Six Sigma Quality: Concepts & Cases- Volume I

STATISTICAL TOOLS IN SIX SIGMA DMAIC PROCESS WITH MINITAB® APPLICATIONS

Chapter 5

Quality Tools for Six Sigma

Basic Quality Tools and Seven New Tools

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Chapter Highlights

This chapter deals with the quality tools widely used in Six Sigma and quality improvement programs. The chapter includes the seven basic tools of quality, the seven new tools of quality, and another set of useful tools in Lean Six Sigma that we refer to –"beyond the basic and new tools of quality." The objective of this chapter is to enable you to master these tools of quality and use these tools in detecting and solving quality problems in Six Sigma projects. You will find these tools to be extremely useful in different phases of Six Sigma. They are easy to learn and very useful in drawing meaningful conclusions from data. In this chapter, you will learn the concepts, various applications, and computer instructions for these quality tools of Six Sigma. This chapter will enable you to:

1. *Learn the seven graphical tools - considered the basic tools of quality. These are:*
   - *(i) Process Maps*
   - *(ii) Check sheets*
   - *(iii) Histograms*
   - *(iv) Scatter Diagrams*
   - *(v) Run Charts/Control Charts*
   - *(vi) Cause-and-Effect (Ishikawa)/Fishbone Diagrams*
   - *(vii) Pareto Charts/Pareto Analysis*
2. *Construct the above charts using MINITAB*
3. *Apply these quality tools in Six Sigma projects*
4. *Learn the seven new tools of quality and their applications:*
   - *(i) Affinity Diagram*
   - *(ii) Interrelationship Digraph*
   - *(iii) Tree Diagram*
   - *(iv) Prioritizing Matrices*
   - *(v) Matrix Diagram*
   - *(vi) Process Decision Program Chart*
   - *(vii) Activity Network Diagram*
5. *Learn the construction and applications of some other quality tools including the stem-and-leaf and box plot.*
6. *Learn a set of powerful tools beyond the basic and new tools of quality that include multi-vari charts, symmetry plots, and variations of scatter plots.*
7. *Learn how to construct the symmetry plots, and multi-vari charts using MINITAB.*

Chapter Outline

Seven Basic Tools of Quality

1. Process Maps
2. Check Sheets
3. Histograms
   - Using Histograms to Detect the Shift and the Variation in the Process
   - Evaluating Process Capability Using Histogram
4. Scatter Plots
5. Run Chart / Control Charts
   - Constructing a Run Chart
   - A Run Chart with Subgroup Size Greater than 1
   - A Run Chart with Subgroup Size Greater than 1
   - Run Chart Showing a Stable Process, a Shift, and a Trend
6. Cause-and-Effect Diagram or Fishbone Diagram
   - Cause-and-Effect Diagram (1)
   - Cause-and-effect Diagram (2)
   - Creating other Types of Cause-and-effect Diagram
7. Pareto Chart
   - A Simple Pareto Chart
   - Pareto Chart with Cumulative Percentage
   - Pareto Chart with Cumulative Percentage when Data are in One Column
   - Pareto Chart by Variable

Some other Quality Tools:

1. Stem-and-leaf Plot
2. Box Plot

The Seven New Tools for Quality Improvement

(1) Affinity Diagram
(2) Interrelationship Digraph
(3) Tree Diagram
(4) Prioritizing Matrices
(5) Matrix Diagram
(6) Process Decision Program Chart
(7) Activity Network Diagram

Chapter Outline…continued

- -Multi-Vari Chart
- -Box Plots
- -Main Effects and Interaction Plots
- Example 21: Determine a Machine-to-Machine, Time-to-Time variation
- Part-to-Part Variation in a Production Run using Multi-vari and Other Plots

Symmetry Plot
Summary and Applications

This chapter explains the quality tools and graphical techniques that have been applied as problem-solving tools in quality and lean six sigma. Many graphs and charts are helpful in detecting and solving quality problems. Some of the graphical techniques in this chapter are described in previous chapters. In this chapter we describe and analyze the graphs and charts as they relate to quality. We also provide examples and specific situations in which these graphical techniques are used in detecting and solving quality problems.

Some examples from the chapter are presented below. The book provides step-wise instructions with data files for each case.

Seven Basic Tools of Quality

The following seven graphical tools are considered the basic tools of quality:

(1) Process Maps
(2) Check sheets
(3) Histograms
(4) Scatter Diagrams
(5) Run Charts/Control Charts
(6) Cause-and-Effect (Ishikawa)/Fishbone Diagrams
(7) Pareto Charts/Pareto Analysis

A logical order of use of these tools is given in Figure 5.1. However, these tools can be used in any order.

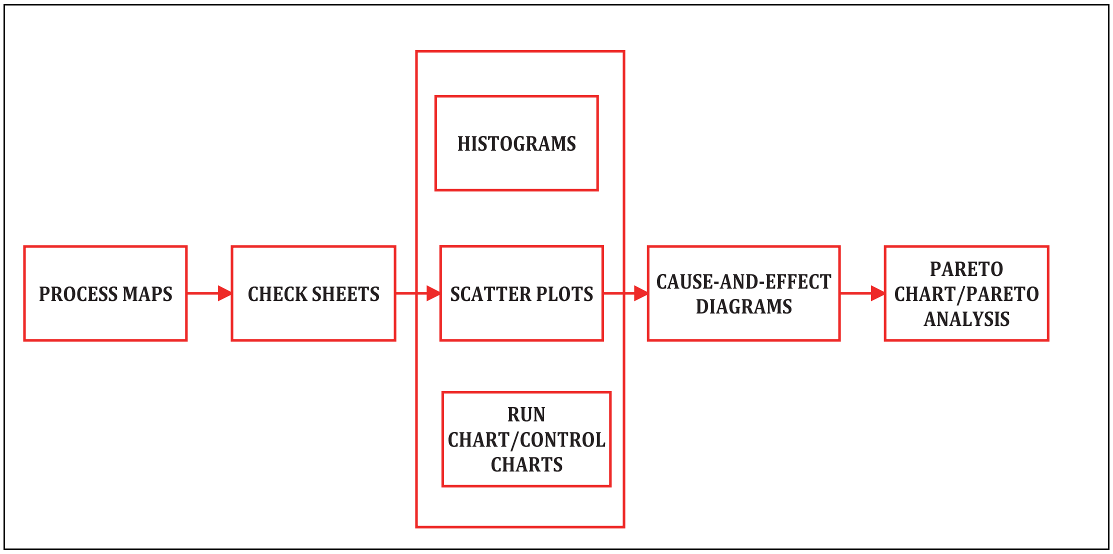

Figure 5.1: A Logical Sequence of Seven Basic Tools of Quality.

