SPC Fundamentals

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Introduction

Scope

This training guide will teach you the basics of several common SPC tools. Each student will learn the theory behind SPC and how to interpret Control Charts, Histograms, Capability indices, Pareto Charts and other statistics. We will also discuss several useful implementation strategies that can be used during the deployment of WinSPC. Upon completion of this course the student will possess knowledge about 7 common SPC tools.

How to Use This Guide

This manual guides the user though a series of exercises designed to illustrate the steps involved in constructing and interpreting SPC charts. Each exercise builds upon the next to construct a complete case study, with each step emphasizing the implementation of SPC as a whole.

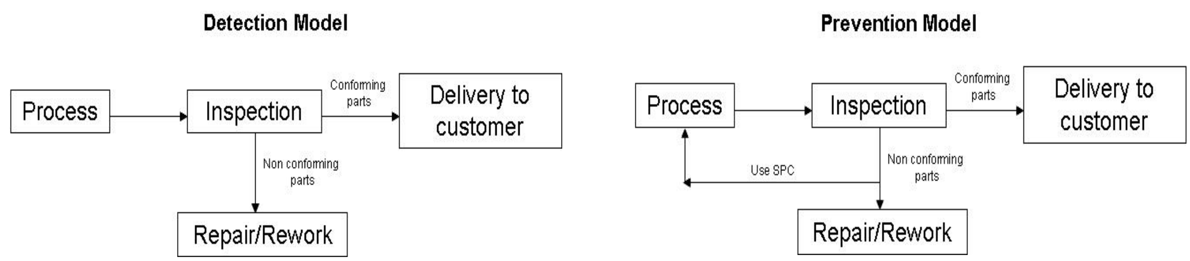
As such, the manual has been organized to fit the following conventions:

- Each chapter begins with a brief summary of the SPC tool. This typically includes a description of the tool, examples explaining the steps to construct the chart, advantages / disadvantages and implementation tips.
- For the SPC tools – Pareto, fishbone diagram, control charts, capability analysis an exercise is designed that users need to solve. Solutions for each exercise will be discussed during the training class.
- A full Glossary of Terms can be found at the back of the manual and serves as a convenient reference for the SPC tools both during and upon conclusion of the training course.

Chapter 1
SPC Basics

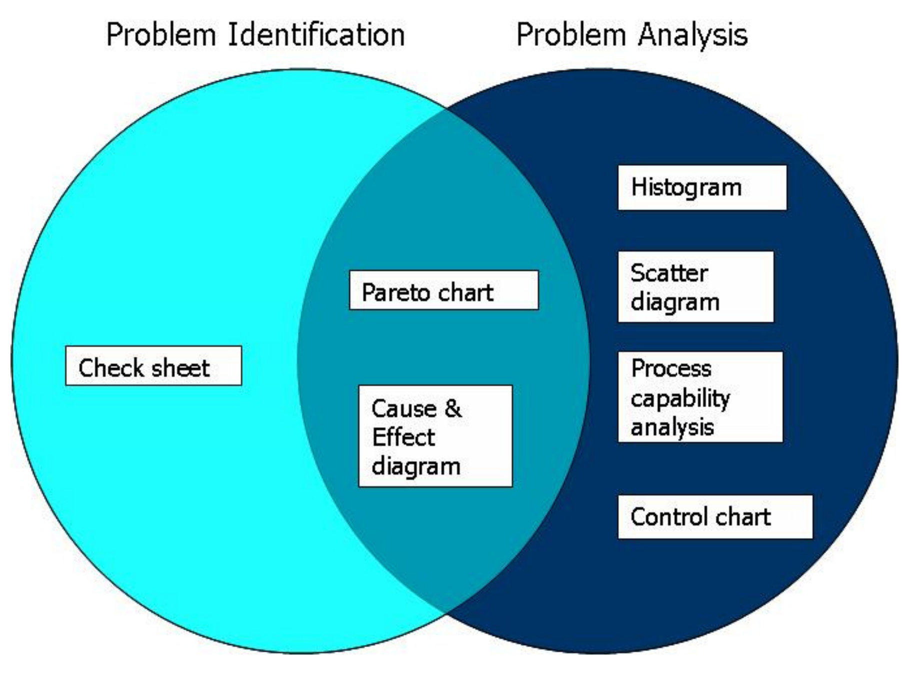
What is SPC?

SPC or Statistical Process Control is a method for monitoring, controlling, and improving a process through statistical analysis. We use a set of 7 core tools to accomplish this task. The idea behind SPC requires us to shift from a detection model toward a prevention model in our manufacturing processes.



This proactive approach uses SPC tools to correct the process so that non conforming parts are not produced in the first place. Thus, the prevention model reduces the cost of producing, finding and repairing non conforming parts.

The 7 SPC Tools



Chapter 2
Check Sheet

SPC Tool: Check Sheet

A check sheet is a simple, user friendly form used to collect data for a period of time. A check sheet is typically used for data collection during a process improvement project. Once the project team is formed, the first thing required during any process improvement/problem solving project is to understand what's happening in the process. How is the process behaving? What are the various factors affecting the process output? What is the quality of parts produced by the process?

Data about the process will tell the improvement team more about the process. Therefore, data collection is the first step in any process improvement. Check sheets are simple data collection forms that can be designed for each project. Check sheets are used at the start of any improvement project so they need to be designed and used correctly. Data should be collected as parts are being produced. That way the true picture of the process can be visualized by the team.

Advantages
- Simple and easy to construct
- Very useful for data collection for an improvement project

Disadvantages
- Lots of paper to manage
- Inspection reports used in place of check sheets

Remember

- ✓ Collect data as it becomes available
- ✓ It is important to create a separate check sheet for each process improvement project
- ✓ If the start of the project is not right, the whole project can go haywire

Example:
A check sheet for data collected for the different types of defects found in pencils produced in one week.

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

In order for check sheets to be useful they should identify the product, the process, the characteristics being tested, the date & time, the operator and any other pertinent information that you deem important to generate a "big picture" of your process.

Chapter 3
Pareto Chart

SPC Tool: Pareto Chart

A Pareto chart is a combination chart – bars for the % frequency and a curve for the cumulative frequency. It is used to prioritize problems or causes of a problem.

Imagine a plant that has lots of quality issues. People at this plant are always firefighting to solve quality problems. It is rather difficult for the quality or the plant manager to decide where to begin improvements. Which process to improve first? Where to allocate resources so that the majority of the problems get solved?
A Pareto Chart helps prioritize the problems so that the manager can then decide where to begin improvements. It helps in proper allocation of time and effort so that most of the quality issues get resolved.

Another example of a situation where a Pareto Chart would be useful is when you are trying to improve a particular process and your team has come up with a whole list of possible causes to the problem. Every team member thinks of a different cause that is the true root cause of the problem. In such situations, Pareto charts help prioritize so that teams can focus on a few causes and analyze them further. In short, a Pareto chart separates the "vital few" from the "trivial many".

How it all began?
An Italian economist Vilfredo Pareto studied the wealth distribution in Italy and found that 80% of the wealth was concentrated with 20% of the people. In the 1940s, Juran applied this principle to Quality. The SPC tool got its name "Pareto" from the founder Vilfredo Pareto.

What is the Pareto Principle?
80% of the problems are due to 20% causes. Also, known as the 80/20 rule.
The Pareto principle can be applied to virtually any area of the workplace.

