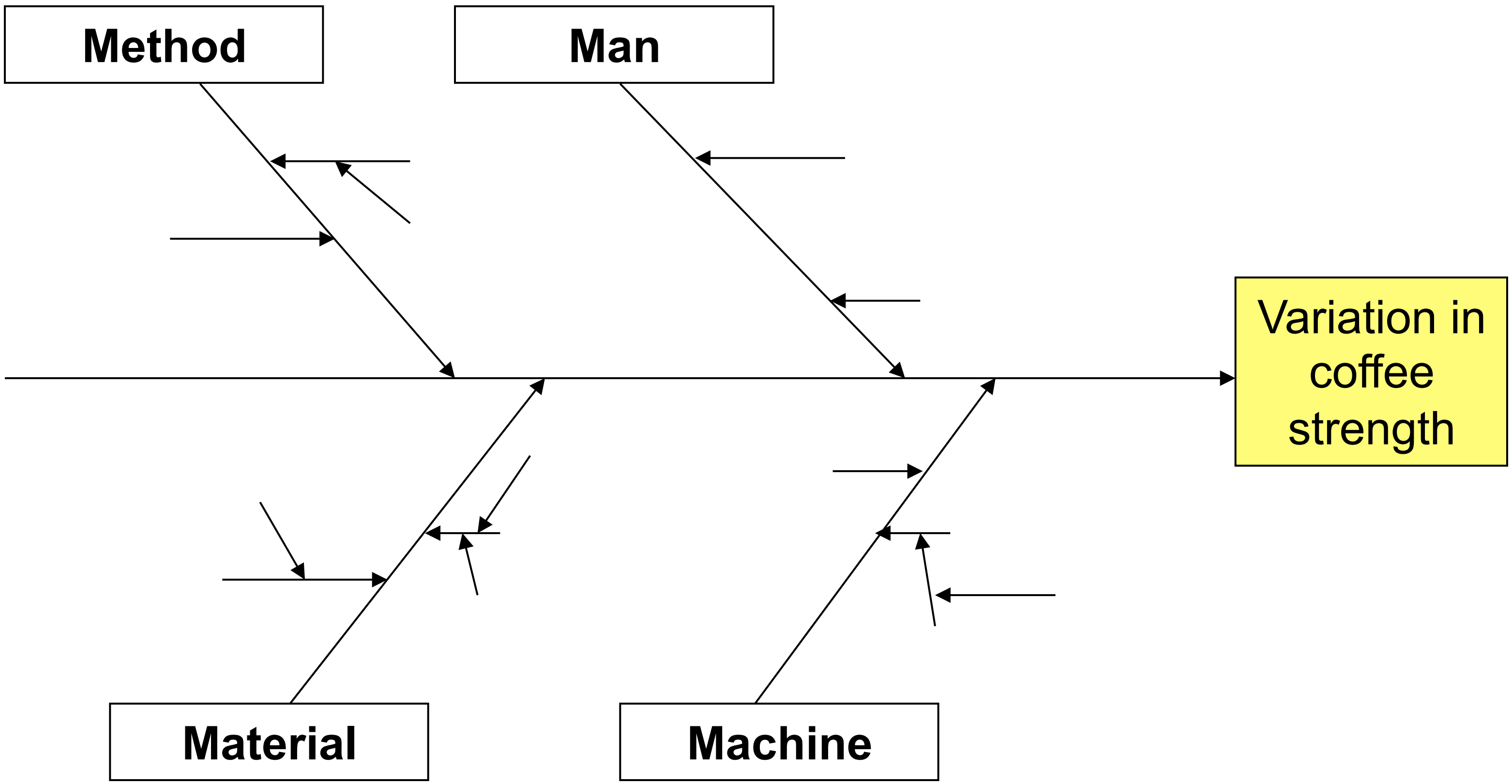
Process: Making a cup of coffee

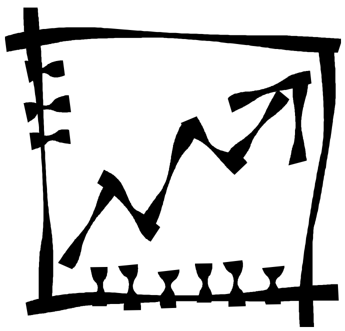
Project: Variation in coffee – sometimes strong coffee, sometimes not.

Brainstorm all possible causes and create a fishbone diagram.

Rank the causes and find the top three causes.

Cause and Effect Diagram





Control Charts

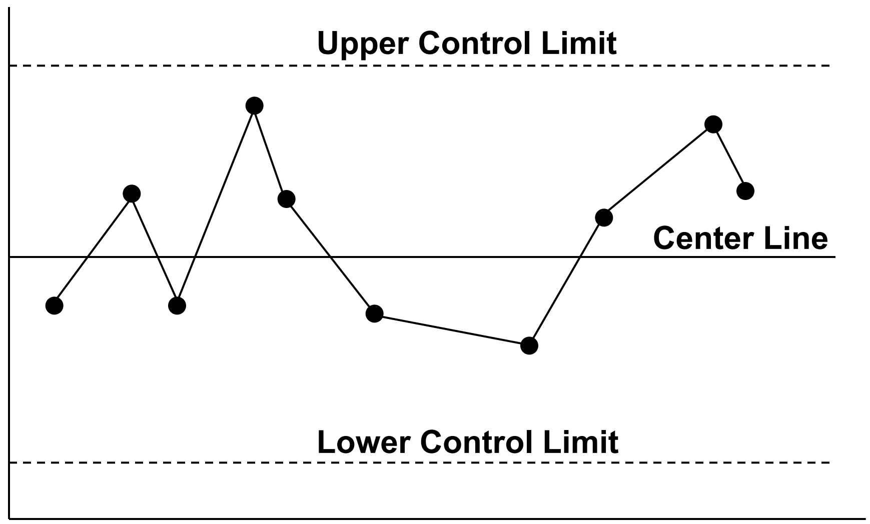
Control Charts

Common and assignable causes

- Common causes are inherent variations that are naturally part of the process. These variations are random in nature. Eg. Voltage fluctuations, environment changes, etc.

- An Assignable cause is a non-random variation that does not occur by chance. If an assignable cause is detected, the process should be looked at more closely and the source identified. Eg. Quality of raw material, changes in machine settings, etc.

What are Control Charts?



- Used for monitoring and controlling ongoing processes
- Used to find out whether the process is in control or not
- Helps determine when an assignable cause has come into play and the process needs to be analyzed
- Also called Shewhart charts after Walter Shewhart who developed these charts in the 1920s.

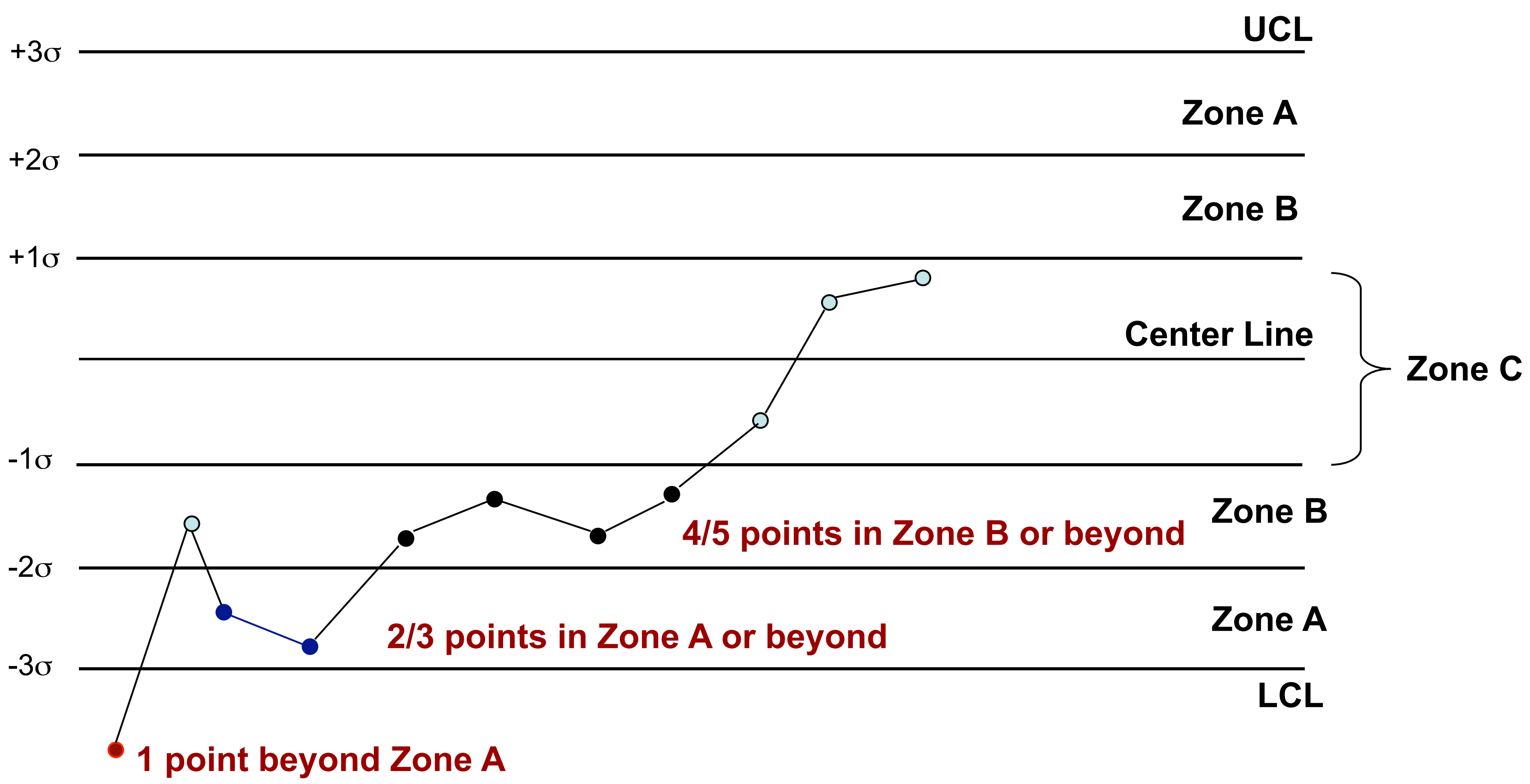
Control Charts

“Out of control” process indicators

- A single point going beyond either the lower or upper control limits
- Run – 7 consecutive points continuously increasing or decreasing.
- Other Patterns : Trends, Mixture, Stratification