Example 5.1: A SIPOC Process Map of Online Order Processing

SIPOC ANALYSIS AND MAP: ONLINE ORDER PROCESSING

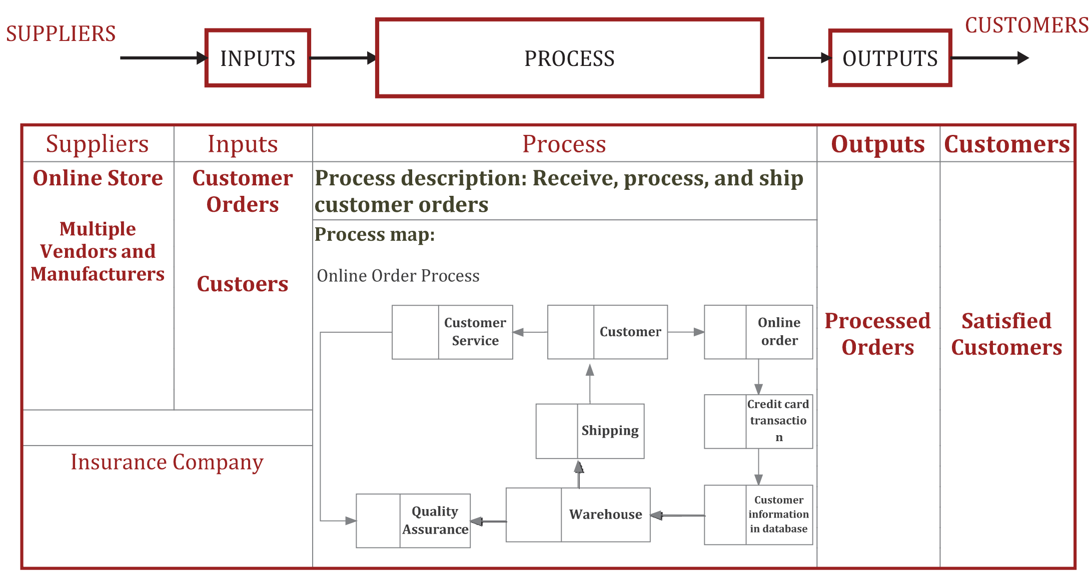

Figure 5.4: An Example of SIPOC Map

Several computer packages are available for process mapping. Microsoft's Visio is one of them. The process mapping process uses a number of symbols to show the major elements of a process. The commonly used symbols used in a process map are shown in Figure 5.5.

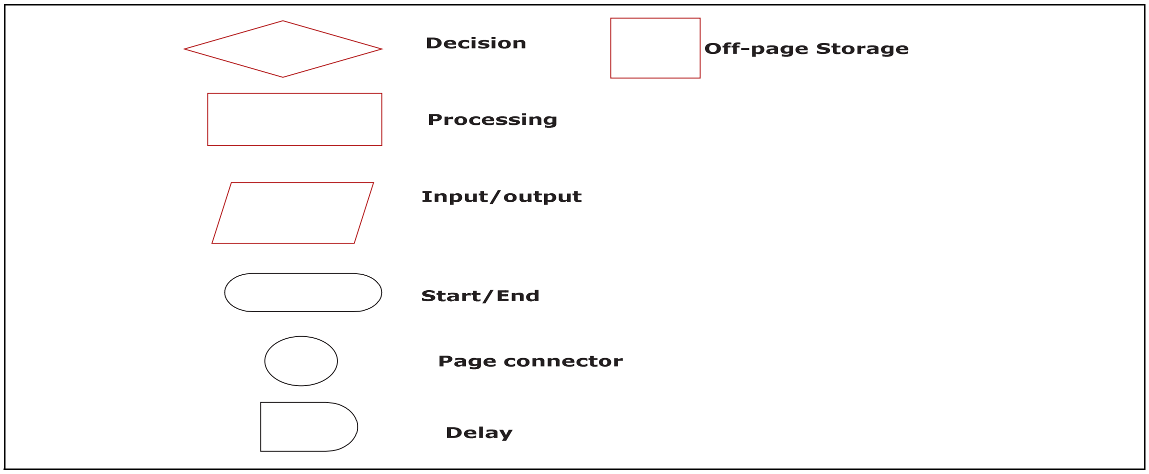

Figure 5.5: Symbols and their Meaning in Process Mapping

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Value Stream Mapping (VSM): Overview

The objective of Value Stream Mapping (VSM) is to document the current and future states of a selected process. It is a special type of process map that shows both the information and material flows along the ***value stream*** from the initial stage or the beginning to the end of a process, or from the supplier to the customer. The activities in a value stream map include the flow of materials throughout the supply chain, the transformation activities in the manufacturing, or the service process being considered, and the information flow to support these activities.
A value stream map is similar to a process map with some *more added features*.

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Major Steps of a Value Stream Mapping Process

The major steps to Value Stream Mapping are:

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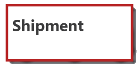
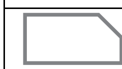
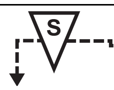
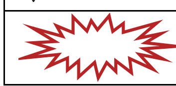
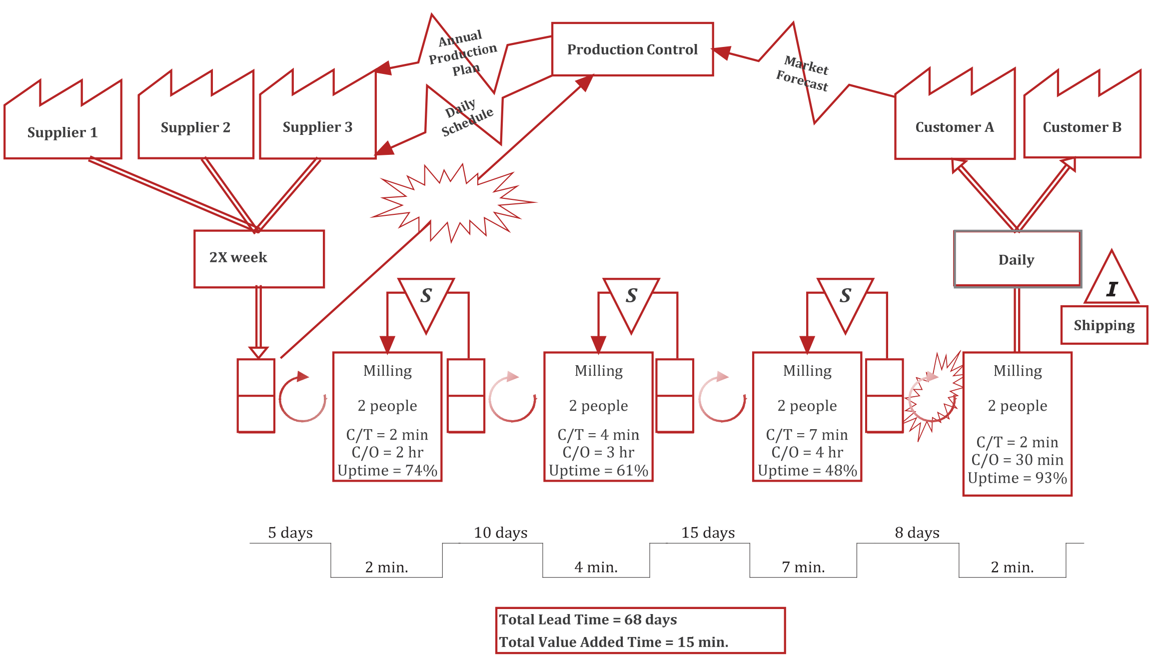
Table 5.1 (a): Symbols used in a Value Stream Map