- 80% of the product costs are due to 20% of the raw material
- 80% of the sales are due to 20% of the customers

Types of Pareto Analysis
1) Based on counts – frequency calculation done on the actual number of defects
2) Based on cost – frequency calculation done on the cost of the defects

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

Disadvantages
- Is only a snapshot of the process at a specific time

Remember

✓ Compare Paretos based on counts and cost for prioritization
✓ Apply the 80/20 rule after plotting a Pareto chart
✓ To monitor progress, do a Pareto analysis before and after process improvement

Example: Pareto based on Counts

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.

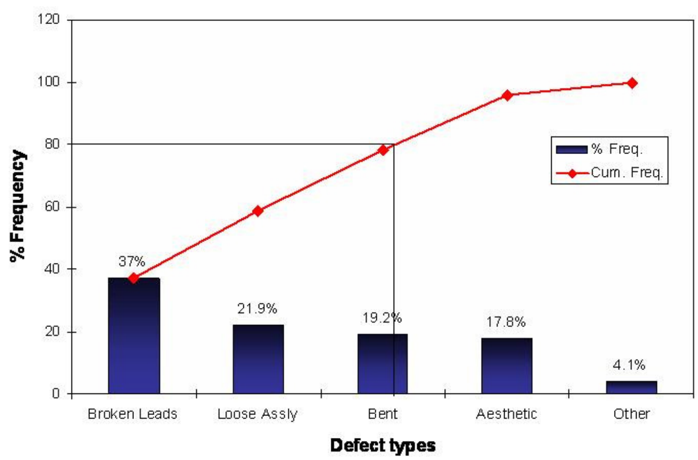
Construct a Pareto chart using the following data:

Sr. No.	Defect Types	Total Counts
1	Broken Leads	27
2	Bent	14
3	Eraser-Pencil assembly loose	16
4	Aesthetic problems	13
5	Other	3

Step 1: Arrange data in descending order
Step 2: Calculate the % frequency and cumulative frequency

Sr. No.	Defect Types	Total Counts	% Frequency	Cumulative Frequency
1	Broken Leads	27	27/73 x 100 = 37	37
2	Eraser-Pencil assembly loose	16	21.9	37 + 21.9 = 58.9
3	Bent	14	19.2	58.9 + 19.2 = 78.1
4	Aesthetic problems	13	17.8	78.1 + 17.8 = 95.9
5	Other	3	4.1	95.9 + 4.1 = 100
	TOTAL	**73**		

Step 3: Plot the chart and identify the vital few



Conclusion: The following defects contribute to 80% of the defect types for pencils

- Broken Leads
- Loose assembly
- Bent

The improvement team should focus their efforts on the above 3 defect types and most of the defects with the pencil should be reduced.

Example: Pareto based on Cost

Part: Pencil
Project: If there is a cost associated with each defect type, then a Pareto chart on the cost can be done. The cost for each defect type can be the cost required for repairing/reworking a defect on the part. Or if the defect cannot be repaired, then the part will be scrapped and the cost for that defect becomes the total cost of producing that part. This type of Pareto analysis is useful to determine where 80% of the cost for the defects, exist.

Let's associate a cost for each defect type in the example above and Construct a Pareto chart based on cost.

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

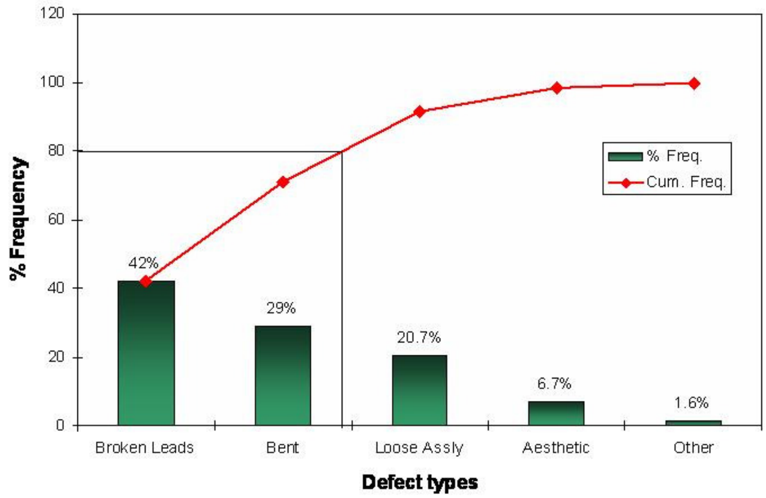
Before we begin with the steps of constructing a Pareto chart, we need to find the total cost for each defect type. On this total cost a Pareto analysis will be done.

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

Step 1 and 2: Arrange data in descending order and calculate the % frequency, cumulative frequency

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

Step 3: Plot the chart and identify the vital few



<u>Conclusion</u>: The following defects contribute to 80% of the defect costs for pencils

- Broken Leads
- Bent

The improvement team should focus their efforts on the above 2 defect types and a cost reduction for the pencil defects can be achieved.
Notice, in the previous example "Loose Assly" had been identified as a major contributor to our defect count but it is not a major contributor to our costs. During implementation, you would see a "bigger bang for you buck" if you focused your efforts on eliminating Broken Leads & Bent defects and ignore Loose Assly defects.

Exercise

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.

Construct two Pareto charts – based on counts, based on cost

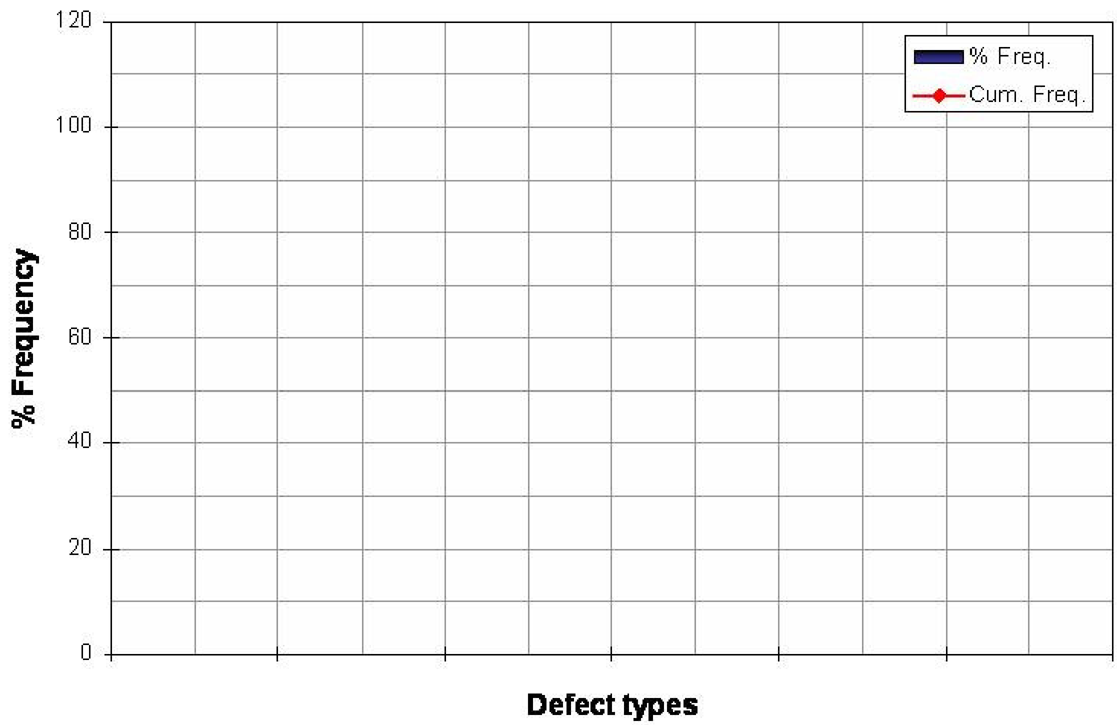
Sr. No.	Defect Types	Counts	Cost ($/defect)	Cost ($)
1	Amplifier problems	50	15	
2	Assembly loose	60	20	
3	Speaker output	20	15	
4	Scratches on the cover	30	2	
5	Loose knobs	10	10	
6	Packaging issues	40	5	