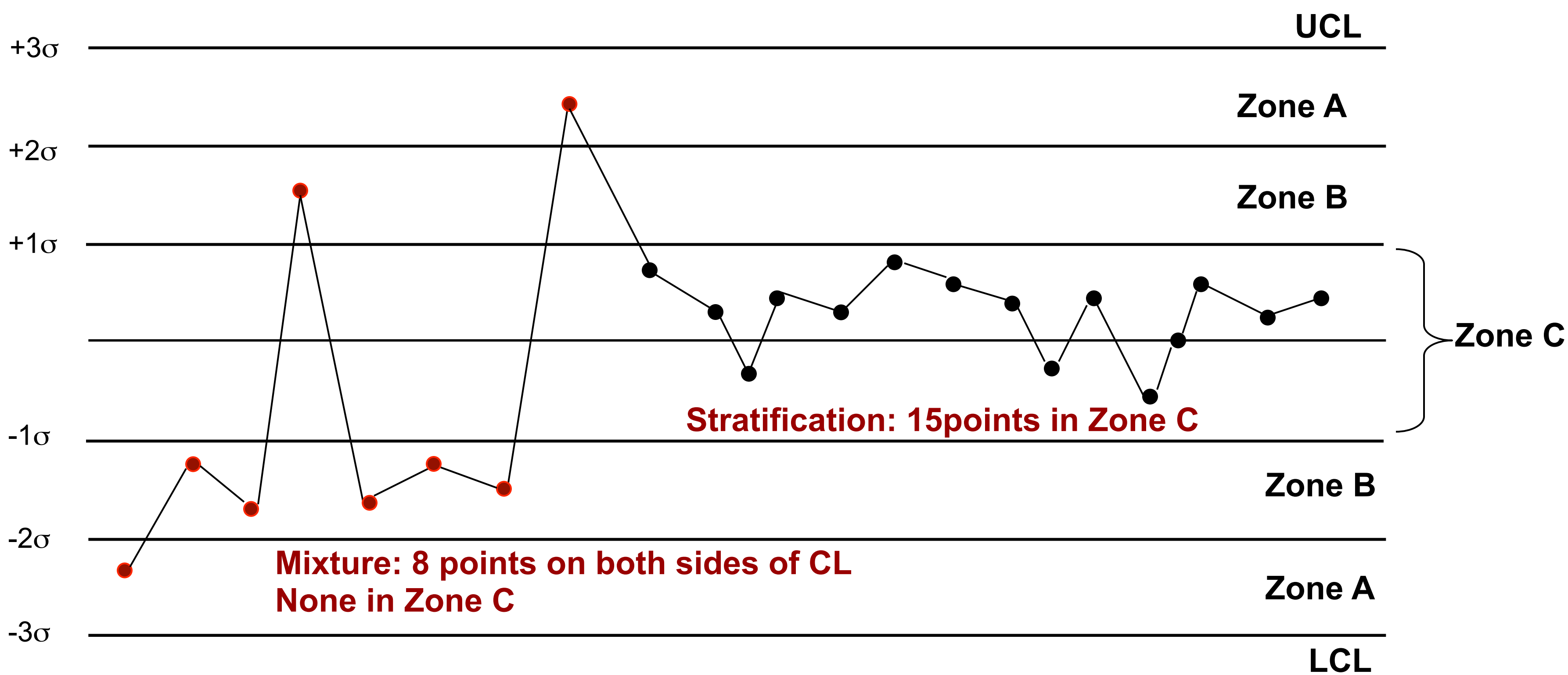
“Out of control” Process Indicators

Western Electric Rules



“Out of control” Process Indicators

Western Electric Rules



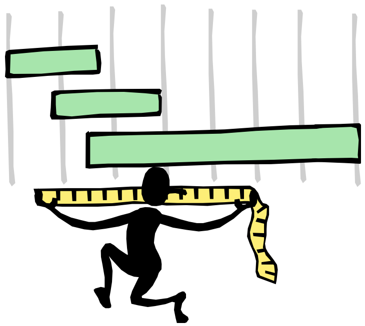
Control and Specification Limits

Control limits	Specification limits
• Calculated on the process data for $\pm 3\sigma$ • A point out of the control limits indicates that the process is out of control	• Directly from the tolerance for the parameter • A point out of the specification limits indicates that the part is out of tolerance

Data Types

- Variable – Measurements

  Eg. Weight, length etc.



- Attribute – Counts

  Eg. Pass/fail, good/bad

Control Charts

Types of Control charts

Variable	Attribute
• Xbar - R • Xbar - S • X - MR	• p • np • c • u

100% Inspection, Sampling and No Inspection

100% Inspection	Sampling	No Inspection
• Inspect every part that is produced	• Inspect a sample from the quantity produced	• Do not inspect at all
• Costly as it requires more time/effort	• Economical	• No cost at all

Count the Number of Fs in the Paragraph

(I)
FINISHED FILES ARE THE RESULT OF YEARS OF SCIENTIFIC STUDY COMBINED WITH THE EXPERIENCE OF YEARS

(II)
FOR CENTURIES IMPORTANT PROJECTS HAVE BEEN DEFERRED BY WEEKS OF INDECISION AND MONTHS OF STUDY AND YEARS OF FORMAL DEBATE.

Variable Control Charts

Subgroup size

- The number of parts measured at the predetermined frequency.

  Examples

  - 5 readings for temp. every batch

  - 3 readings for height every hour

Variable Control Charts

Xbar-R	Subgroup size less than or equal to 7
Xbar-S	Subgroup size more than 7
X-MR	Subgroup size equal to 1

Xbar – R Chart: Example

Xbar – R Chart: Example

The diameter of 5 pencils is measured every 30min.

The specifications are 6.7 ± 0.5mm

Plot an Xbar-R chart for the readings for last 4hours.

Xbar – R Chart: Example

Time	Subgroup	X1	X2	X3	X4	X5
9am	1	6.7	6.6	6.7	6.5	6.4
9:30am	2	6.8	6.7	6.8	6.8	6.6
10am	3	6.6	6.5	6.6	6.5	6.4
10:30am	4	6.5	6.5	6.6	6.7	6.4
11am	5	6.6	6.6	6.7	6.8	6.8
11:30am	6	6.7	6.7	6.8	6.9	6.7
12noon	7	6.8	6.7	6.8	6.8	6.8
12:30pm	8	6.9	6.8	6.9	6.7	6.8

Step 1: Calculate the Xbar and R values for each subgroup

Subgroup	X1	X2	X3	X4	X5	$\bar{X}$	R
1	6.7	6.6	6.7	6.5	6.4	**6.58**	**0.3**
2	6.8	6.7	6.8	6.8	6.6	**6.74**	**0.2**
3	6.6	6.5	6.6	6.5	6.4	**6.52**	**0.2**
4	6.5	6.5	6.6	6.7	6.4	**6.54**	**0.3**
5	6.6	6.6	6.7	6.8	6.8	**6.70**	**0.2**
6	6.7	6.7	6.8	6.9	6.7	**6.76**	**0.2**
7	6.8	6.7	6.8	6.8	6.8	**6.78**	**0.1**
8	6.9	6.8	6.9	6.7	6.8	**6.82**	**0.2**

Step 2: Calculate the $\bar{\bar{X}}$ and $\bar{R}$ values

$\bar{\bar{X}} = 6.68$ $\bar{R} = 0.2$

Step 3: Calculate the control limits

For $\bar{X}$ chart

UCL = $\bar{\bar{X}} + A_2\bar{R} = 6.68+0.577(0.2) =$ **6.79**

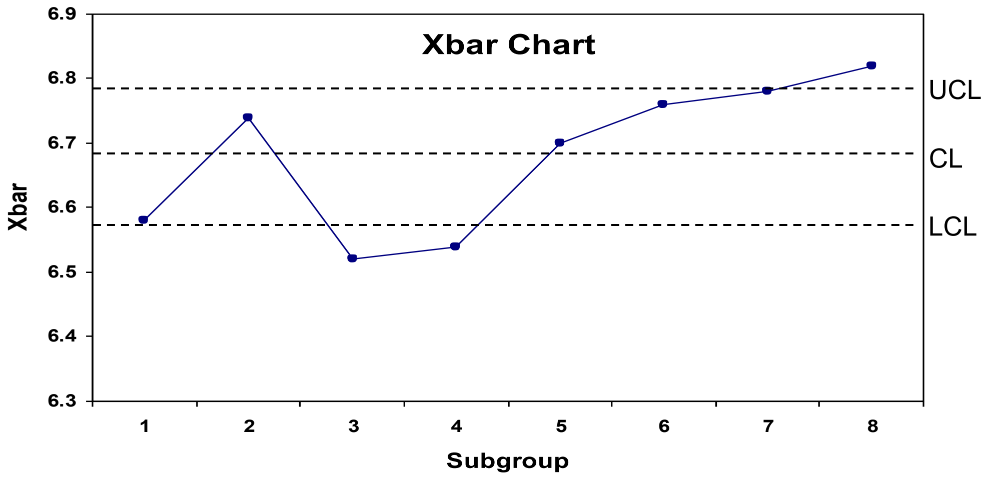
LCL = $\bar{\bar{X}} - A_2\bar{R} = 6.68-0.577(0.2) =$ **6.56**

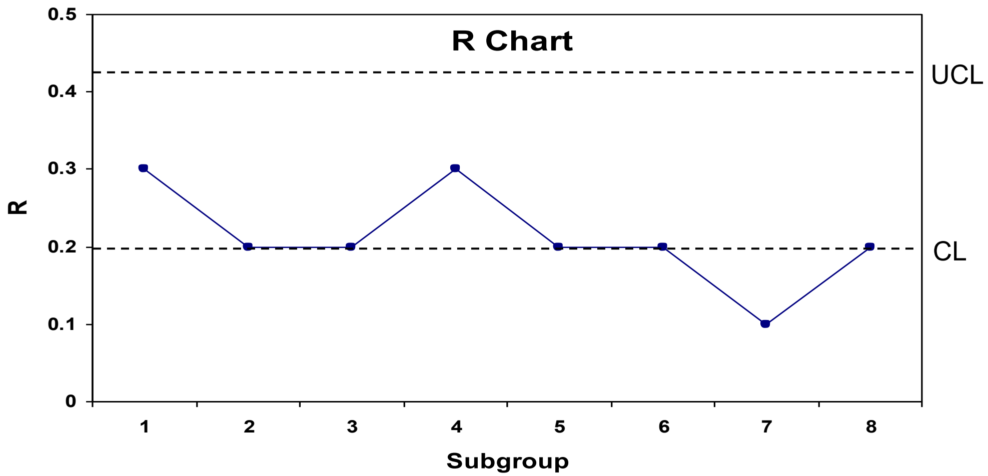
For R chart

UCL = $D_4\bar{R} = 2.114(0.2) =$ **0.42**

LCL = $D_3\bar{R} =$ **---**

Step 4: Plot and interpret the charts





Xbar chart

1) Readings for subgroup 3 and 4 are beyond the LCL
2) Readings for subgroup 8 is beyond the UCL

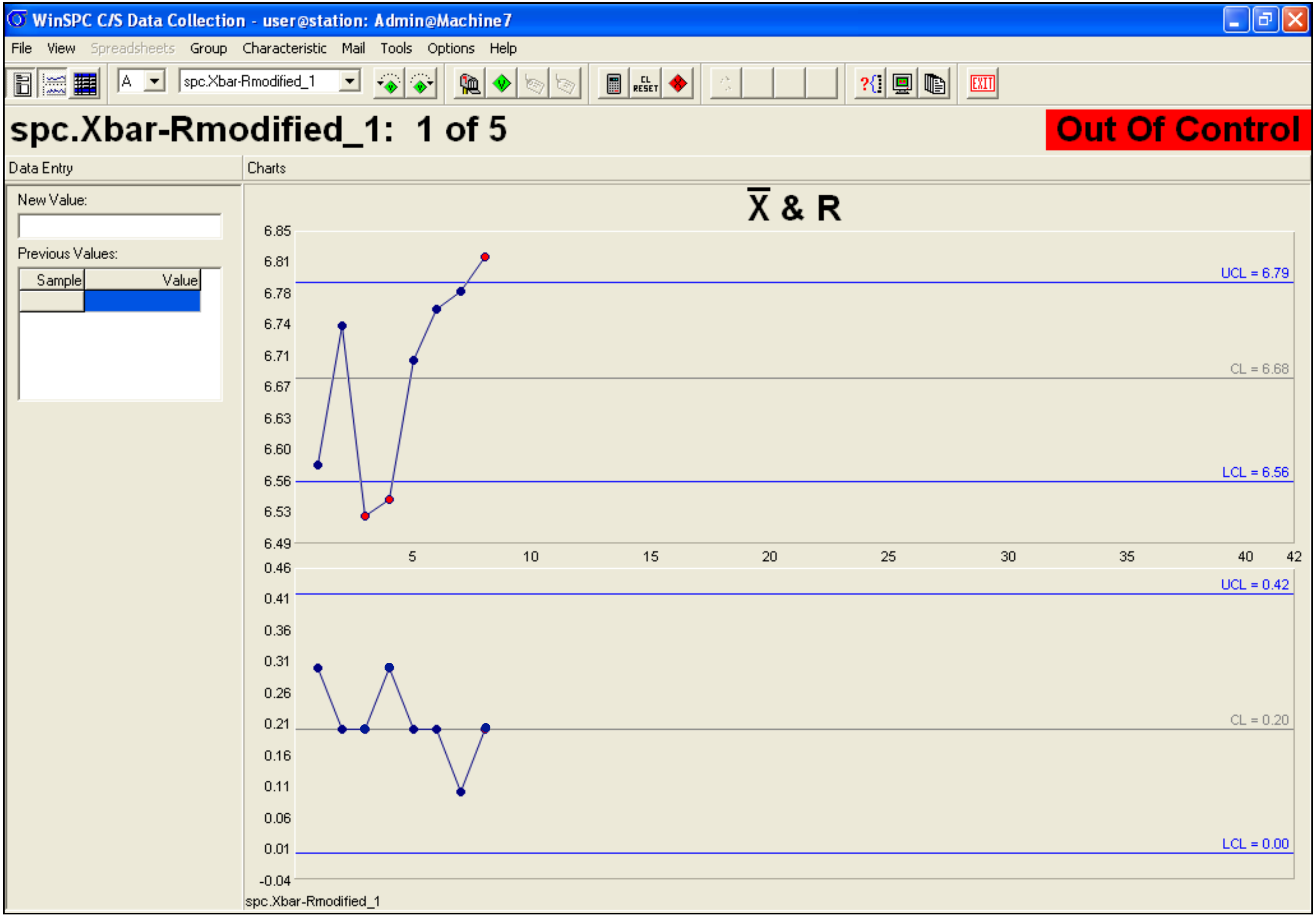
R chart

1) All points within control limits and varying randomly about the CL

Process is out of control.

Look for assignable causes.