Symbol	Explanation
C/T	Cycle Time
C/O	Changeover Time
	Inventory
	Truck Shipment
	External Source (Supplier, Customer)
	Electronic Information
	Movement of Material
	Supermarket (a controlled inventory of parts)
	Withdrawal (pull of material)
	Production (card or device that signals how many of what to produce)
	Signal kanban (shows when a batch of parts in needed)
	Kaizen Burst (identifies improvement needs)

A Current State Value Stream Map of a Production and Distribution System

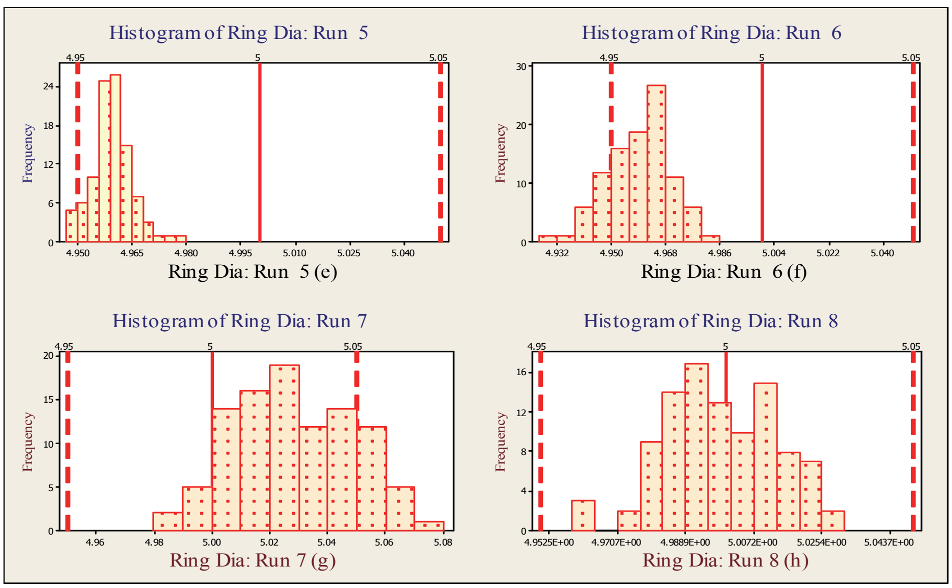


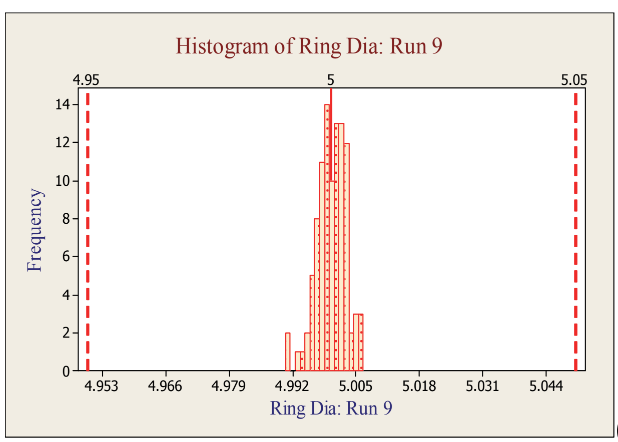
Example 5.5: Using Histograms to Detect the Shift and the Variation in the Process

MINITAB Instructions

HISTOGRAM	Open the worksheet **PROCESSHIST.MTW** From the main menu, select **Graph ➢Histogram** Click on **With Outline and Groups** then click **OK** For **Graph Variables** type or select **C1 Ring Dia: Run1** Click on **Scale** then click the **Reference Lines** tab In the **Show reference lines at data values** type **4.95 5.0 5.05** (with a space between each value) Click **OK** in all dialog boxes.

Reults:





(i)

Figure 5.9(e) The process has shifted to the left; products out of specification, Figure 5.9(f) Process shift to the left; more variation compared to (e), Figure 5.9(g) Process out of control and has large variation, Figure 5.9(h) Process within control but has large variation, Figure 5.9 (i)

Process stable and close to the target (desirable)

Continued….

Example 5.8: Scatterplot Showing a Nonlinear Relationship between x and y

The data file **YIELD.MTW** shows the yield of a chemical process at different temperatures. The scatterplot of the variables temperature (x) and the yield (y) shows a nonlinear relationship. The scatterplot in this case can be best approximated by a quadratic equation. To do the scatterplot and fit a quadratic equation to the data, follow the instructions in Table 5.7.

The plot shows a strong relationship between x and y. The equation relating the temperature and the yield can be very useful in predicting the maximum yield or optimizing the yield of the process.

Table 5.7

FITTED LINE PLOT	Open the worksheet **YIELD.MTW** From the main menu, select **Stat ➢Regression ➢Fitted Line Plot** For **Response (Y)** type or select **C2** or **Yield** For **Predictor (X)** type…. : : Click **OK**

The fitted curve along with the equation is shown in Figure 5.12.