Part I – Pareto on counts

Step 1 and 2: Arrange data in descending order and calculate the % frequency, cumulative frequency

Sr. No.	Defect Types	Counts	% Frequency	Cumulative Frequency
1				
2				
3				
4				
5				
6				
	TOTAL			

Step 3: Plot the Pareto chart on counts and identify the vital few



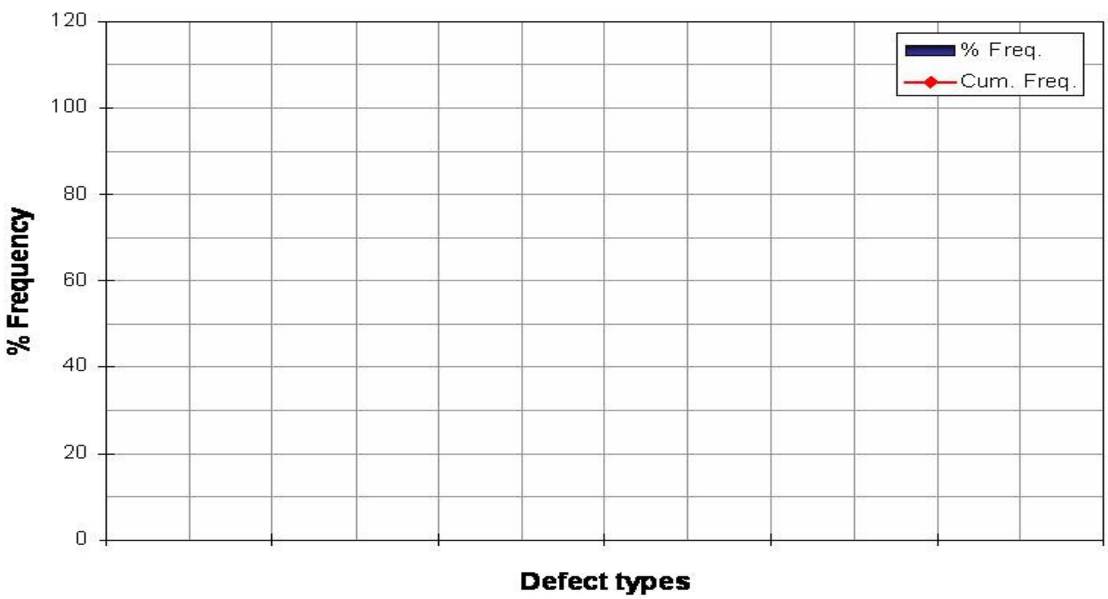
Conclusion:

Part II – Pareto on cost

Step 1 and 2: Arrange data in descending order and calculate the % frequency, cumulative frequency

Sr. No.	Defect Types	Cost	% Frequency	Cumulative Frequency
1				
2				
3				
4				
5				
6				
	TOTAL			

Step 3: Plot the Pareto chart on cost and identify the vital few



Conclusion:

Chapter 4
Cause and Effect Diagram

SPC Tool: Cause and Effect diagram

The cause and effect diagram uses brainstorming to identify all possible causes of the problem. A team that includes all people closest to the problem come together to brainstorm the reasons for the problem. During brainstorming everyone gets a chance to speak up their ideas/causes for the problem. Repetition of ideas is allowed and no idea is ridiculed.

One of the team members who is the facilitator, records these ideas. All ideas are then listed in front of the team and the facilitator makes sure that everyone understands all the ideas.

These ideas are then put on the cause & effect diagram. The cause and effect diagram is also known as the fishbone diagram because of its shape or the Ishikawa diagram after its inventor, Dr Ishikawa. The problem is placed on the right side of the "main bone" of the fishbone diagram (see picture below). The causes are categorized under Man, Method, Machine and Material which are the main branches of the diagram. Each cause can have sub causes and sub sub causes. After the diagram is constructed, the top 3 causes found by the ranking method are highlighted on the diagram.

Advantages
- Useful for initial brainstorming
- Based on the team inputs, the fishbone diagram helps list and categorize all possible causes of the problem

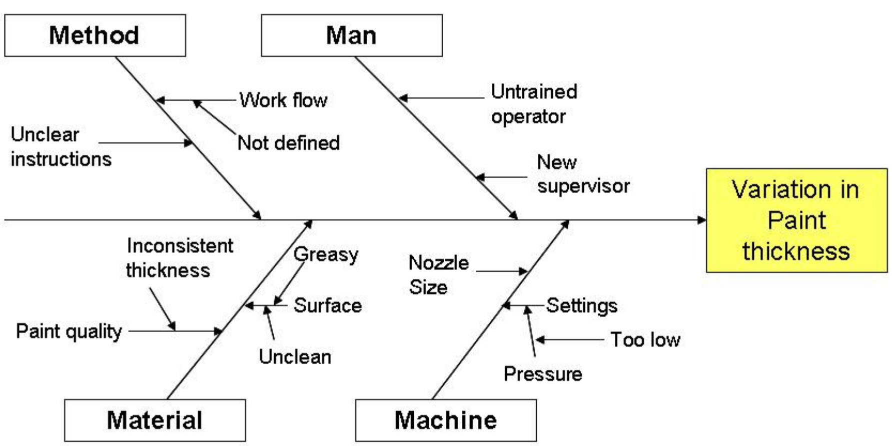
Disadvantages
- The diagram sometimes tends to be too simplistic or too detailed

Remember

✓ As new ideas become available, update the fishbone diagram even after it is constructed
✓ During brainstorming, active participation from all team members is encouraged

<u>Example</u>: Fishbone diagram

The problem of variation in the paint thickness is being studied. All possible causes from the brainstorming session are listed under the 4Ms. A fishbone diagram is constructed.



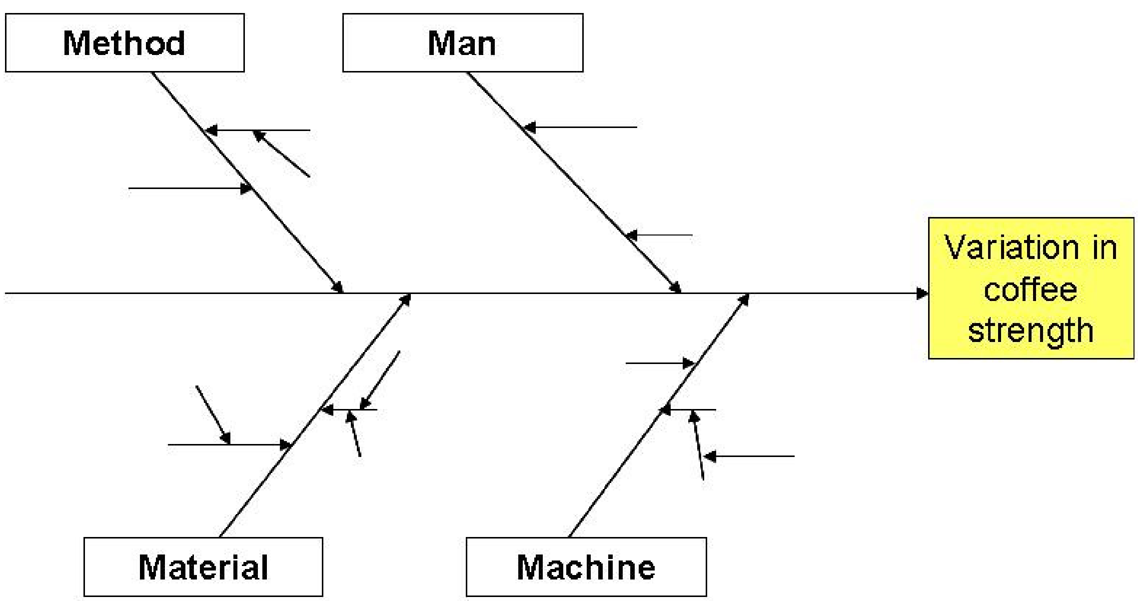
<u>Exercise</u>:

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.