Xbar – R Chart from WinSPC



Exercise: Xbar – R Chart

Exercise: Xbar – R Chart

The sound output of 4 radios is measured every hour.

The specifications are 80 ± 10db

Plot an Xbar-R chart for the readings for last 10hours.

Exercise: Xbar – R Chart

Time	Subgroup	X1	X2	X3	X4
9am	1	80	80	85	80
10am	2	75	75	70	80
11am	3	75	80	75	90
12noon	4	90	85	90	90
1pm	5	80	90	85	80
2pm	6	80	80	85	80
3pm	7	90	90	80	90
4pm	8	80	80	80	80
5pm	9	85	85	90	90
6pm	10	90	90	90	90

Step 1: Calculate the Xbar and R values for each subgroup

Subgroup	X1	X2	X3	X4	$\bar{X}$	R
1	80	80	85	80		
2	75	75	70	80		
3	75	80	75	90		
4	90	85	90	90		
5	80	90	85	80		
6	80	80	85	80		
7	90	90	80	90		
8	80	80	80	80		
9	85	85	90	90		
10	90	90	90	90		

Step 2: Calculate the $\bar{\bar{X}}$ and $\bar{R}$ values

$\bar{\bar{X}}$ = **$\bar{R}$ =**

Step 3: Calculate the control limits

Statistical constants for subgroup size = 4
A_2 = 0.729 D_3 = -- D_4 = 2.282

For $\bar{X}$ chart

UCL = $\bar{\bar{X}} + A_2\bar{R}$ =

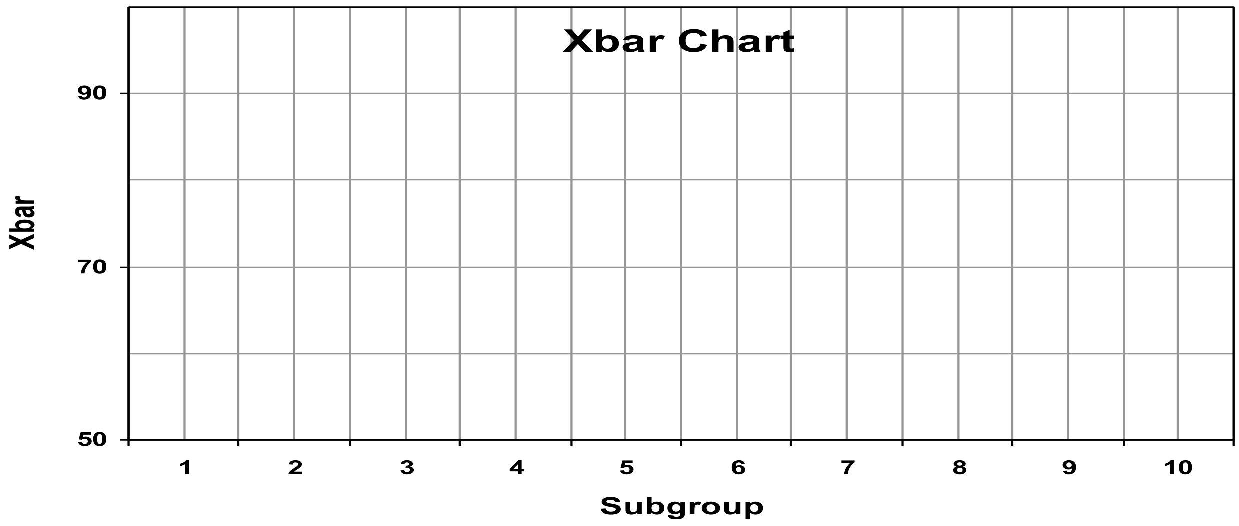
LCL = $\bar{\bar{X}} - A_2\bar{R}$ =

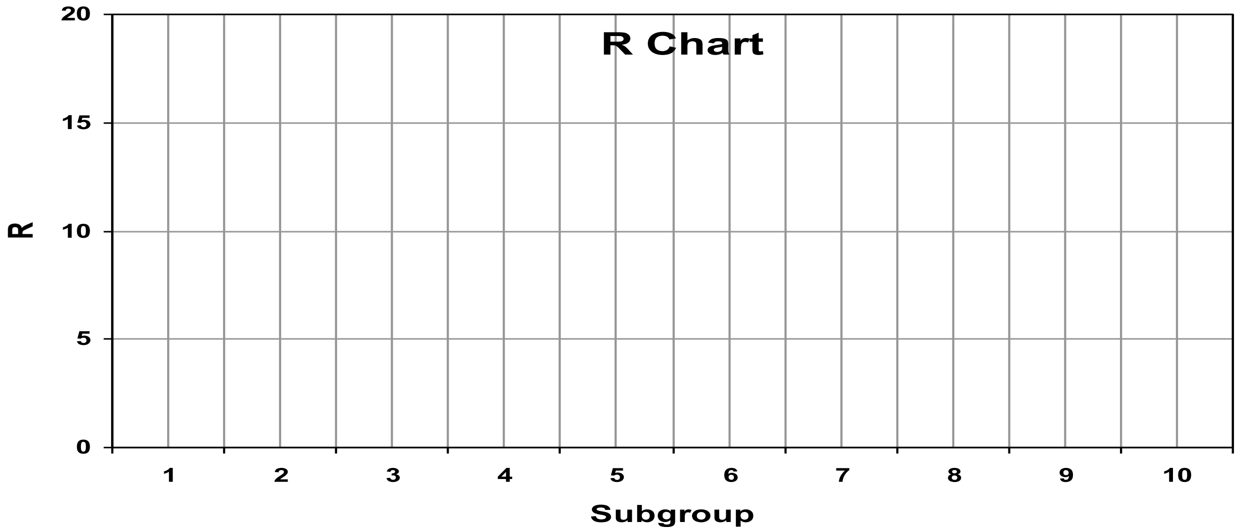
For R chart

UCL = $D_4\bar{R}$ =

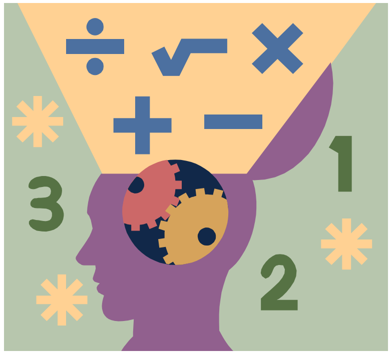
LCL = $D_3\bar{R}$ =

Step 4: Plot and interpret the charts





Xbar – R Chart : Solution



Step 1: Calculate the Xbar and R values for each subgroup

Subgroup	X1	X2	X3	X4	$\bar{X}$	R
1	80	80	85	80	81.3	5
2	75	75	70	80	75.0	10
3	75	80	75	90	80.0	15
4	90	85	90	90	88.8	5
5	80	90	85	80	83.8	10
6	80	80	85	80	81.3	5
7	90	90	80	90	87.5	10
8	80	80	80	80	80.0	0
9	85	85	90	90	87.5	5
10	90	90	90	90	90.0	0

Step 2: Calculate the $\bar{\bar{X}}$ and $\bar{R}$ values

$\bar{\bar{X}}$ **= 83.5** $\bar{R}$ **= 6.5**

Step 3: Calculate the control limits

Statistical constants for subgroup size = 4
A_2 = 0.729 D_3 = -- D_4 = 2.282

For $\bar{X}$ chart

UCL = $\bar{\bar{X}} + A_2\bar{R} = 88.24$

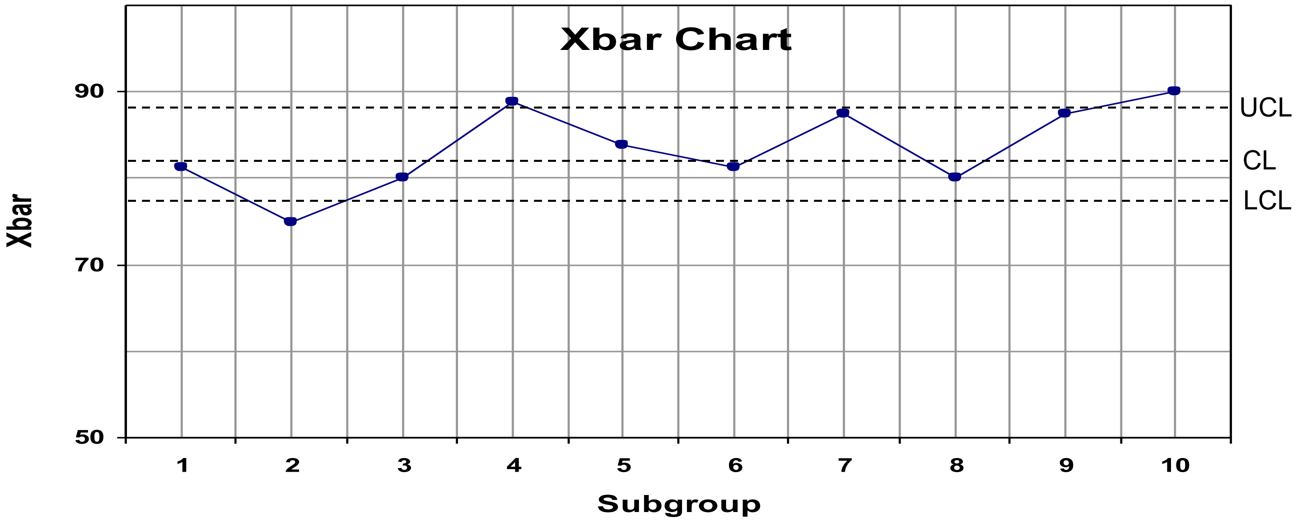
LCL = $\bar{\bar{X}} - A_2\bar{R} = 78.76$

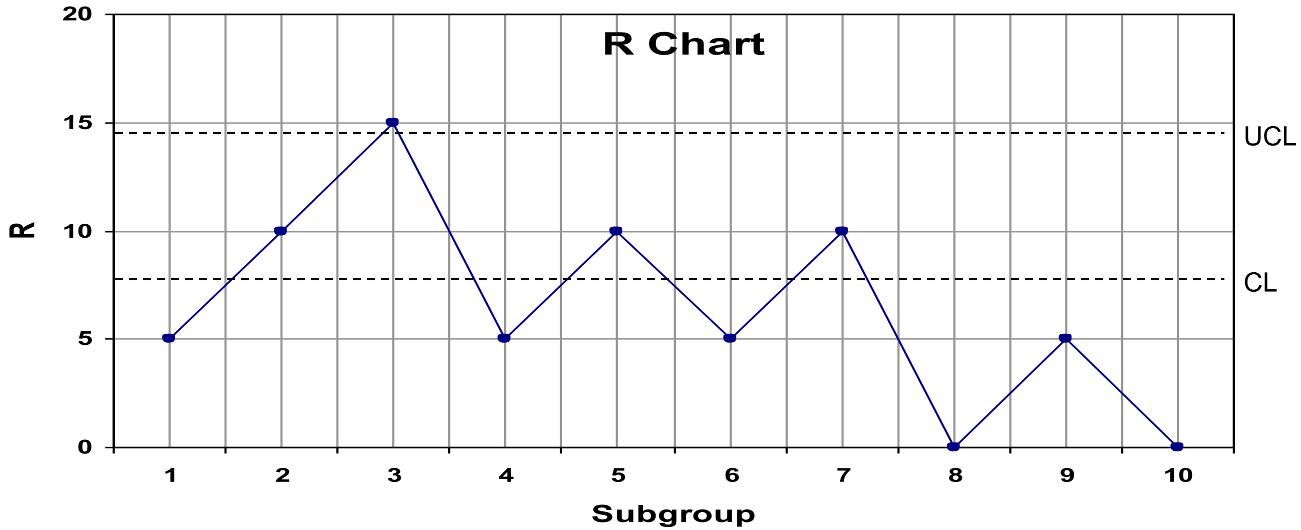
For R chart

UCL = $D_4\bar{R} = 14.83$

LCL = $D_3\bar{R}$ = ---

Step 4: Plot and interpret the charts





<u>Xbar Chart</u>

Point for subgroup 2 is out of LCL.

Point for subgroup 4 and 10 are out of UCL.

<u>R chart</u>

Point for subgroup 3 is out of UCL.

Process is out of control.

X – MR Chart: Example

X – MR Chart: Example

The diameter of a pencil is measured every lot.

The specifications are 6.7 ± 0.5mm

Plot X-MR chart for the last 10 lots.