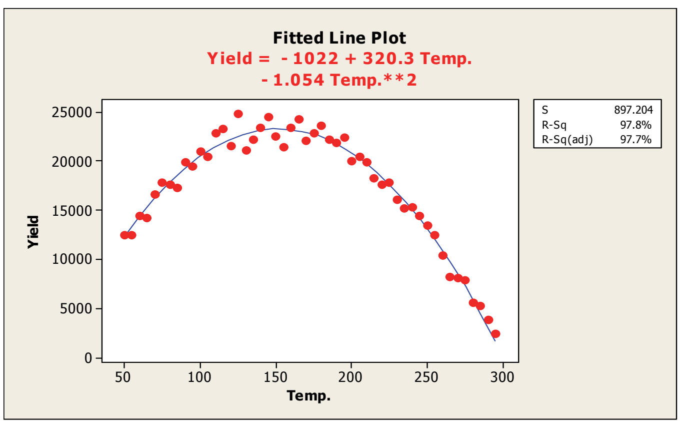


Figure 5.12: Scatterplot with Best Fitting Curve

Note that the equation of the fitted curve in Figure 5.12 is

Continued….

Example 5.10: Scatterplots with Histograms, Box plots, and Dot plots

To construct a scatterplot with histograms, box plots, or dot plots of x and y variables, follow the instructions in Table 5.10.

Table 5.10

SCATTER PLOT WITH HISTOGRAMS	Open the worksheet **SALES&AD.MTW** From the main menu, select **Graph ➢Marginal Plot** Click on **With Histograms** then click **OK** For **Y variable** select **C3 or Profit ($)** For **X variable** select **C2 or Sales ($)** **:** **:** Click **OK** in all dialog boxes.

The scatterplot with histograms of x and y variables shown in Figure 5.15 will be displayed.

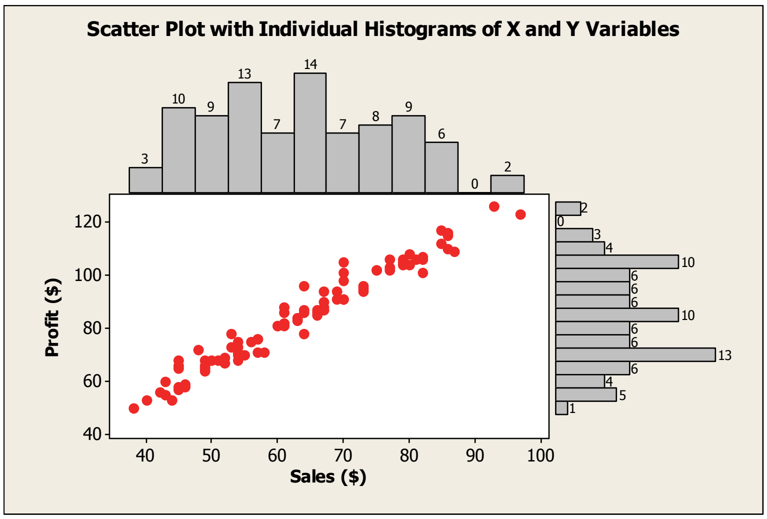


Figure 5.15: Scatterplot with Histograms of x and y Variables

Continued….

Example 5.15: Run Chart Showing a Stable Process, a Shift, and a Trend

Below we have shown three different run charts showing a stable process, a shift in the process, and a process with an upward trend. The data for these charts are in the data files **RUNCHART2.MTW** and **RUNCHART3.MTW**. To construct these charts, follow the steps in Table 5.15.

Table 5.15

RUN CHART	Open the worksheet **RUNCHART2.MTW** From the main menu, select **Stat ➢Quality Tools ➢Run Chart** Under **Data are arranged as** click the circle next to **Single column** and : : : In the **Subgroup size** box type **1** Click the **Options** tab and type a title for your plot Click **OK**

A run chart will be displayed on the graphics window. The default chart has dotted lines and square points. To change the dotted line, double click on the line. The **Edit**

Line Attribute dialog box will be displayed. Click on the circle next to **Custom** and select the line type and color from the drop down menus. Similarly, to change the symbol from a square to a circle, double click on the symbol; then from the **Edit Symbol** dialog box, select the desired symbol, color, and size from the drop down menus. We have selected the solid line and circle for the line and plotted points. The run chart is shown in Figure 5.22. This run chart does not show a shift or trend, so the process can be considered stable.

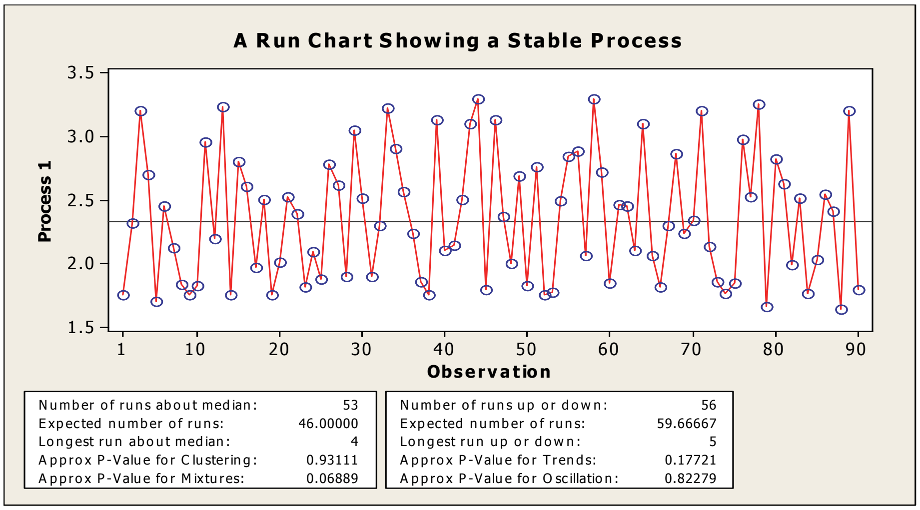


Figure 5.22: A Run Chart Showing a Stable Process

Figures 5.23 and 5.24 show run charts with other possible patterns. Figure 5.23 shows a run chart with a trend while Figure 5.24 displays a shift in the process. To construct these charts, open the worksheet **RUNCHART3.MTW** and create the charts for **Process 2** and **Process 3** one at a time. Follow the instructions in Table 5.15. Note that you can edit the graphs to change the line type and plotted symbols.

Figure 5.23 shows that the process is not stable. Immediate action is required to prevent it from exceeding the upper specification limit. Figure 5.24 is an indication of a drastic shift in the process. The process shows a sudden shift. Corrective actions are required to stabilize the process.

Control Charts: Fundamentals and Concept

A control chart is one of the tools used to monitor and control a process and systematically reduce process variability. Systematic variation reduction in product and process quality characteristics leads to better product/service performance, better perceived quality by customers, and eventually enhanced competitive position and improved market share. Since the control charts are used to study the variation in a process, an understanding of types of variations is important to understand the control charts.