<u>List of possible causes</u>:

<u>Fishbone diagram</u>



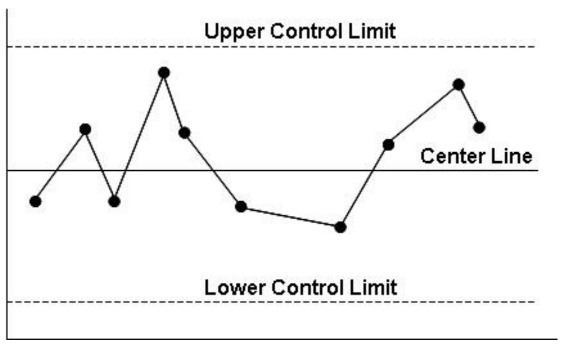
Chapter 5
Control charts

SPC Tool: Control charts

Common and assignable causes

Common causes	Assignable causes
• Inherent variations that are naturally part of the process • These variations are random in nature Eg. Voltage fluctuations, environment changes	• Non-random variation that does not occur by chance • If non-random trends are detected, the process should be analyzed Eg. Quality of the raw material, changes in machine settings

What are Control charts?
A run chart with upper, lower control limit lines and the centerline (average). The upper and lower control limits are statistically calculated. The calculation uses process data.



Control charts are used for monitoring and controlling ongoing processes. From the control chart, one can find out whether the process is in control or not. A control chart helps determine when an assignable cause has come into play and the process needs to be analyzed.

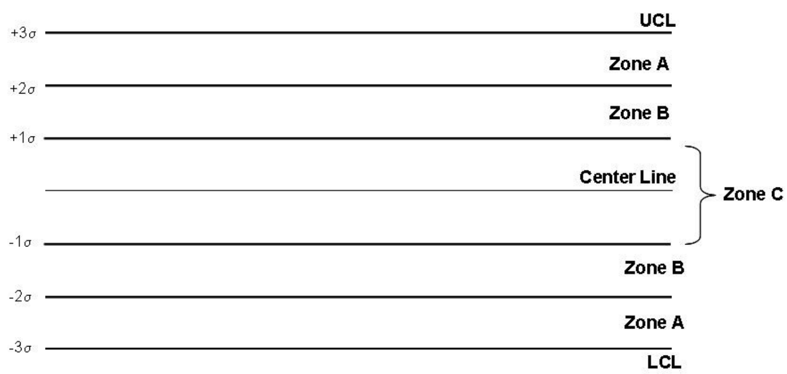
They are also called Shewhart charts after Walter Shewhart who developed these charts in the 1920s. They are still the most popular and commonly used charts for monitoring processes in the industry today.

"Out of control" process indicators

- A single point going beyond either the upper or lower control limits
- Run - e.g. Seven consecutive points going up or down. A run indicates an out of control process

Control chart Zones

We first divide the area between the centerline and the UCL into 3 equal zones.
We then repeat the division between the centerline and LCL.



Some common Western Electric Rules for "out of control" process indicators
- 1 point beyond Zone A
- 2 out of 3 consecutive points in Zone A or beyond
- 4 out of 5 consecutive points in Zone B or beyond
- 8 consecutive points on both sides of the centerline and no points in Zone C. Also known as Mixture
- 15 consecutive points in Zone C. Also known as Stratification

Types of Control charts
1) Variable control charts used for measurements like weight, length etc.
   Three types
   i) Xbar-R ii) Xbar-S iii) X-MR

2) Attribute control charts used for pass/fail, go/no go type of data
   Four types
   i) p ii) np iii) c iv) u

Steps for constructing Variable Control charts
1) Decide the subgroup size which is the number of parts measured at predetermined frequency. Eg. 3 readings every hour.
2) Based on the subgroup size, decide the type of control chart to be plotted.
3) Collect data
4) Calculate and plot the values for the points in the upper and lower chart.
5) Calculate average, upper and lower control limits. Draw these as lines on the chart
6) Observe and interpret the control chart

Choosing the right control chart for the given data set

Chart type	**Used when…**
Xbar – R	Subgroup size less than or equal to 7
Xbar – S	Subgroup size greater than 7
X-MR	Subgroup size equal to 1

<u>Example</u>: Xbar – R Control chart

Part: Pencil
Measurement: The diameter of 5 pencils is measured every 30min in production
Specification: 6.7 ± 0.5mm

Construct an Xbar-R chart for the data collected in the last 4hours.

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
Noon	7	6.8	6.7	6.8	6.8	6.8
12:30pm	8	6.9	6.8	6.9	6.7	6.8

Subgroup size = 5
No. of subgroups = 8

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

Subgroup	**X1**	**X2**	**X3**	**X4**	**X5**	**Xbar**	**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	6.7	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 $\overline{\overline{X}}$ and $\overline{R}$ values

$\mathbf{\overline{\overline{X}} = 6.68}$ $\mathbf{\overline{R} = 0.2}$

Step 3: Calculate the control limits

For $\overline{X}$ chart

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

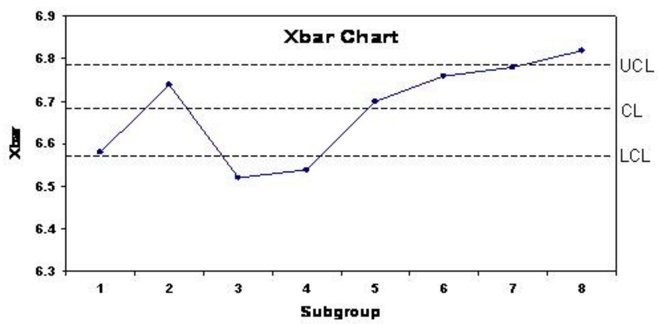
LCL = $\overline{\overline{X}} - A_2\overline{R} = 6.68-0.577(0.2) = \mathbf{6.56}$

For R chart

UCL = $D_4\overline{R} = 2.114(0.2) = \mathbf{0.42}$

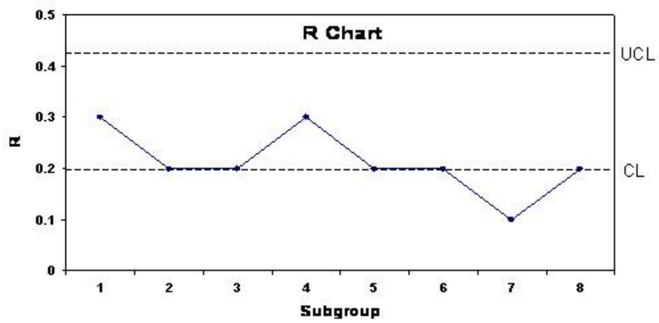
LCL = $D_3\overline{R}$ = **---**

Step 4: Plot the control charts and interpret them



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

<u>Conclusion</u>:
Process is out of control. Observe the process closely and analyze for assignable causes.