X – MR Chart: Example

Lot	X
1	6.8
2	6.9
3	6.6
4	6.5
5	6.7
6	6.4
7	6.8
8	6.2
9	6.6
10	6.7

Step 1: Calculate the MR values

Lot	X	MR
1	6.8	-
2	6.9	$\|6.9 - 6.8\| = 0.1$
3	6.6	$\|6.6 - 6.9\| = 0.3$
4	6.5	$\|6.5 - 6.6\| = 0.1$
5	6.7	$\|6.7 - 6.5\| = 0.2$
6	6.4	$\|6.4 - 6.7\| = 0.3$
7	6.8	$\|6.8 - 6.4\| = 0.4$
8	6.2	$\|6.2 - 6.8\| = 0.6$
9	6.6	$\|6.6 - 6.2\| = 0.4$
10	6.7	$\|6.7 - 6.6\| = 0.1$

Step 2: Calculate the $\overline{X}$ and $\overline{MR}$ values

$\overline{X} = 6.6$ $\overline{MR} = 0.3$

Step 3: Calculate the control limits

For X chart

UCL = $\overline{X} + E_2\overline{MR} = 6.6+2.66(0.3) =$ **7.4**

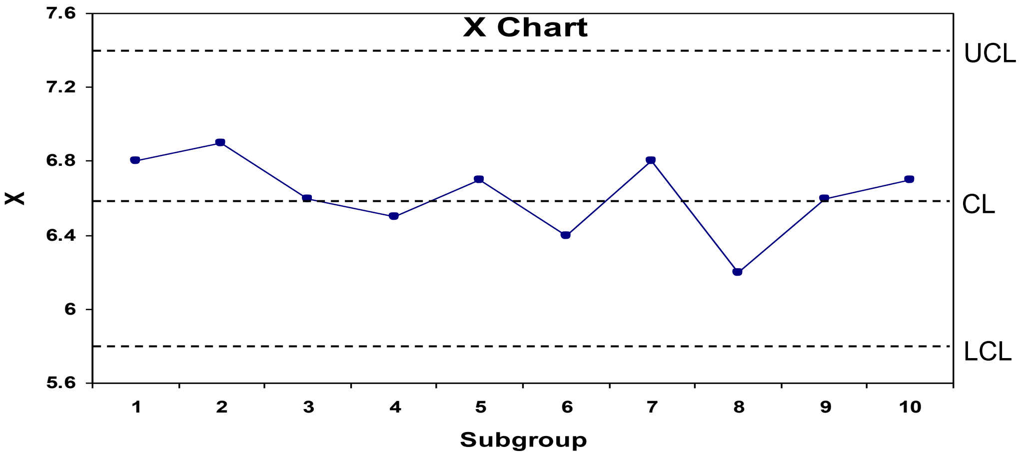
LCL = $\overline{X} - E_2\overline{MR} = 6.6-2.66(0.3) =$ **5.8**

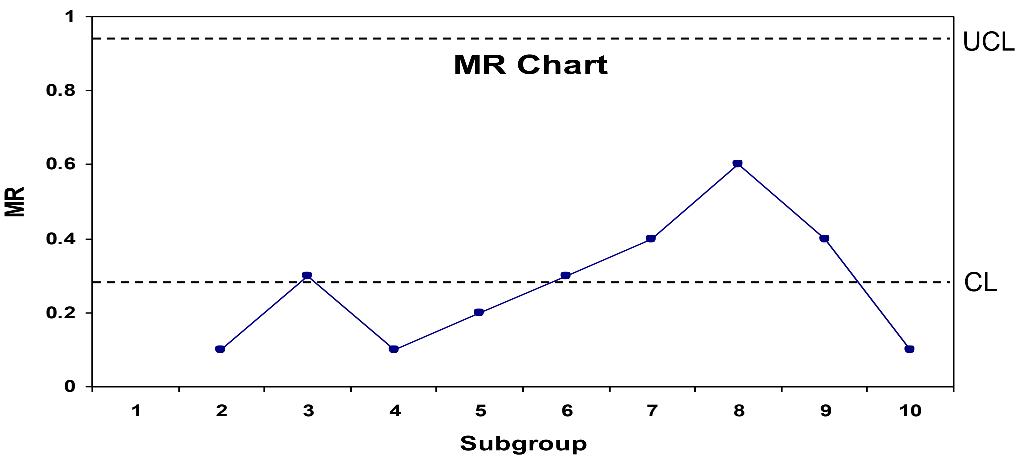
For MR chart

UCL = $D_4\overline{MR} = 3.267(0.3) =$ **0.98**

LCL = $D_3\overline{MR} =$ **---**

Step 4: Plot and interpret the charts





X chart

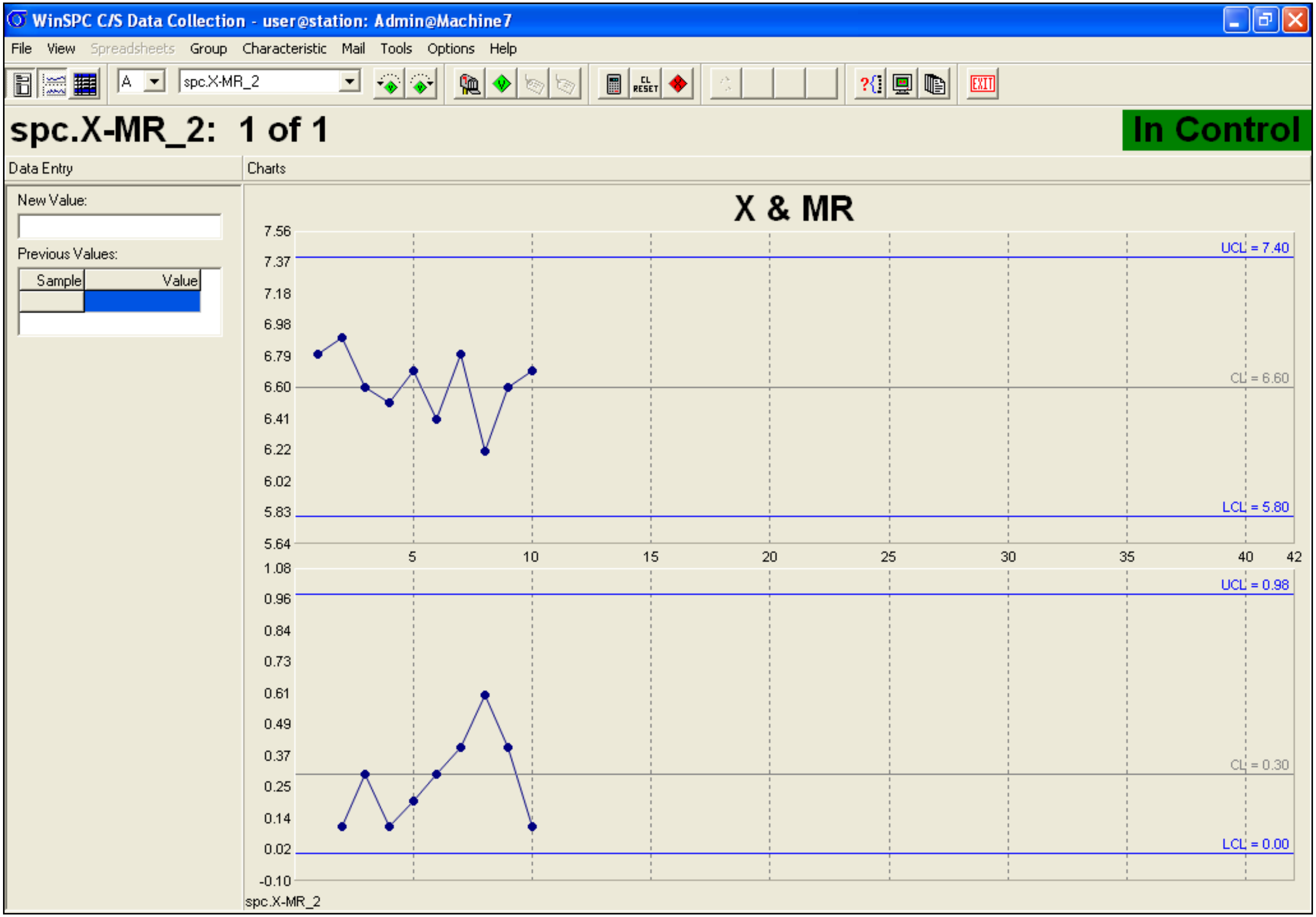
1) All points within control limits and randomly varying about the CL

MR chart

1) All points within control limits and randomly varying about the CL

Process is in control.

X-MR Chart from WinSPC



Exercise: X – MR Chart

Exercise: X – MR Chart

The sound output of 1 radio is measured every hour.

The specifications are 80 ± 10db

Plot X-MR chart for the last 10 hours.

Exercise: X – MR Chart

Subgroup	Time	X
1	8am	85
2	9am	88
3	10am	90
4	11am	92
5	Noon	83
6	1pm	92
7	2pm	91
8	3pm	90
9	4pm	70
10	5pm	75

Step 1: Calculate the MR values

Subgroup	X	MR
1	85	-
2	88	
3	90	
4	92	
5	83	
6	92	
7	91	
8	90	
9	70	
10	75	

Step 2: Calculate the $\overline{X}$ and $\overline{MR}$ values

$\overline{X}$ = **$\overline{MR}$ =**

Step 3: Calculate the control limits

Values for $E_2 = 2.66$ $D_3 = --$ $D_4 = 3.267$ for subgroup size 1

For X chart

UCL = $\overline{X} + E_2\overline{MR} =$

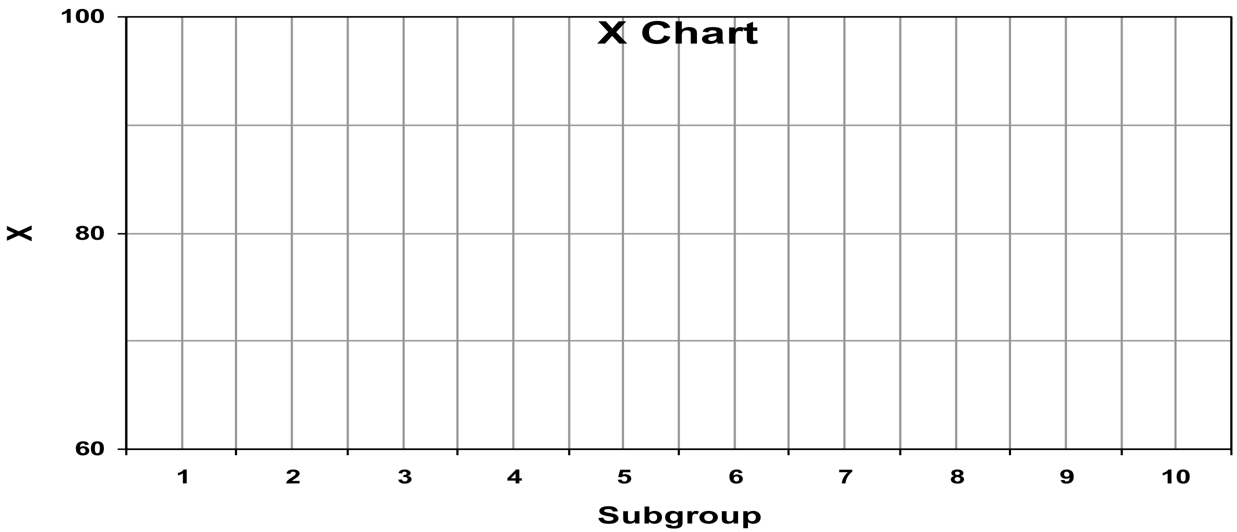
LCL = $\overline{X} - E_2\overline{MR} =$