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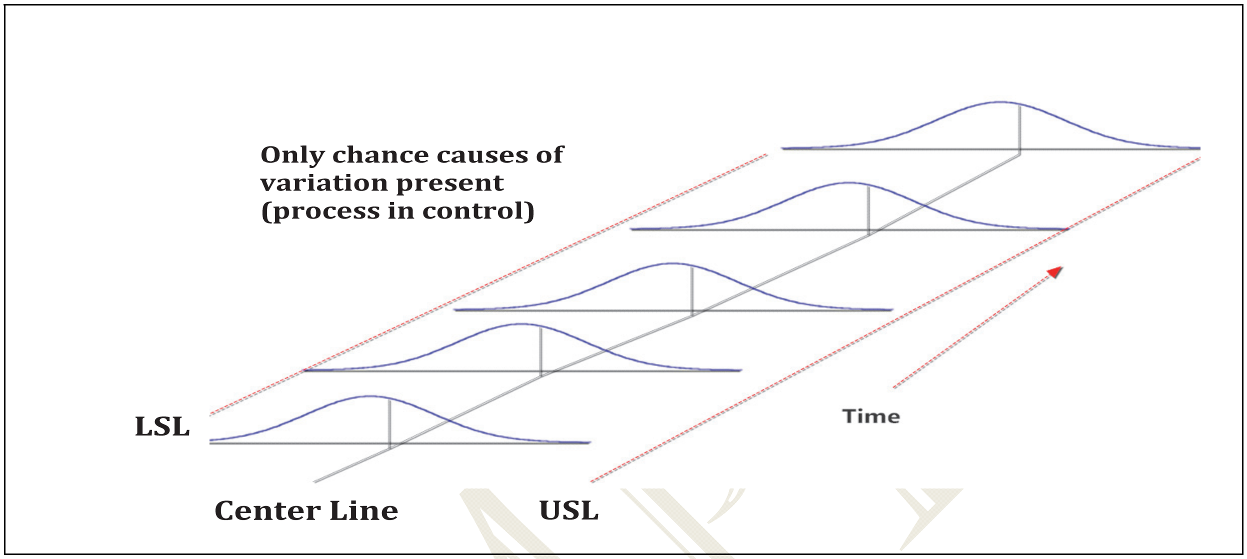


Figure 5.25: A Process Running with Only Chance Causes of Variatio

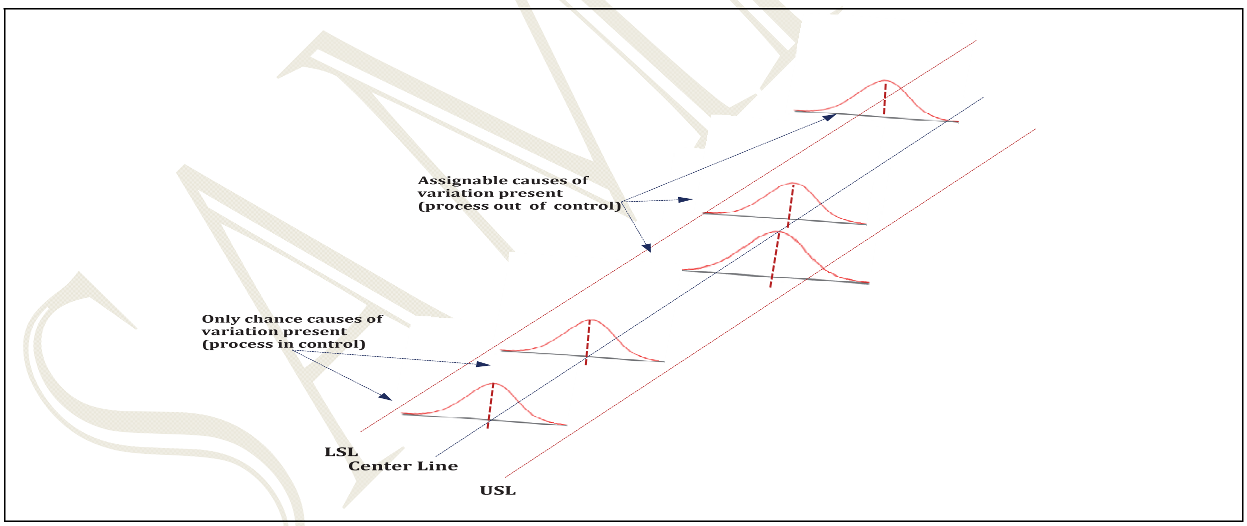


Figure 5.26: A Process Running with Assignable Causes of Variation

Continued....

Requirements for Control Charts

The following are some of the requirements for using the control charts:

- Understand the process for implementing the process charts
- Know how to interpret the charts
- Know when different process charts are used

- Know how to compute the limits for different charts and the statistical basis behind them