Exercise

Part: Radio
Measurement: Sound output of 4 radios is measured every hour
Specifications: 80 ± 10 db

Construct an Xbar-R chart for the data collected in the last 10 hours.

Time	Subgroup	X1	X2	X3	X4
9am	1	80	80	85	80
10am	2	75	75	70	80
11am	3	75	80	75	90
Noon	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

Subgroup size = 4
No. of subgroups = 10

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

Subgroup	X1	X2	X3	X4	Xbar	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

Step 3: Calculate the control limits

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

Use the statistical constants given above for the control limit calculations.

For $\bar{X}$ chart

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

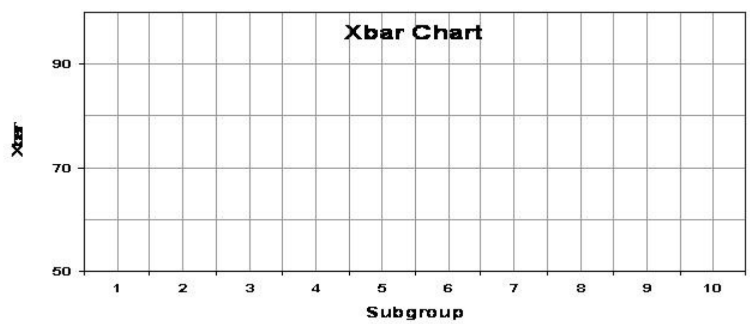
LCL = $\bar{\bar{X}} - A_2\bar{R} =$

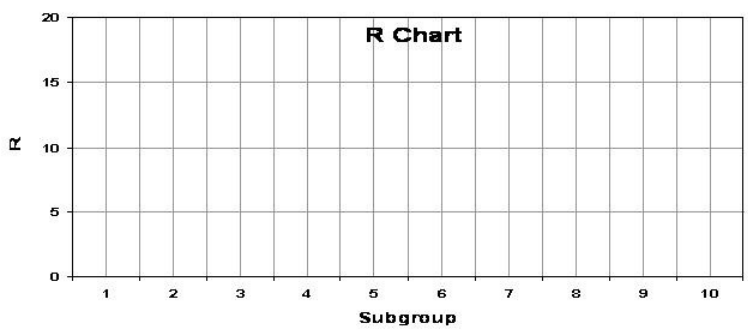
For R chart

UCL = $D_4\bar{R} =$

LCL = $D_3\bar{R} =$

Step 4: Plot and interpret the control charts





Conclusion:

Example: X – MR Control chart

Part: Pencil
Measurement: The diameter of 1 pencil is measured every lot
Specification: 6.7 ± 0.5mm

Construct X-MR chart for the last 10 lots.

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	$\lvert 6.9 - 6.8 \rvert = 0.1$
3	6.6	$\lvert 6.6 - 6.9 \rvert = 0.3$
4	6.5	$\lvert 6.5 - 6.6 \rvert = 0.1$
5	6.7	$\lvert 6.7 - 6.5 \rvert = 0.2$
6	6.4	$\lvert 6.4 - 6.7 \rvert = 0.3$
7	6.8	$\lvert 6.8 - 6.4 \rvert = 0.4$
8	6.2	$\lvert 6.2 - 6.8 \rvert = 0.6$
9	6.6	$\lvert 6.6 - 6.2 \rvert = 0.4$
10	6.7	$\lvert 6.7 - 6.6 \rvert = 0.1$

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**

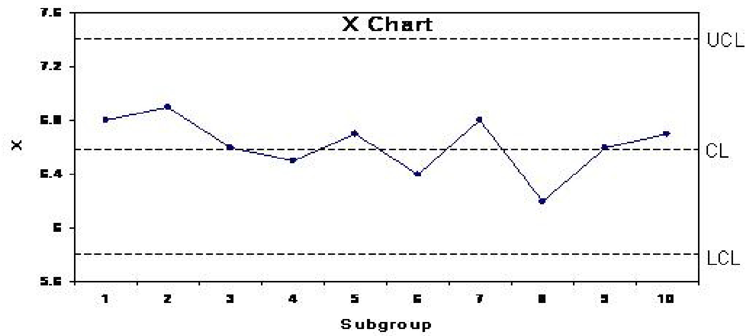
LCL = $\overline{X} - E_2\overline{MR} = 6.6-2.66(0.3) =$ **5.8**

For MR chart

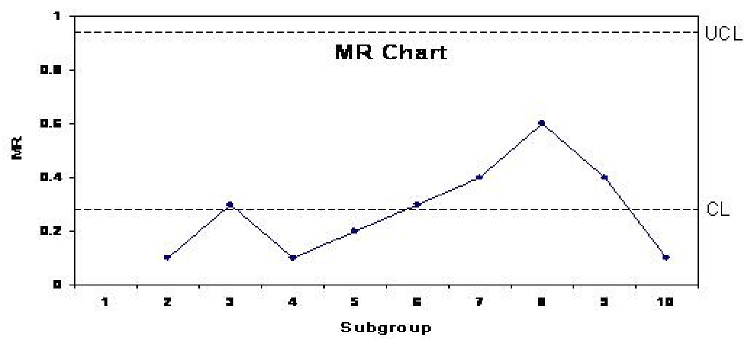
UCL = $D_4\overline{MR} = 3.267(0.3) =$ **0.98**

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

Step 4: Plot and interpret the charts



X chart
All points within control limits and randomly varying about the CL



MR chart
All points within control limits and randomly varying about the CL

<u>Conclusion</u>: Process is in control.

Exercise

Part: Radio
Measurement: Sound output of 1 radio is measured every hour
Specifications: 80 ± 10 db

Construct an X-MR chart for the data collected in the last 10 hours.

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

Step 1: Calculate the MR values for each subgroup

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

Step 3: Calculate the control limits

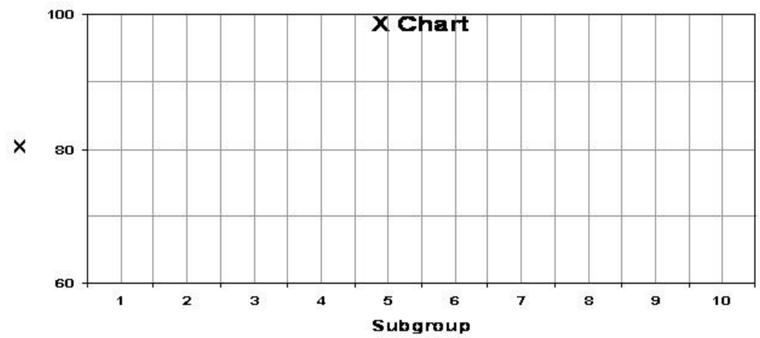
Statistical constants for subgroup size = 1
$E_2 = 2.66$ $D_3 = --$ $D_4 = 3.267$

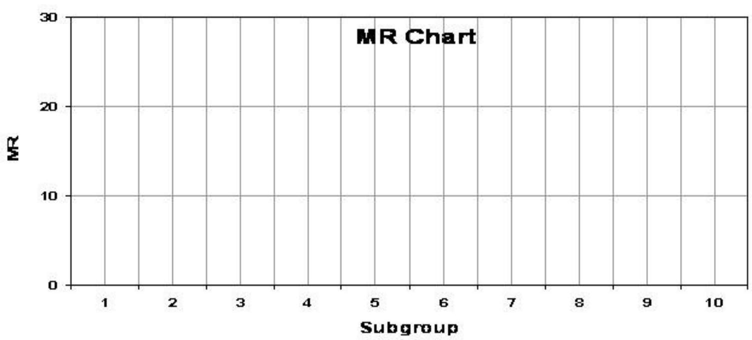
Use the statistical constants given above for the control limit calculations.