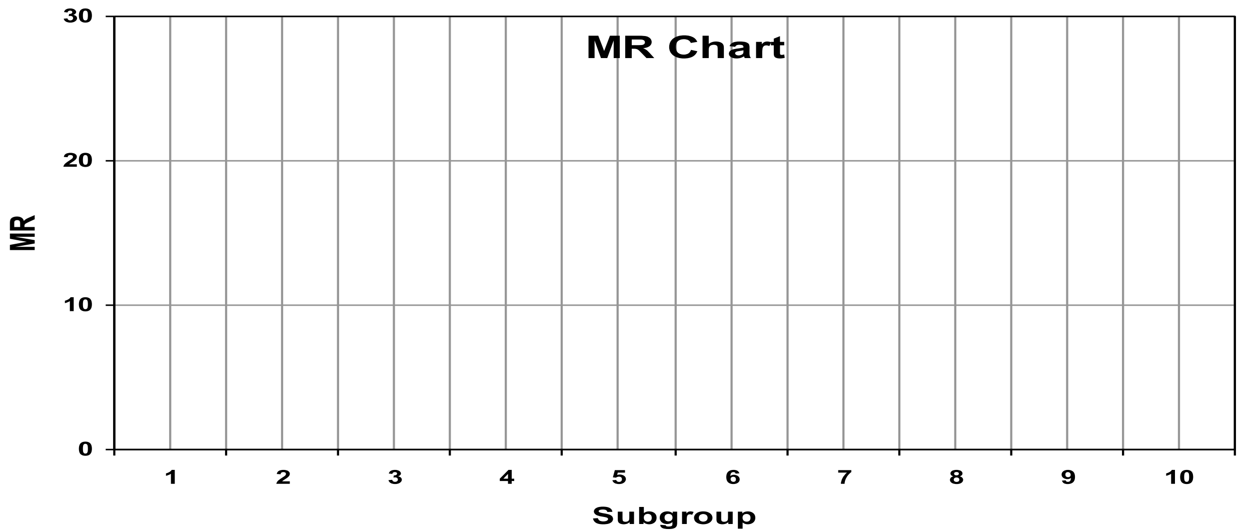
For MR chart

UCL = $D_4\overline{MR} =$

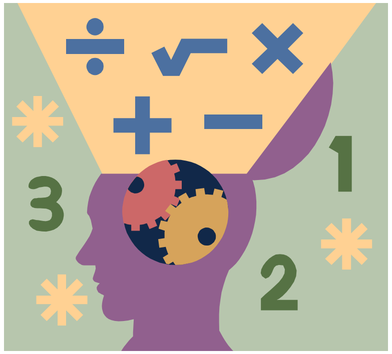
LCL = $D_3\overline{MR} =$ **---**

Step 4: Plot and interpret the charts





X – MR Chart : Solution



Step 1: Calculate the MR values

Subgroup	X	MR
1	85	-
2	88	3
3	90	2
4	92	2
5	83	9
6	92	9
7	91	1
8	90	1
9	70	20
10	75	5

Step 2: Calculate the $\overline{X}$ and $\overline{MR}$ values

$\overline{X} = 85.6$ $\overline{MR} = 5.78$

Step 3: Calculate the control limits

Values for $E_2 = 2.66$ $D_3 = --$ $D_4 = 3.267$ for subgroup size 1

For X chart

UCL = $\overline{X} + E_2\overline{MR} = 101$

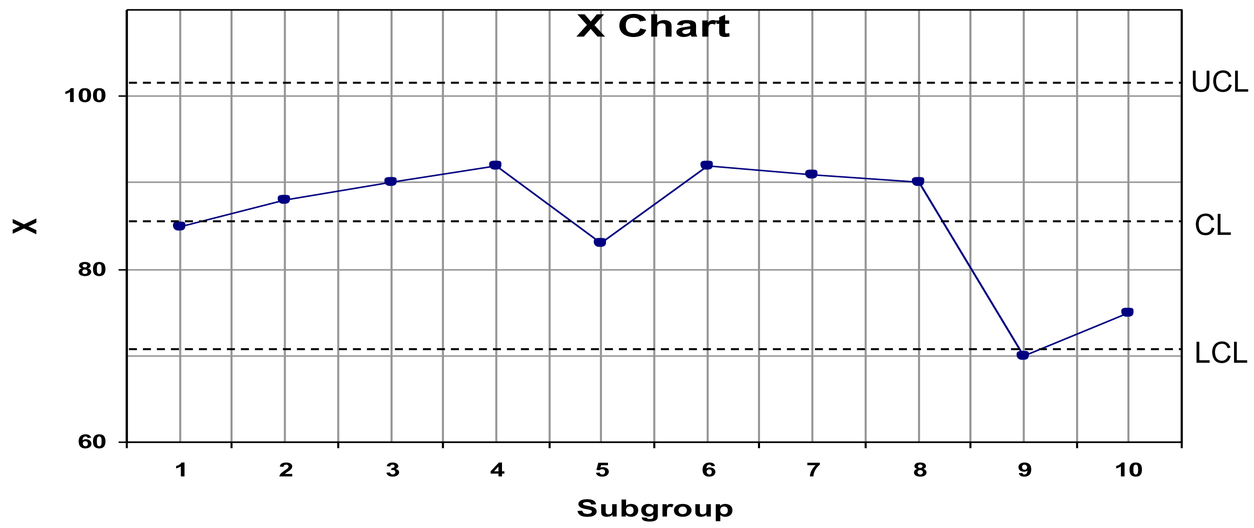
LCL = $\overline{X} - E_2\overline{MR} = 70.2$

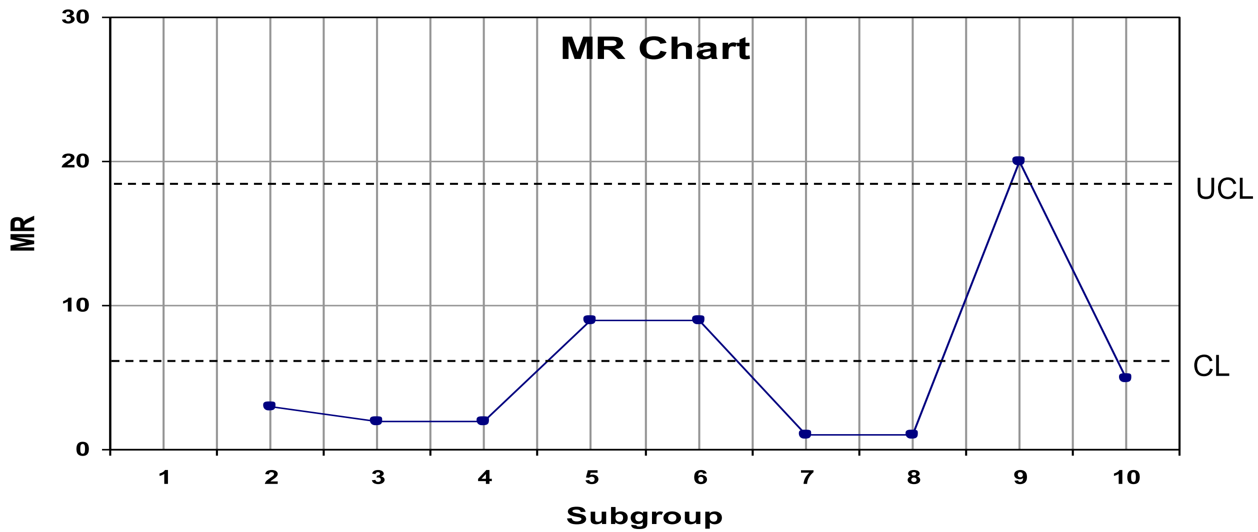
For MR chart

UCL = $D_4\overline{MR} = 18.9$

LCL = $D_3\overline{MR} =$ **---**

Step 4: Plot and interpret the charts





<u>X chart</u>
Point for subgroup 9 is out of LCL.

<u>MR chart</u>
The point for subgroup 9 is out of UCL.

The process is out of control.
Look for changes in the process around subgroup 9
as the measurement for sound output is too low.

Attribute Control Charts

Attribute Control Charts

	Defects	Defectives
Varying	u	p
Constant	c	np

p Chart: Example

p Chart: Example

Everyday, the number of defective pencils is counted from an inspection lot size of 50.

Plot a p chart for the last 10 days data.

p Chart: Example

Date	Number defectives	Quantity inspected
1/1/06	14	50
1/2/06	8	50
1/3/06	7	50
1/4/06	10	50
1/5/06	12	50
1/6/06	3	50
1/7/06	9	50
1/8/06	7	50
1/9/06	4	50
1/10/06	0	50

Step 1: Calculate the p values

Lot	Number defectives	Quantity inspected	p
1	14	50	=14/50 = 0.28
2	8	50	=8/50 = 0.16
3	7	50	=7/50 = 0.14
4	10	50	=10/50 = 0.2
5	12	50	=12/50 = 0.24
6	3	50	=3/50 = 0.06
7	9	50	=9/50 = 0.18
8	7	50	=7/50 = 0.14
9	4	50	=4/50 = 0.08
10	0	50	=0/50 = 0

Step 2: Calculate the $\bar{p}$ value

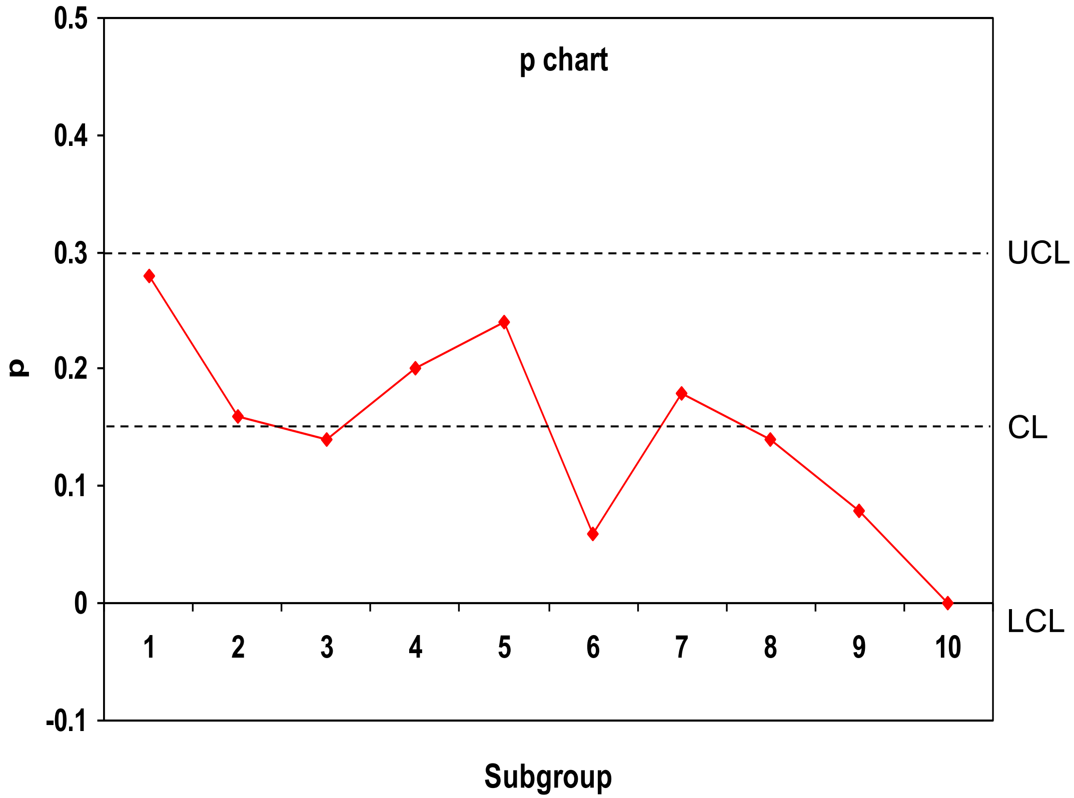
$\bar{p}$ **= 0.15**

Step 3: Calculate the control limits

$$\textbf{UCL} = \bar{p} + 3 \times \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.15 + 3 \times \sqrt{\frac{0.15(1-0.15)}{50}} = \mathbf{0.3}$$

$$\textbf{LCL} = \bar{p} - 3 \times \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.15 - 3 \times \sqrt{\frac{0.15(1-0.15)}{50}} = \mathbf{-0.003}$$