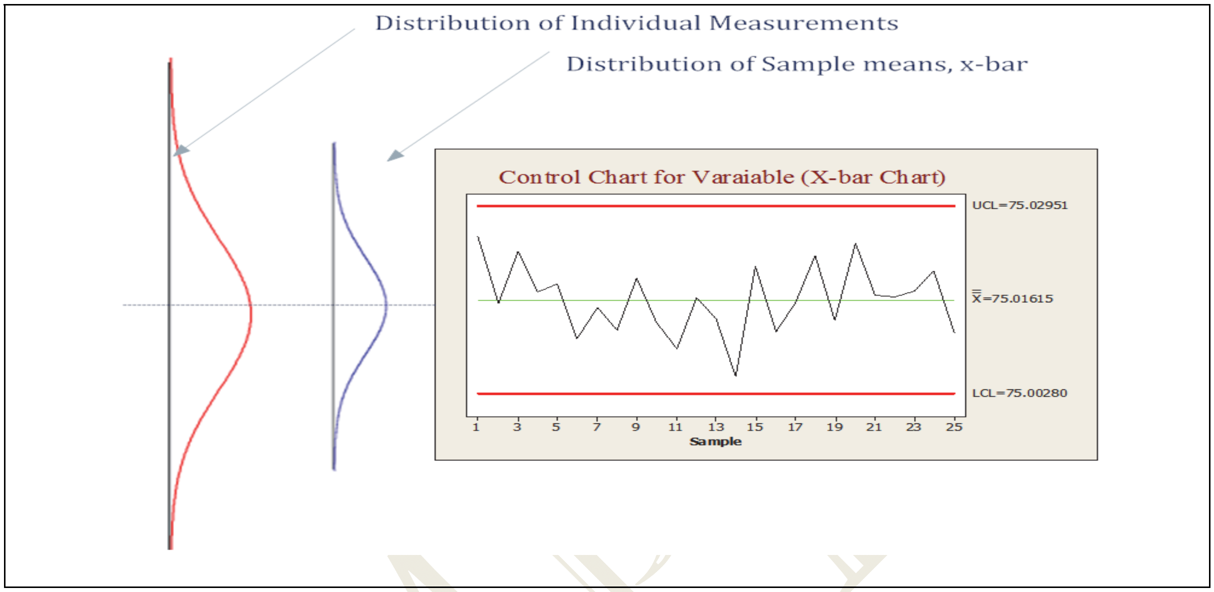


Figure 5.29: Statistical Basis of Control Chart

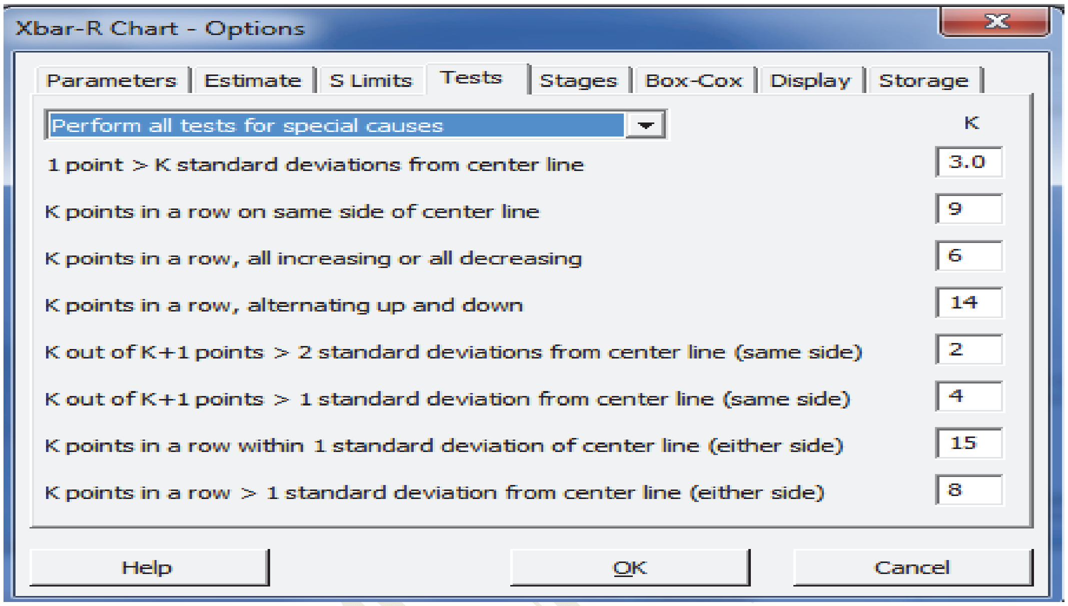
Continued….

Xbar and R CHART Table 5.18

Xbar and R CHART	Open the worksheet **SHAFT1.MTW** From the main menu, select **Stat ➢Control Charts ➢ Variables Charts for Subgroup ➢ X-bar-R** Select **Observations for a subgroup are in one row of columns** In the box select the columns **C1-C5** (labeled n1-n5) Click on the **Scale** tab and select **Index** under **x Scale;** click **OK** **:** **:** Click on **Xbar-R Options…** tab and select **Tests** From the drop down menu select: **Perform all tests for special causes** Click **OK** in all dialog boxes

Selecting the option to perform all the tests for assignable causes will test for the causes shown in Table 5.19. The X-bar and R control charts shown in Figure 5.30 will be displayed on the graphics window.

Table 5.19



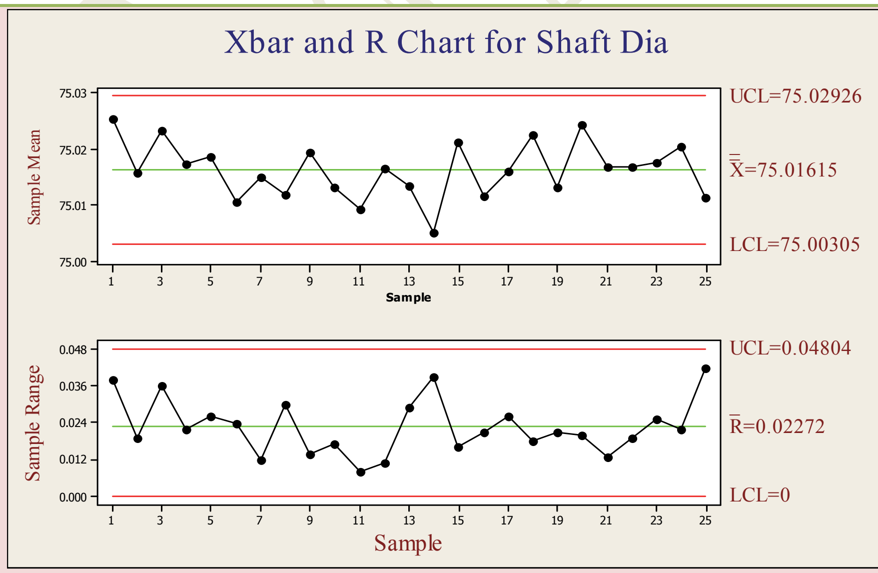


Figure 5.30: Variable Control Charts for the Shaft Diameter

Cause-and-Effect Diagrams or Fishbone Diagrams

Table 5.22

CAUSE-AND-EFFECT DIAGRAM	Open the worksheet **CAUSE1.MTW** From the main menu, select **Stat ➢Quality Tools ➢Cause-and-Effect** Complete the **Cause-and-Effect** dialog box shown in Figure 5.35 Click in the first box under **Causes** then double click on **Internal Failure Cost** from the left pane of the dialog box to appear in the box under **Causes** Repeat for all other causes The boxes under **Label** will show the default labels : : : In the Title box type the title shown in Figure 5.35 below Check the box next to **Do not display empty branches** Click **OK**

Continued….