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 control charts





Conclusion:

Attribute Control Charts

Defects are the type of problems that can occur on a part. Eg. Bad components on a Circuit board.
Defectives are the non conforming parts in the process. Eg. Bad Circuit boards

The production quantities vary based on the customer demands. Therefore, the lot sizes change. For varying lot size and the number of defects/defectives counted the type of attribute control chart changes.

The Matrix below shows the attribute control chart to choose for a given dataset…

	Defects	Defectives
Varying	u	p
Constant	c	np

<u>Example</u>: p chart

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.

Constant lot size of 50 pencils

Date	Number of 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	13	50
1/7/06	15	50
1/8/06	7	50
1/9/06	4	50
1/10/06	0	50

Step 1: Calculate the p values

Date	Number of defectives	Quantity inspected	p
1/1/06	14	50	0.28
1/2/06	8	50	0.16
1/3/06	7	50	0.14
1/4/06	10	50	0.2
1/5/06	12	50	0.24
1/6/06	3	50	0.06
1/7/06	9	50	0.18
1/8/06	7	50	0.14
1/9/06	4	50	0.08
1/10/06	0	50	0

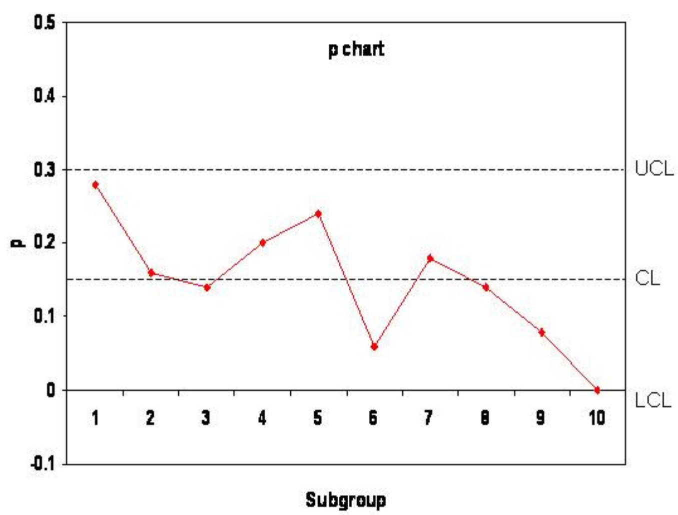
Step 2: Calculate the $\overline{p}$ values $\overline{p} = 0.15$

Step 3: Calculate the control limits

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

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

Step 4: Plot and interpret the p 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.

<u>Conclusion</u>: The proportion defective for subgroup 10 is 0. The quality of the pencils is perfect. Try to maintain the process at the same condition always so that no defective product is produced.

Exercise:

The number of defective radios is counted from an inspection lot size of 20 parts.
Plot the p chart for the last 10 lots.

Lot	Number of 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

Lot	Number of defectives	Quantity inspected	p
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 2: Calculate the $\overline{p}$ values

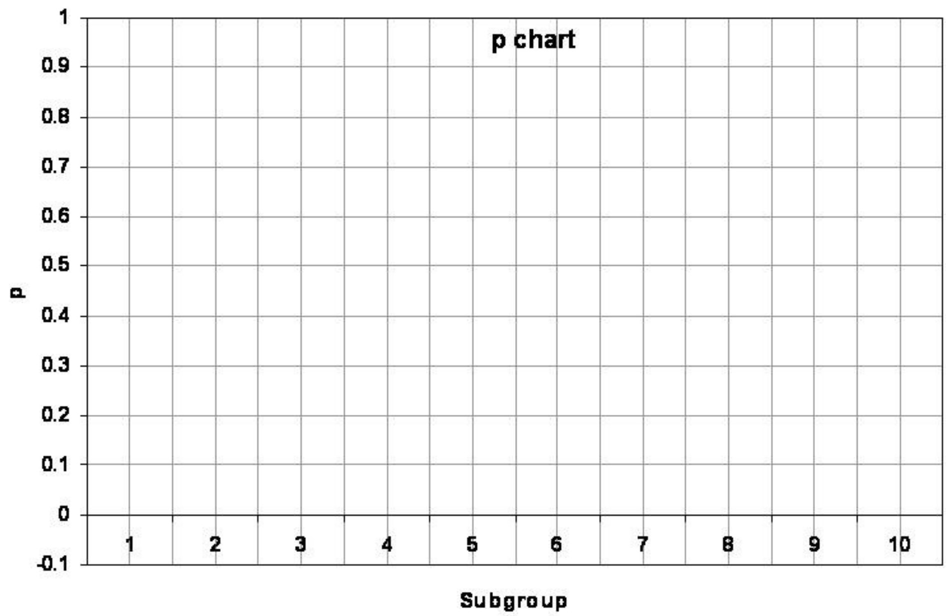
$\overline{p} =$

Step 3: Calculate the control limits

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

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

Step 4: Plot and interpret the chart



Conclusion:

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

Remember

✓ Choose the right control chart for the data
✓ Decide the subgroup size before setting up data collection

Chapter 6
Histogram
and
Process Capability

SPC Tool: Histogram

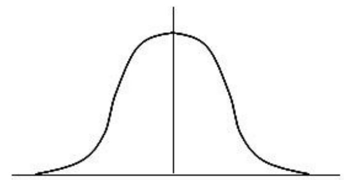
What is a histogram?
It is a bar graph drawn for variable data. The measurements are plotted on the X axis and the bars indicate the frequency counts for the measurements. A histogram shows the spread of the measurements and hence it is also called a “frequency diagram” that tells the amount of variation in the process.

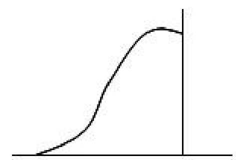
The most important aspect of the histogram is to observe the pattern it follows and the total spread.

Typical Patterns in a Histogram

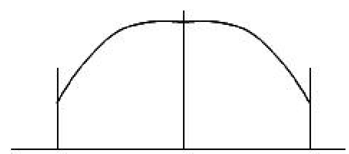
1) Most of the measurements tend to be clustered around the middle of the distribution with a small number around the tails. This pattern is called a “bell curve” or the “normal distribution”.

   A distribution that does not follow a normal distribution curve usually indicates the presence of an assignable cause.

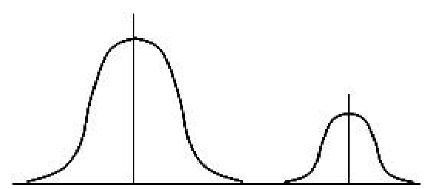




2) A truncated distribution indicates a part of the distribution has been removed through 100% inspection or there a natural limit in the process



3) A flat plateau -like distribution indicates that there is no defined process for producing the part.
   Therefore there are different measurements coming into a single distribution.

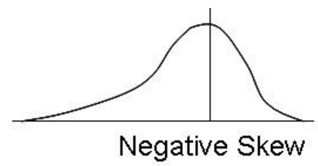


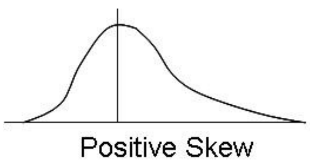
4) Separated twin peaked distributions indicate that measurements are coming from different sources

Skewness and Kurtosis

Skewness is the measure of symmetry of the data in a distribution. A normal distribution is symmetrical about the center and has a skewness of 0.