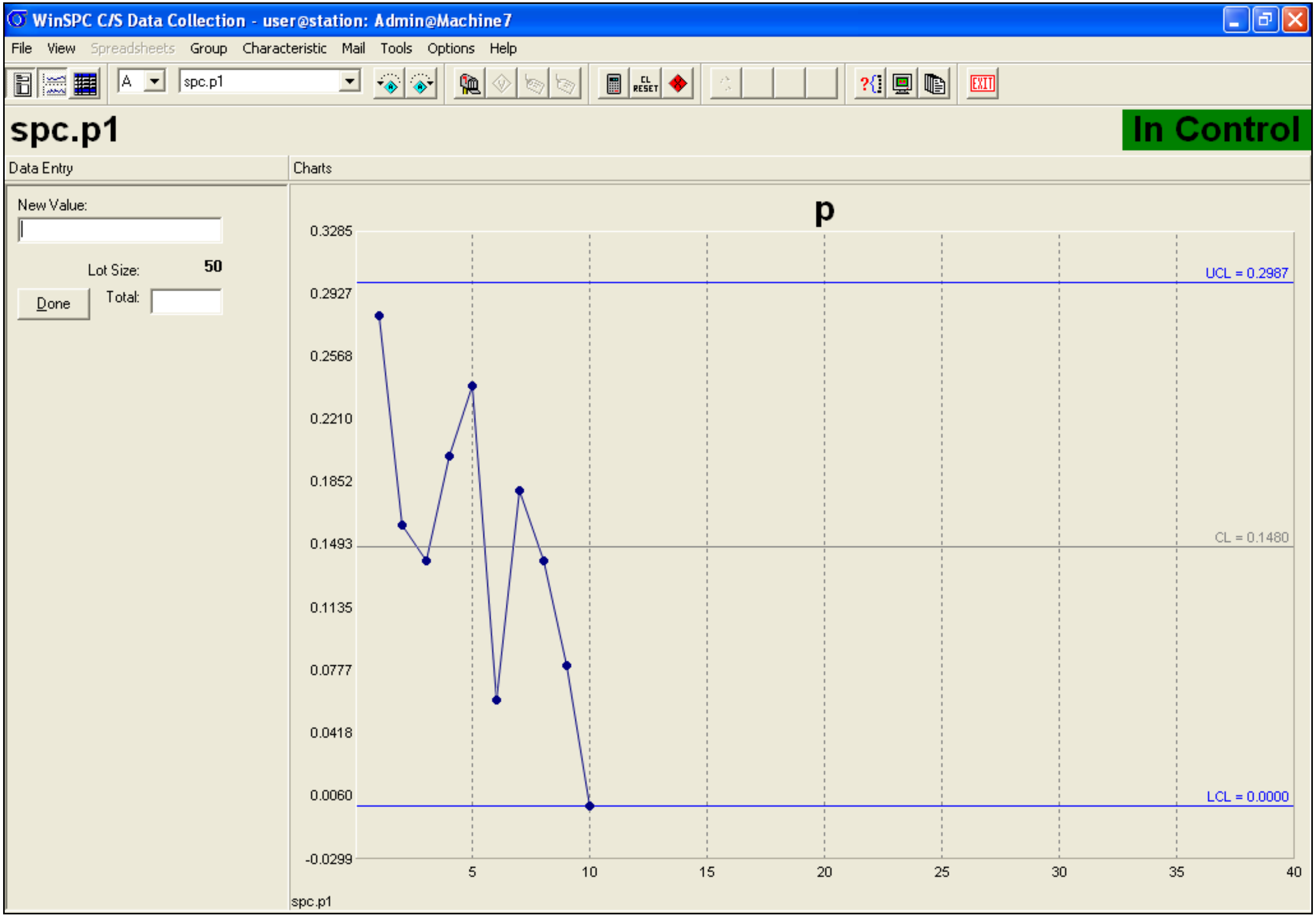
Step 4: Plot and interpret the chart



All points are within control limits.

The p values for subgroup 7-10 are decreasing
And subgroup 10 has
p = 0.
So the quality of the pencils is actually improving as there are no defectives.

p Chart from WinSPC



Exercise: p Chart

Exercise: p Chart

The number of defective radios is counted from an inspection lot of 20.

Plot a p chart for the last 10 lots.

Exercise: p Chart

Lot	Number defectives	Quantity inspected
121	3	20
122	4	20
123	1	20
124	0	20
125	0	20
126	5	20
127	6	20
128	8	20
129	5	20
130	4	20

Step 1: Calculate the p values

Subgroup	Number defectives	Quantity inspected	p
1	3	20	
2	4	20	
3	1	20	
4	0	20	
5	0	20	
6	5	20	
7	6	20	
8	8	20	
9	5	20	
10	4	20	

Step 2: Calculate the $\overline{p}$ value

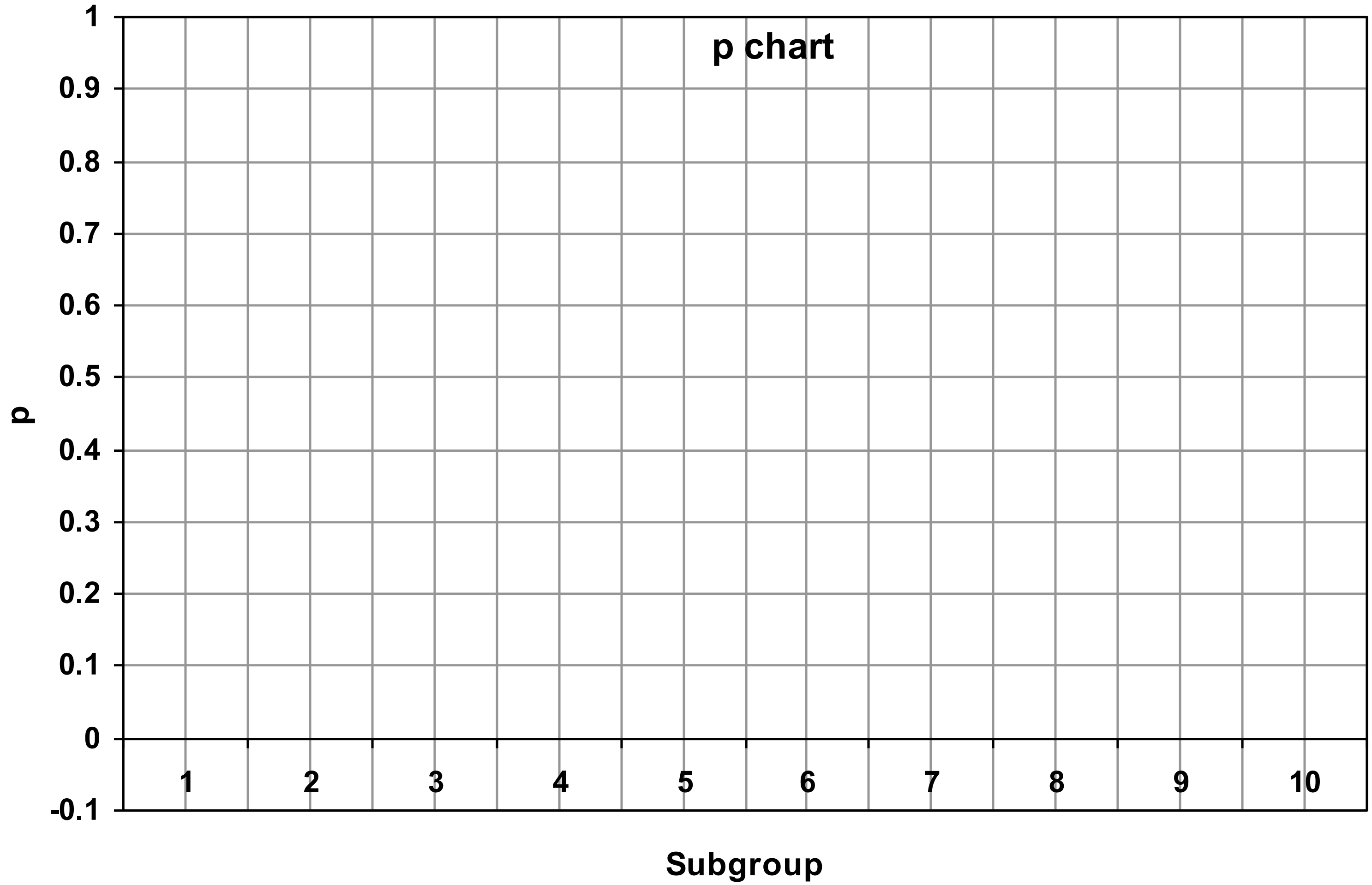
$\overline{p}$ =

Step 3: Calculate the control limits

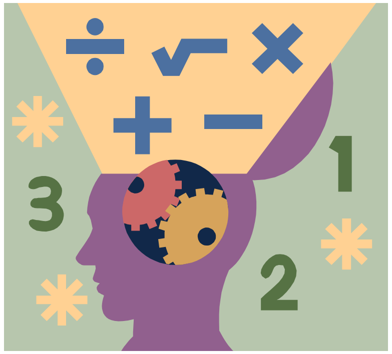
$$\text{UCL} = \overline{p} + 3 \times \sqrt{\frac{\overline{p}\,(1 - \overline{p})}{n}} =$$

$$\text{LCL} = \overline{p} - 3 \times \sqrt{\frac{\overline{p}\,(1 - \overline{p})}{n}} =$$

Step 4: Plot and interpret the chart



p Chart : Solution



Step 1: Calculate the p values

Subgroup	Number defectives	Quantity inspected	p
1	3	20	0.15
2	4	20	0.2
3	1	20	0.05
4	0	20	0
5	0	20	0
6	5	20	0.25
7	6	20	0.3
8	8	20	0.4
9	5	20	0.25
10	4	20	0.2

Step 2: Calculate the $\bar{p}$ value

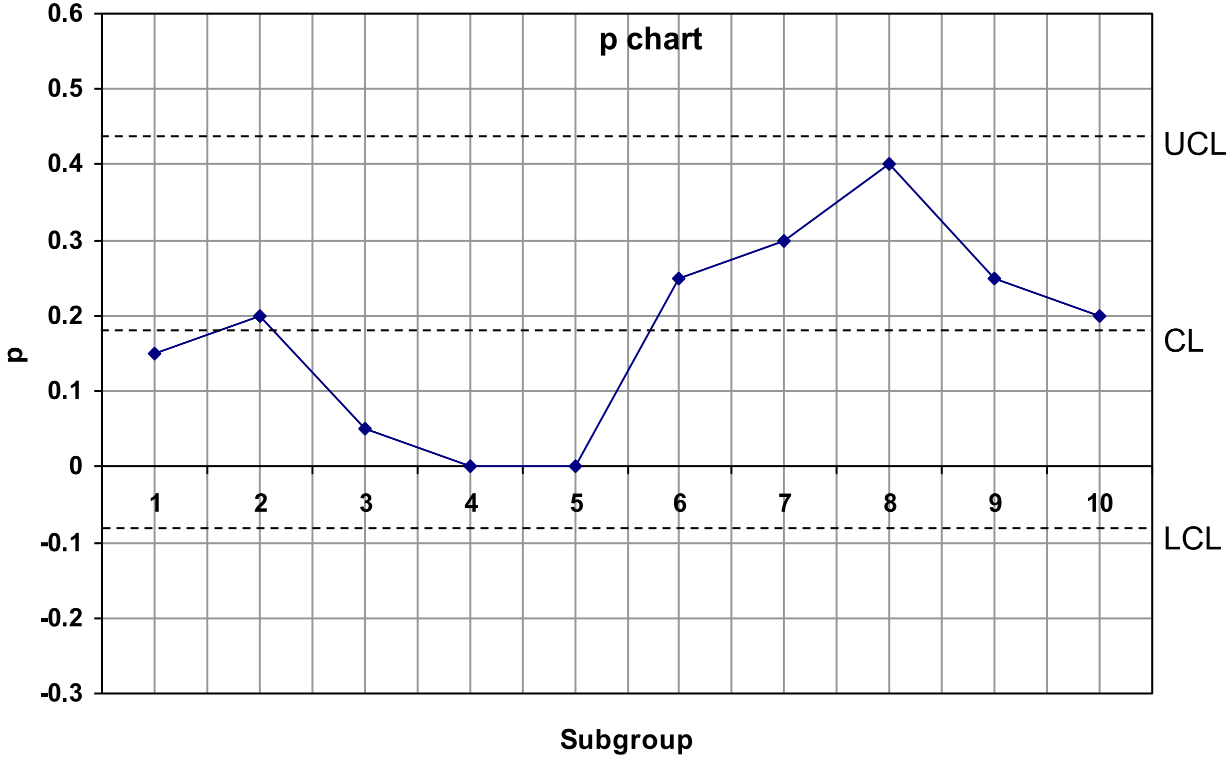
$\bar{p}$ **= 0.18**

Step 3: Calculate the control limits

$$\textbf{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}\,(1 - \bar{p})}{n}} = 0.44$$

$$\textbf{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}\,(1 - \bar{p})}{n}} = -0.078$$

Step 4: Plot and interpret the chart



All points are within control limits.

The p values for subgroup 4-5 is 0.

So no defective radios were produced at that time. However, the quality deteriorated after that indicated by the increasing trend in the p chart.