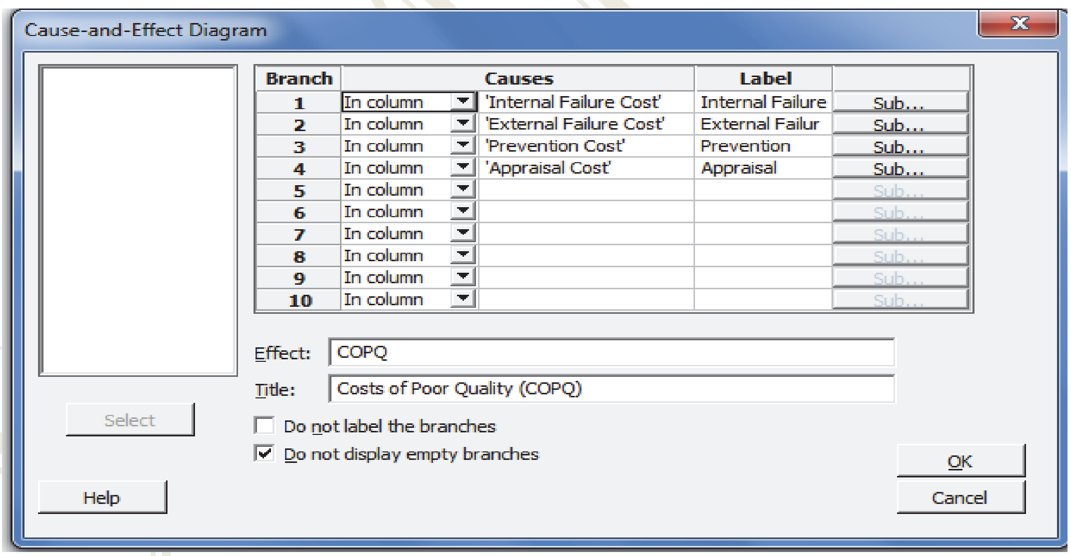


Figure 5.35: The Cause-and-Effect Dialog Box for Cost of Poor Quality

Figure 5.36 shows the edited cause-and-effect diagram. To edit the graph, double click anywhere in the background to get the **Edit Graph and Figure** dialog box. Next, click the circle next to **Custom** and change the background color. Similarly, you can double click on the labels and change the font color, font size, and font type. Make the font size smaller if the graph does not display the causes completely.

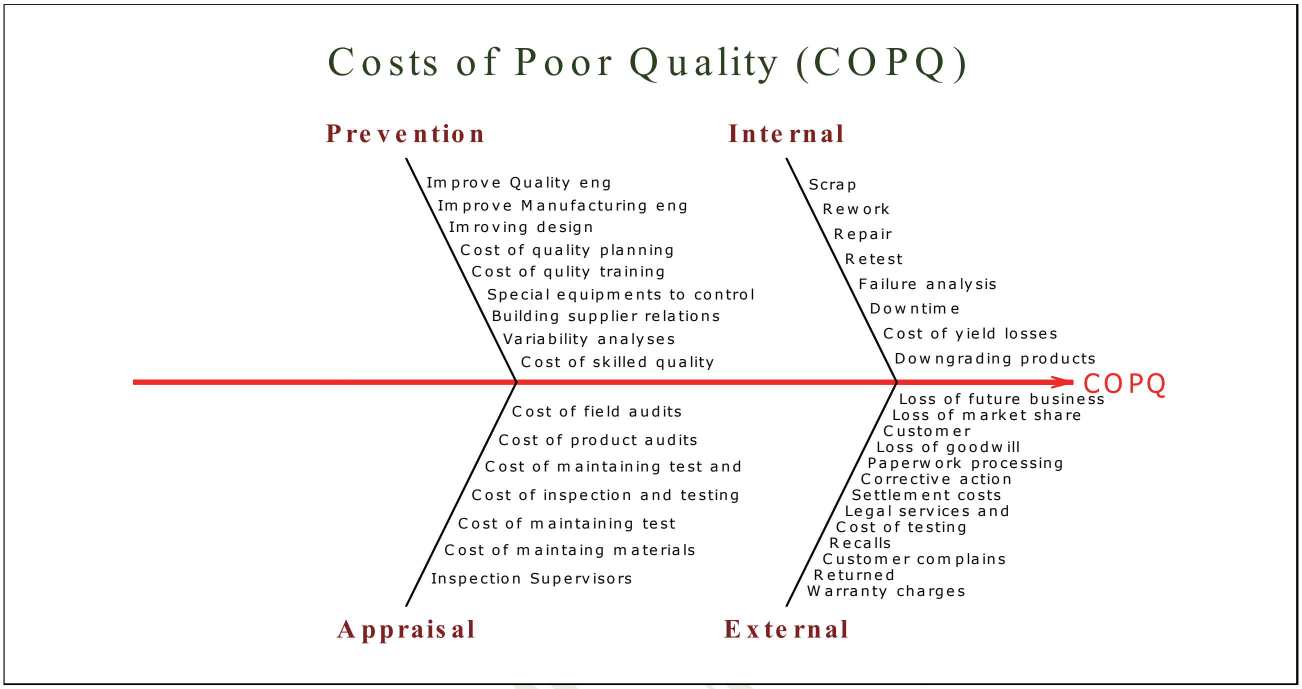


Figure 5.36: A Cause-and-Effect Diagram of Cost of Poor Quality

Pareto Charts

A Pareto chart is very similar to a histogram or a frequency distribution of attribute data where the bars are arranged by categories from largest to smallest with a line that shows the cumulative percentage and count of the bars. This chart is widely used in quality improvement projects. Through this chart, the problem that occur most frequently can be identified quickly and easily.

To construct a simple Pareto chart, follow the instructions in Table 5.23.

Table 5.23

A SIMPLE PARETO CHART	Open the worksheet **PARETOCHART.MTW**
	From the main menu, select **Stat ➢Quality Tools ➢ Pareto Chart**
	Defect or attribute data in: select **C1** or **Failure Cause**
	Frequencies in: **C2 or Count**
	In the **Combine remaining defects into one category …**
	:
	:
	:
	Next**,** type a title for your plot **and** click **OK** in all the boxes