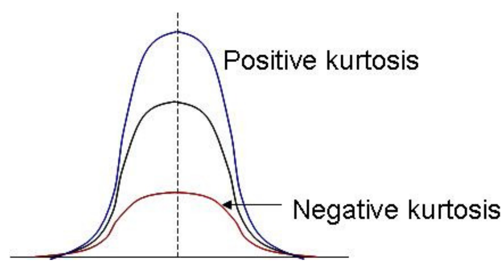
If more data is clustered to the right and the “tail” extends far into the negative side of the graph, the skewness is negative.





And if data is clustered to the left and the “tail” extends far into the positive side of the graph, the skewness is positive.

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



Advantages

- From the spread of the distribution, the variation in the process can be determined.
- Used to find the nature of distribution of the data
- Helps find out the where the data is coming from

Disadvantages

- Patterns not clear
- A snapshot of the process

Remember

- ✓ Have sufficient readings for plotting a histogram
- ✓ Look for unusual patterns in the histogram

SPC Tool: Process Capability

Process capability studies are used to determine whether the process is capable of producing product that conforms to customer specifications and whether it is able to do this consistently or not. These studies compare the process data with specifications.

Capability studies must be done on statistically stable processes. The control chart for a process that has points within control limits is statistically stable and suitable for capability studies.

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

Capability Indices Cp, Cpk are the measures of the capability of the process. They indicate whether the process is capable or not.

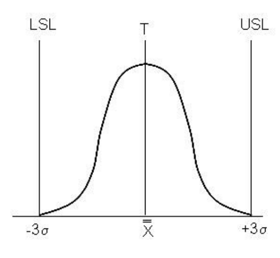
Cp – Capability Index compares the specification spread to the process data.

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

USL – Upper Specification limit
LSL – Lower Specification limit
σ – Process sigma

What do different values for Cp indicate?

1

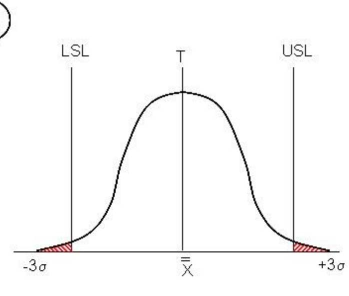


Cp = 1

When the specification spread and the process spread are the same, Cp is 1.

Cp of 1 means the process is producing some parts that fall right at the specification limits.
If the process shifts a little, parts will be out of specifications and the process will produce scrap.

2

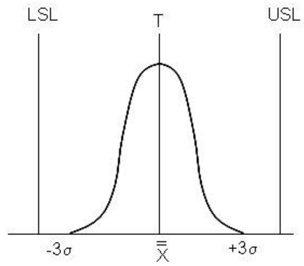


Cp < 1

When the specification spread is smaller than the process spread are the same, Cp less than 1.

Cp less than 1 means the process is producing some parts that fall out of the specification limits.
The process is incapable and is producing scrap.

3

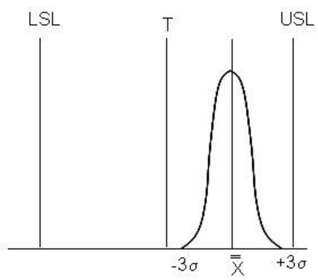


Cp > 1

When the specification spread is greater than the process spread, Cp is more than 1.

Cp greater than 1 means the process can produce parts that fall within the specification limits.
The process can be capable of producing all good parts.

4



Cp = 2

When the specification spread is far greater than the process spread, Cp is 2.

The process can be capable as all parts may fall within specifications.

Thus, higher the value of Cp, the more capable the process may be.
However, this does not consider process centering. So if the process shown in figure 4 is outside the upper specification limit, then it is producing 100% rejects. Therefore it is important to consider process centering before determining the actual capability of the process which requires the calculation of the capability index Cpk.

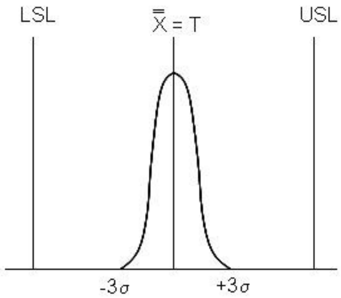
Cpk – Process capability with process centering

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

USL – Upper Specification limit
LSL – Lower Specification limit
σ – Process sigma
$\bar{\bar{X}}$ - Process Average

Interpreting the Cpk index for a given value of Cp

1

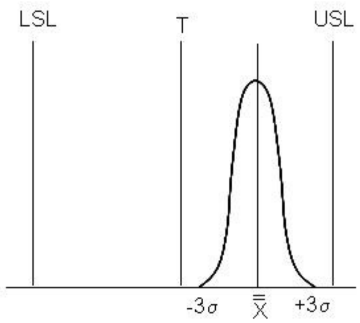


Cp = Cpk

If the process is centered, the process average matches with the target and Cp = Cpk.

This is the ideal situation as most of the parts are produced at target.

2



Cp > Cpk

If the process is not centered, the process average does not match with the target and Cp > Cpk.

Though the value of Cp may be high, the process has shifted to one side related to the target.
If the process shifts a little more, it may go out of specification and produce scrap.

Thus, a high value of Cp and low value of Cpk indicates an incapable process. Cp value must be as close to Cpk value as possible. Only then the process is centered.

In practice, one should look at the values of both Cp and Cpk to determine the capability of the process.

Example: Capability indices for pencils

Using the values from the Xbar – R Control chart, we will calculate the capability indices..

Part: Pencil
Specifications for pencil diameter: 6.7 ± 0.5mm
USL = 7.2 mm and LSL = 6.2mm

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

$\bar{R} = 0.2$

Standard deviation from Xbar – R chart

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

$$\sigma = 0.086$$

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

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

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

$$Cpk = 2.01 \text{ or } 1.86$$

$$Cpk = 1.86$$

Interpreting the values of Cp and Cpk

1) Cp is close to the Cpk. The process average is close to the target.
2) Cp and Cpk values near 2.

Conclusion: Process is capable.

Exercise:
Capability indices for the radio example

Part: Radio
Specifications for sound output from Radio: 80 ± 10db
USL = 90 db and LSL = 70 db

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

$\sigma = \bar{R} / d_2 \qquad\qquad d_2 = 2.059$ for subgroup size of 4

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

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

$Cpk =$

Interpretations and Conclusion:

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

Remember

✓ Conduct process capability studies on stable processes
✓ Higher the Cp, Cpk values, more is the process capability

Chapter 7
Scatter Diagram

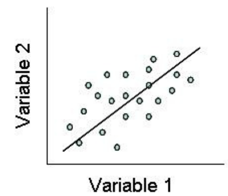
SPC Tool: Scatter diagram

What is a scatter diagram?
It is a point graph drawn for variable data. The measurements for 2 variables are plotted on the X and Y axis. The scatter diagram is used to find relations between two variables. It finds whether the two variables are related or not. And if they are, what is the nature of the relationship.

Typical Patterns in Scatter diagram

1) Positive Correlation
When the values for variable 1 increase along with those for variable 2, then the relation is positive.

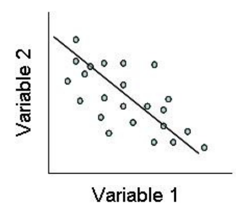
The coefficient of correlation(r) = +1
Practically, r will have value less than 1. However any value near 1 can be considered as a positive correlation



Positive Correlation
r = +1

2) Negative Correlation
When the values for variable 1 decrease as those for variable 2 increase, then the relation is negative.