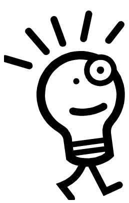
Control Charts

Advantages

- Used to monitor and control ongoing processes
- Initiate problem solving when an assignable cause comes into the process

Disadvantages

- Tamper with the process too frequently based on the signals from the control charts

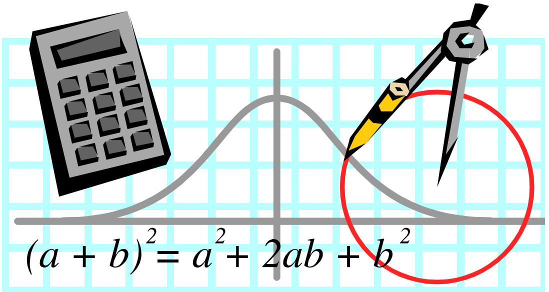


Useful Tips

✓ Choose the right control chart for the data

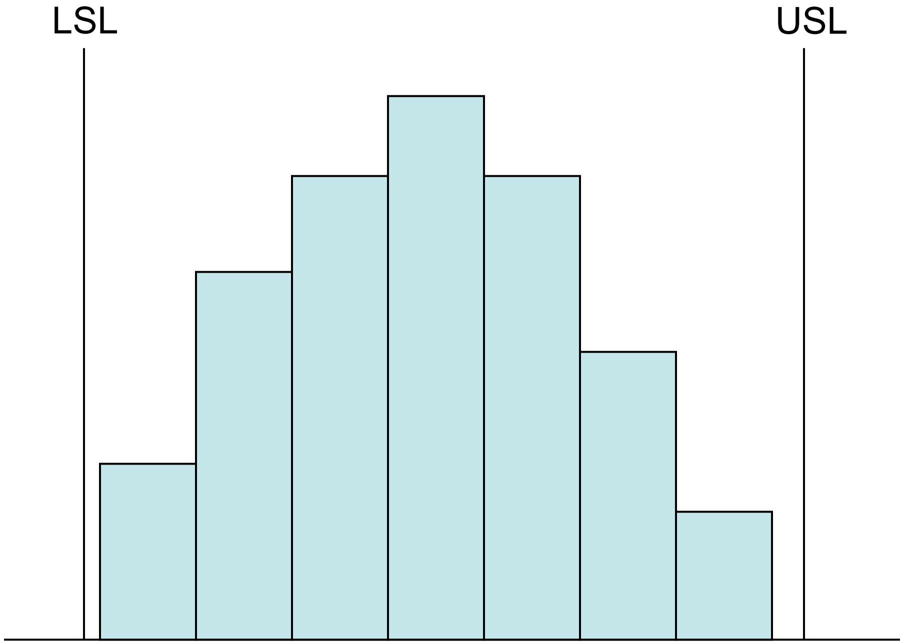
✓ Decide the subgroup size before setting up data collection

Process Capability and Histogram



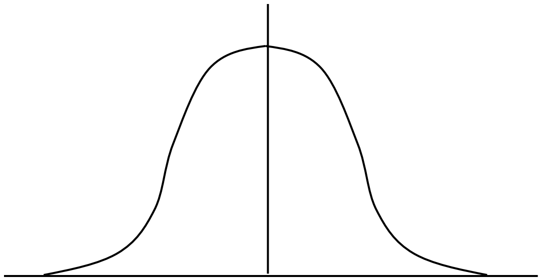
What is Histogram?

- A frequency distribution for a data set (variables)
- A bar graph that shows the amount of variation in the process



Patterns in a Histogram

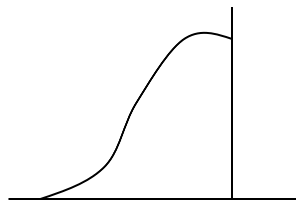
- Measurements tend to cluster around the middle of the of the distribution with less data around the tails



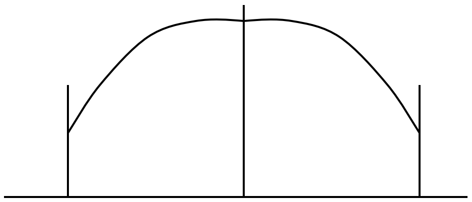
- When the distribution does not follow the normal distribution curve, an assignable cause has come into play

Patterns in a Histogram

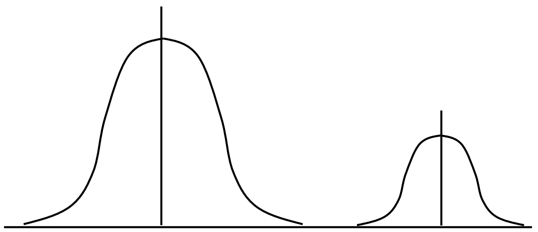
- Truncated distribution indicates a part of the distribution has been removed through 100% inspection or there is a natural limit in the process



- A flat plateau like distribution indicates that there is no defined process for producing the part. Therefore there are different measurements.



- Separated twin peaked distributions indicate that measurements are coming from different sources



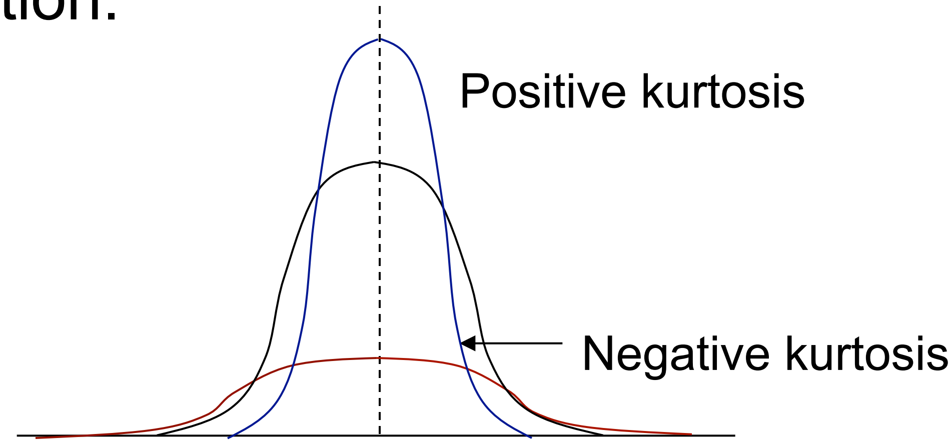
Skewness and Kurtosis

- Measurements tending to cluster to one side are called skewed.

Positive Skew

Negative Skew

- Kurtosis is a measure of the peakedness or flatness of the distribution.



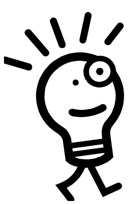
Histogram

Advantages

- Used to find the nature of distribution of the data
- Helps find out the where the data is coming from

Disadvantages

- Patterns not clear



Useful Tips

✓ Have sufficient readings for plotting a histogram

✓ Look for unusual patterns in the histogram

Process Capability

- To determine whether the process is capable of producing a product that conforms to customer specifications, consistently; a capability study needs to be done.

- Capability studies are performed on statistically stable processes

- The objective of a process capability study is to establish a state of control over a manufacturing process to be used in maintaining that state over time

Measure of Process Capability
Cp, Cpk Indices

Cp – Process capability index

$$Cp = \frac{USL - LSL}{6\sigma}$$

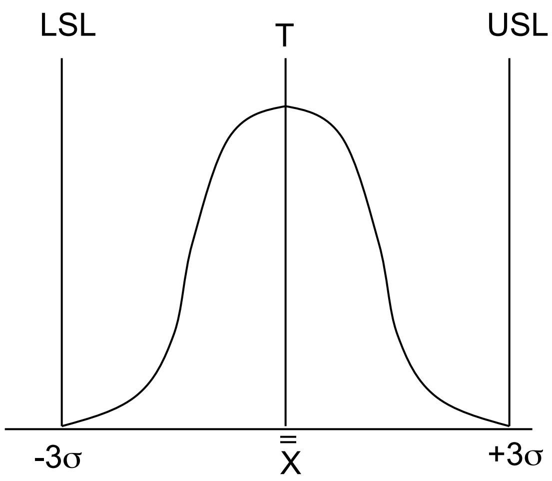
USL – Upper Specification limit

LSL – Lower Specification limit

σ – Sigma (Process)

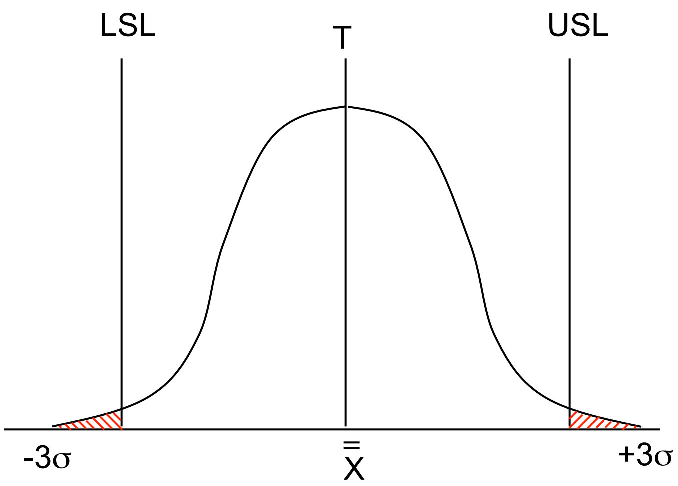
Cp Index

1



Cp = 1

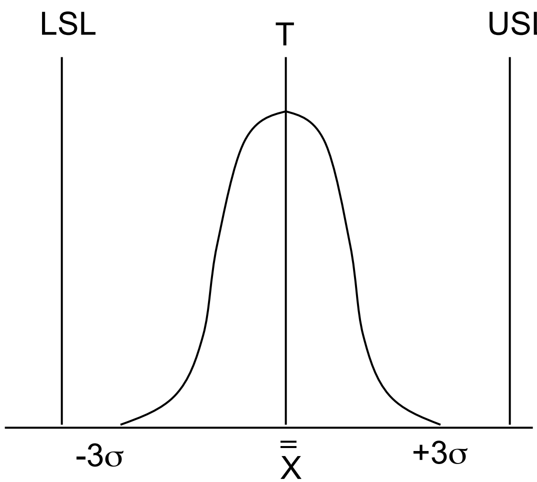
2



Cp < 1

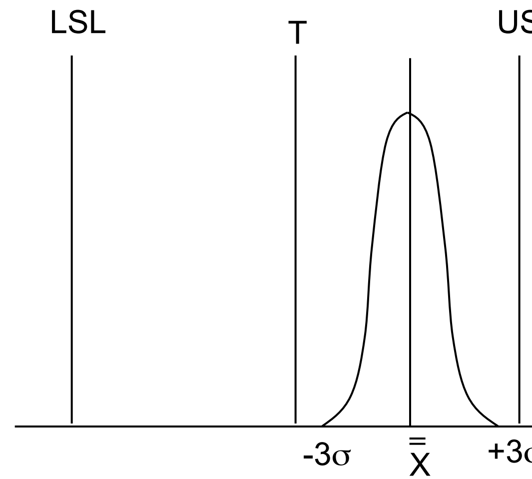
Cp Index

3



Cp > 1

4



Cp = 2

Cpk Index

Cpk – Process capability index with process centering

$$Cpk = \text{Minimum of } \frac{USL - \bar{\bar{X}}}{3\sigma} \text{ or } \frac{\bar{\bar{X}} - LSL}{3\sigma}$$

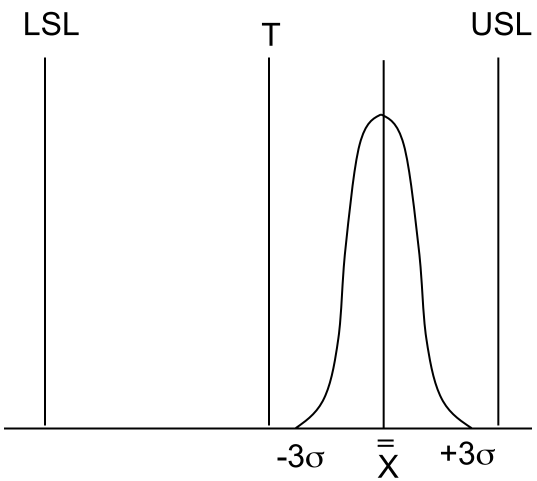
USL – Upper Specification limit

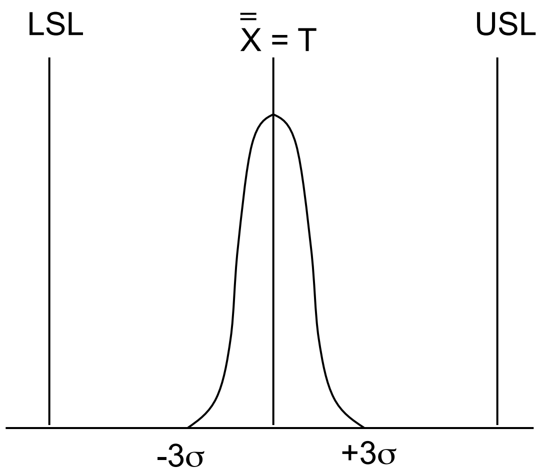
LSL – Lower Specification limit

σ – Sigma (Process)

$\bar{\bar{X}}$ – process average

Cpk Index





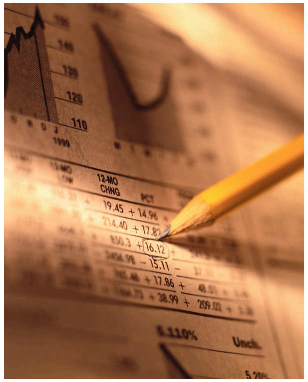
Cp = 2

Cpk < 2

If the process is centered, the process average matches with the target.