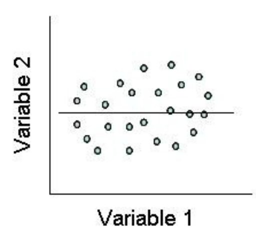
The coefficient of correlation(r) = -1
Practically, r will have value between 0 and -1. However any value near -1 can be considered as a negative correlation



Negative Correlation
r = -1

3) No Correlation
When the values for variable 1 behave randomly as compared to as those for variable 2 increase, then the two variables are not related at all.

The coefficient of correlation(r) = 0



No Correlation
r = 0

Advantages

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

Disadvantages

- Cause and effect relation between variables

Remember

✓ Plot scatter diagrams before beginning a correlation-regression analysis

Chapter 8
SPC Tools and Uses

Summary of SPC Tools and Uses

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. Helps determine the top three causes by group consensus.
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

Do's 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

Appendix

Assignable Cause
An assignable cause is a special cause that causes non random variation in the process. Usually, an "out of control" process indicates the presence of an assignable cause.

Attribute Data

Data that counts the occurrences for good/bad products.

Brainstorming

A group of people discuss the problem and come up with a list of ideas/causes.

c-chart

The c-chart measures the number of nonconformities (or defects) in an inspection lot. It requires a constant sample size or amount of material inspected.

Capability

A process is said to be capable when all the parts produced are within specifications.

Cause and Effect diagram

Lists all possible causes for the problem under the 4Ms – Man, Method, Machine, Material. Also, known as the Fishbone or Ishikawa diagram.

Check Sheet

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

Cp

Process capability index that compares the specification width with the process spread.

Cpk

Process capability index with process centering. This index determines how much the process average has shifted from the target.

Common Causes

Inherent variations present in the process. These random variations cause the control charts to vary up and down around the centerline.

Control Chart

A line graph plotted for process data with central line, and upper/lower control limits. It is used to find out whether the process is in control or not.

Control Limits

A control limit is denoted by a line (UCL, LCL) on a control chart and is used as a basis for judging the significance of the variation from subgroup to subgroup. Variation beyond a control limit is evidence that special causes are affecting the process. Control limits are calculated from process data and should not to be confused with specifications.

Coefficient of Correlation

The coefficient of correlation(r) indicates the strength of the relation between two variables. It can take any value between -1 and 1.

Defect

Types of non conformities observed in a part. A single part can have many defects.

Defective

The entire part that did not conform to the acceptance criteria. Example of defectives is the number of parts that failed in a lot.

Detection Model

This model uses a reactive approach that just detects defects produced by a process. And if the product is good it is delivered to the customer, otherwise it is repaired or scrapped.

Histogram

A bar graph used to represent a frequency distribution. The graph is divided into ranges, and the bars show how many data points fall in each range. Often a distribution curve is transposed over a histogram to classify the data's type of distribution.

Kurtosis

Kurtosis refers to the degree of peakedness or flatness of the curve laid over a histogram.

Mean

The average of values in a group measurement, indicated by the symbol $\bar{x}$.

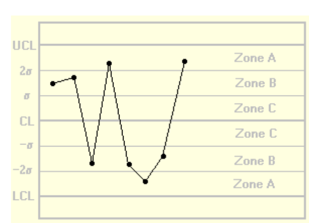
Median

The middle value in a group of measurements arranged from lowest to highest, indicated by the symbol $\tilde{x}$. If the number of values is even, by convention, the average of the middle two values is used as the median.

Mixture

A pattern on the control chart that indicates that data is coming from different systems/processes.

Control test which checks for 8 points in a row on both sides of the center line in Zone B or beyond, but with no points in Zone C.



Mode

The mode is the most frequently occurring value in a set of values.

Moving Range

Range based on values of sequential subgroups. Generally used when the subgroup size = 1.

Nonconformities

Specific occurrences of a condition that does not conform to specifications or other inspection standards (also called defects).

Non-conforming

The number of parts that did not meet the acceptance criteria (also called defectives).

np-chart

The np-chart measures the number of nonconforming (or defective) items in an inspection lot. It is identical to the p-chart except that the actual number of nonconforming items, rather than their proportion of the sample, is recorded.

Pareto Chart

A chart that ranks all potential problem areas or sources of variation according to their contribution to cost or to the total defect count.

Pareto Principle

80% of the problems are because of 20% causes. Also, known as the 80/20 rule.

p-chart

The p-chart measures the proportion of nonconforming (or defective items) in a group of items being inspected.

Prevention Model

This model uses the proactive approach that corrects the process using SPC so that defects are not produced in the first place.

Range

The difference between the highest and lowest values in a subgroup.
Example: For the data (1, 2, 6, 4, 5) the range is 6 - 1 = 5.

Run

A trend seen on the control chart. Usually, a run is 7 consecutive points continuously increasing or decreasing.

Scatter Diagram

The Scatter Diagram plots one variable characteristic against another as a point graph. It is used to see if there is a relationship between these characteristics and if there is, to study the correlation.

Sigma

The Greek letter σ used to designate a standard deviation.

Skewness

The distribution's lack of symmetry. Distribution is said to have positive or negative skewness depending on the direction of the longer tail.

SPC

Statistical Process Control or SPC is a method for achieving quality control in the manufacturing environment.

Specification Limits

The Lower (LSL) and Upper (USL) Specification Limits are the engineering requirement for judging acceptability of a particular characteristic.

Standard Deviation

A measure of the spread of the process output or a spread of a sampling statistic from the process denoted by the S standard deviation calculated from all process data, and by σ to indicate standard deviation estimated from a set of samples from the collected data.

Stratification

When the output of several processes that are identical is plotted on a control chart, stratification occurs.
Control test which refers to the presence of points near the center line.

Subgroup

The number of measurements of a variable characteristic collected at any given time. Eg. 5 readings for temperature every hour.

Target

The target is the nominal value of a measurement for the part, typically centered between the upper and lower specifications.

u-chart

The u-chart measures the number of nonconformities (or defects) per inspection lot. This chart is used with attributes that have variable lot sizes.

Variable Data

Variable data is a physical measurement, such as the diameter of a bearing journal in millimeters, the closing effort of a door in kilograms, the concentration of a chemical in a liquid. $\bar{X}$ and R, $\bar{X}$ and S, $\tilde{x}$ and R, and $\tilde{x}$ (r) and R control charts are used for variable data.

Xbar –R chart

Variable control chart that plots the Average and Range of the measurements in a subgroup.

Xbar –S chart

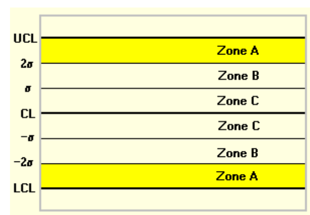
Variable control chart that plots the Average and Standard deviation of the measurements in a subgroup.

X – MR chart

Variable control chart that plots the Actual measurement and Moving Range of the measurements in a subgroup. Used when subgroup size is 1. It is also called the Individuals-Moving Range chart.

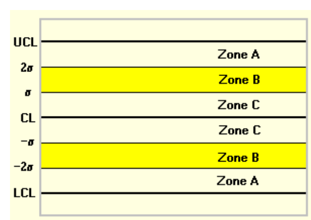
Zone A

Zone A is the outermost one-third of the area between the centerline and the upper and lower limits on a control chart. This area is the band between 2 σ and 3 σ from the CL value for a characteristic.



Zone B

Zone B is the center one third of the area between the centerline and the upper and lower limits on a control chart. This area is the band between 1 σ and 2 σ from the CL value for a characteristic.



Zone C

Zone C is the innermost one third of the area between the centerline and the upper and lower limits on a control chart. This area is the band between the target value and 1 σ from the CL value for a characteristic.