Cp = Cpk

Calculating Indices Using Control Charts



Calculating Capability Indices for the Example for Xbar-R

For our example,

$\bar{\bar{X}} = 6.68$ and $\bar{R} = 0.2$

Specs for pencil diameter = 6.7 ± 0.5mm

USL = 7.2, LSL = 6.2

Standard deviation from Xbar – R chart

$$\sigma = \frac{\bar{R}}{d_2} = \frac{0.2}{2.326}$$

$\sigma = 0.086$

Calculating Capability Indices for the Example for Xbar-R

$\sigma = 0.086$

$$Cp = \frac{USL - LSL}{6\sigma} = \frac{7.2 - 6.2}{6(0.086)} = 1.94$$

$$Cpk = \text{Min. of } \frac{USL - \bar{\bar{X}}}{3\sigma} \text{ or } \frac{\bar{\bar{X}} - LSL}{3\sigma}$$

$$Cpk = \frac{7.2 - 6.68}{3(0.086)} \text{ or } \frac{6.68 - 6.2}{3(0.086)}$$

$Cpk = 2.01$ or 1.86

$Cpk = 1.86$

Interpreting Capability Indices

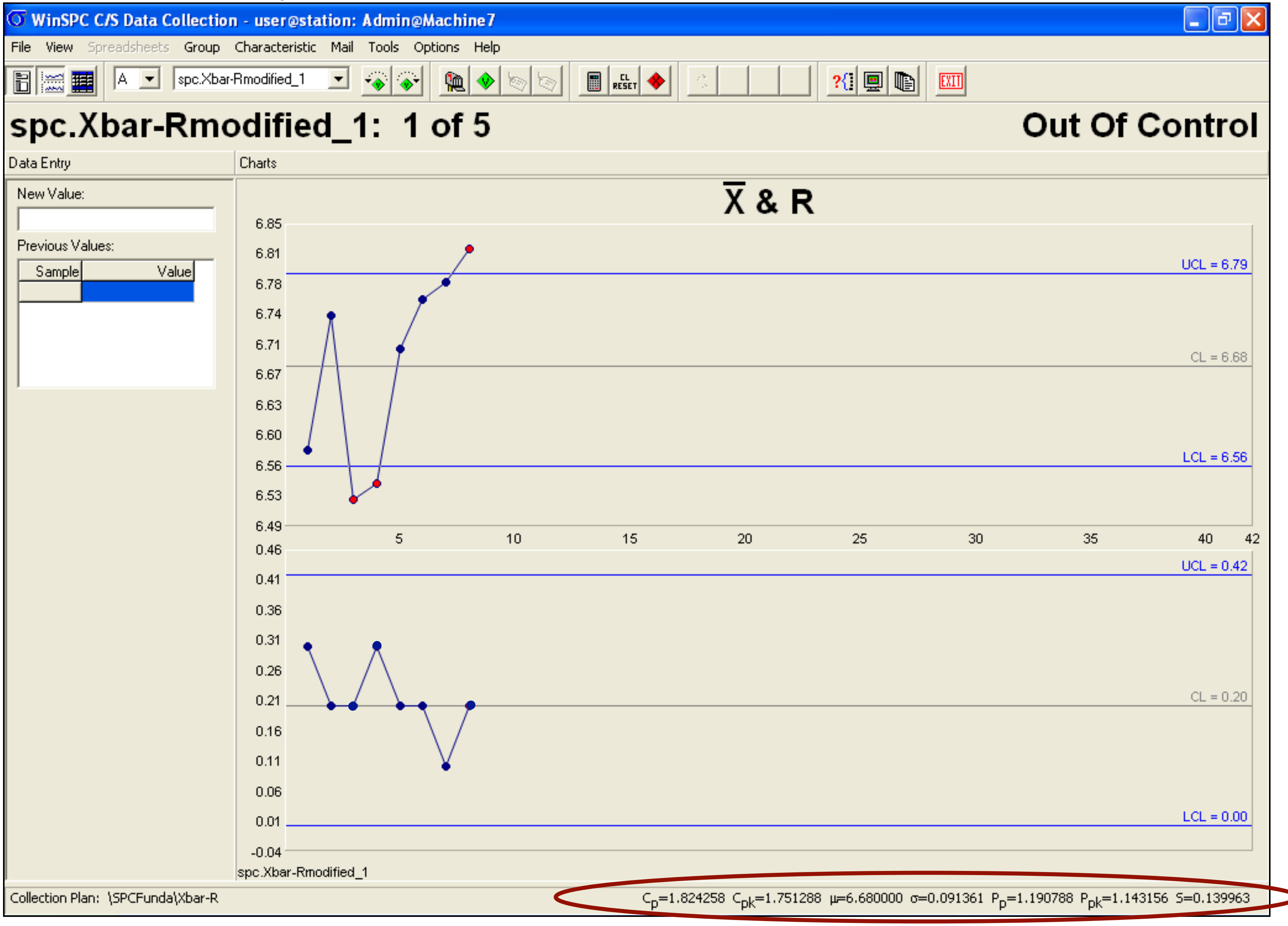
1) Cp is close to the Cpk

   The process average is close to the target.

2) Cp and Cpk values near 2.

3) Process is capable.

Capability & Performance Indices from WinSPC



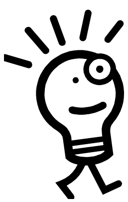
Process Capability Analysis

Advantages

- Used to find whether the process is capable of consistently producing parts that are conforming to specifications

Disadvantages

- Only one index is used for analyzing the process capability



Useful Tips

✓ Conduct process capability studies on stable processes

✓ Higher the Cp, Cpk values, more is the process capability

Exercise: Calculating Capability Indices

Calculating Capability Indices for the Xbar-R Exercise

For our example,

$\bar{\bar{X}} = 83.5$ and $\bar{R} = 6.5$

Specs for sound output for radio = 80 ± 10db

$\sigma = \bar{R} / d_2$

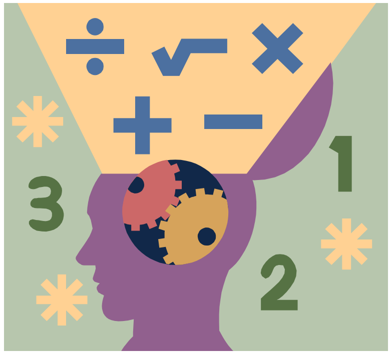
$d_2 = 2.059$ for subgroup size of 4

$$Cp = \frac{USL - LSL}{6\sigma} =$$

$$Cpk = \text{Min. of } \frac{USL - \bar{\bar{X}}}{3\sigma} \text{ or } \frac{\bar{\bar{X}} - LSL}{3\sigma}$$

Cpk =

Solution: Capability Indices for Xbar-R Exercise



Calculating Capability Indices for the Xbar-R Exercise

For our example,

$\bar{\bar{X}} = 83.5$ and $\bar{R} = 6.5$

Specs for sound output for radio = 80 ± 10db

$\sigma = \bar{R} / d_2 = 3.16$

$d_2 = 2.059$ for subgroup size of 4

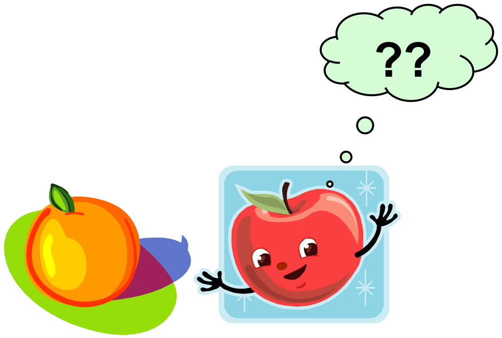
$$Cp = \frac{USL - LSL}{6\sigma} = 1.05$$

$$Cpk = \text{Min. of } \frac{USL - \bar{\bar{X}}}{3\sigma} \text{ or } \frac{\bar{\bar{X}} - LSL}{3\sigma} = 0.68 \text{ or } 1.42$$

Cpk = 0.68

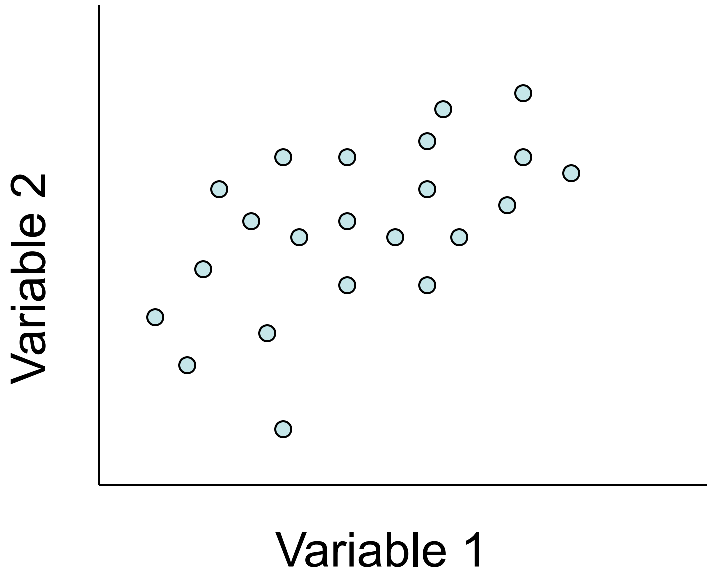
Process is incapable.

Scatter Diagram

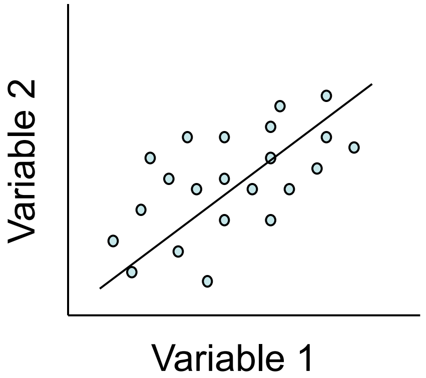


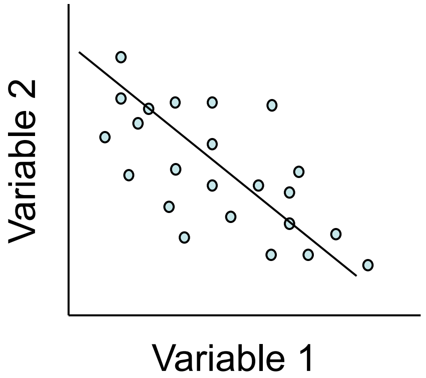
What is a Scatter Diagram?

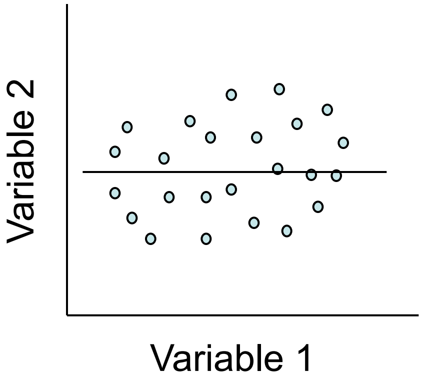
- A point graph of measurements from 2 variables
- Used to find the relation between the two variables



Patterns in a Scatter Diagram







Positive Correlation
r = +1

Negative Correlation
r = -1

No Correlation
r = 0

where
r = Coefficient of correlation

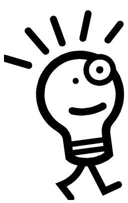
Scatter Diagram

<u>Advantages</u>

- Used to find whether 2 variables are related or not
- The type of relation between 2 variables

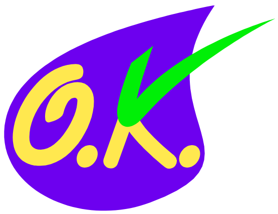
<u>Disadvantages</u>

- Cause and effect relation between variables

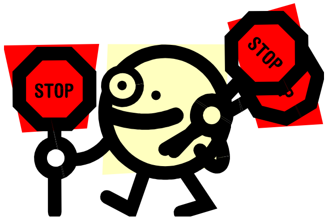


Useful Tips

✓ Plot scatter diagrams before beginning a correlation-regression analysis



Dos and Don’ts During SPC Implementation



Dos	Don’ts
• Use SPC for improving processes • Plot control charts to monitor ongoing processes • Look for “out of control” process indicators • Analyze the process for assignable causes when the process is out of control	• Just plot control charts • Adjust the process too often to bring it under control • Confuse control limits with specification limits • Look at the Cp values only

SPC Tools and Their Use

SPC Tool	Use
• Check Sheet	Data collection for specific process improvement project
• Pareto Chart	Prioritize the main causes of the problem
• Cause and Effect diagram	Lists all possible causes of the problem under the 4Ms
• Control charts	Monitor and control ongoing processes
• Histogram	Helps determine the nature of distribution of the data
• Capability study	Finds process capability and performance
• Scatter diagram	Finds relations between 2 variables

Question-Answer Session

Thank You!