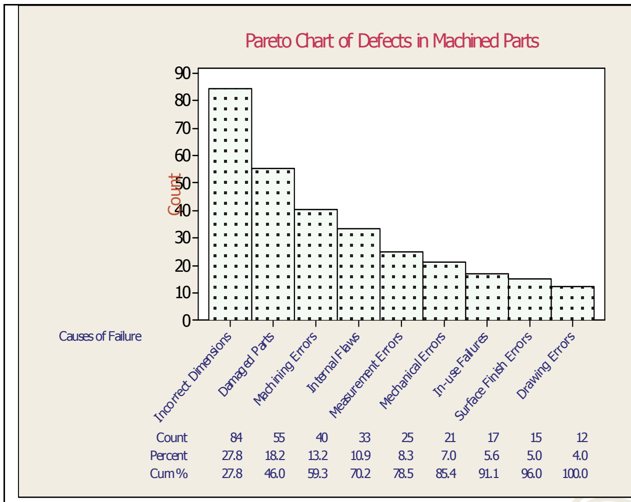


Figure 5.37: Pareto Chart of Defect Data with No Cumulative Points Plotted

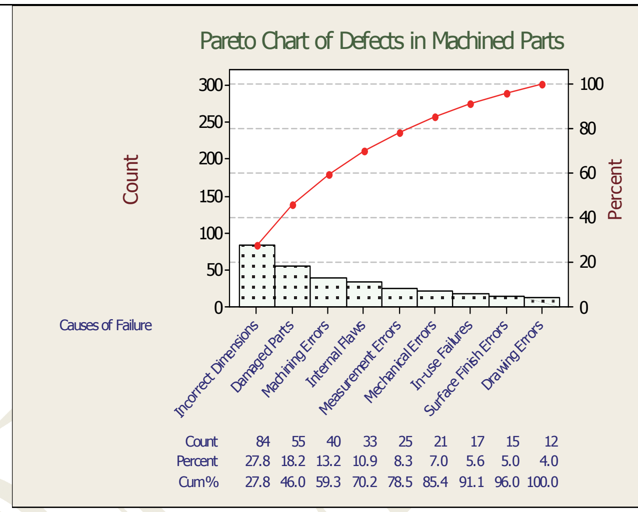


Figure 5.38: Pareto Chart of Defect Data with Cumulative Points Plotted

Continued…

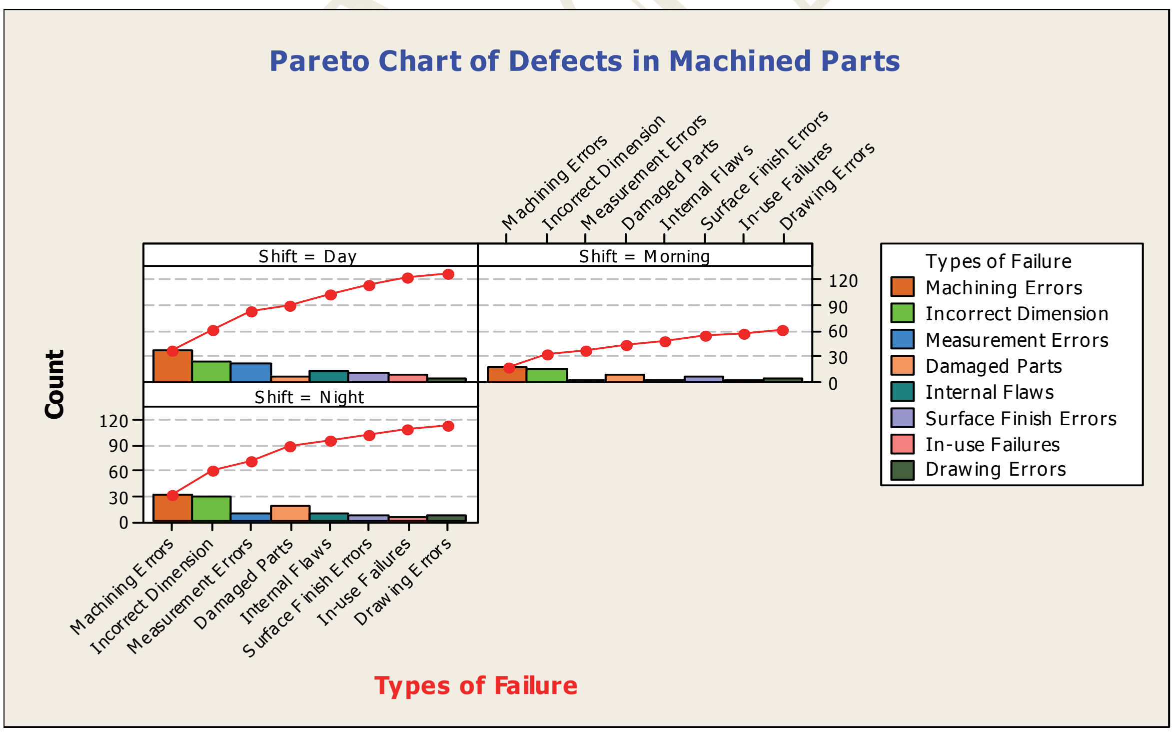
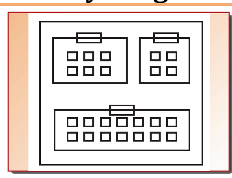
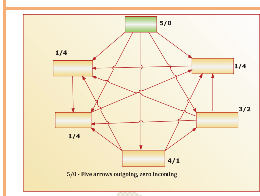
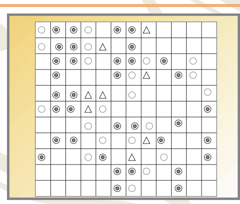
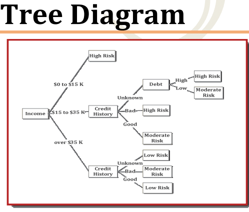
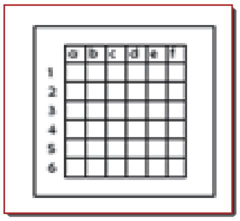
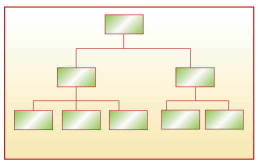
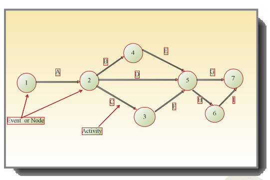


Figure 5.41: Pareto Chart of Defects vs. Shift (all shifts plotted on one graph)

Seven New Tools for Quality: **For Examples, construction and application of each tool below, see the text**

The seven new tools for quality are a powerful set of tools that have been successfully used as decision making tools for managing projects that involve team. Combined with the basic seven tools of quality (discussed earlier in this chapter), these tools provide simple visual tools to understand different processes. These tools are particularly useful in solving unstructured problems. The table below provides a summary of these tools.

Affinity Diagram	
	Affinity diagram is a visual tool that gathers large amounts of data and organizes them into ….
Interrelationship Digraph	
	The interrelationship digraph is used to identify the relationships between different issues relating to a problem. This graph may be used as an extension to the affinity diagram and …..
Matrix Diagram	
	The matrix diagram is a tool used to identify, analyze, and rate the relationship among two or more variables…….The factors with higher ratings or a higher relationship are given high priority. Variations of this matrix include six differently shaped matrices: L, T, Y, X, C, R and roof-shaped, depending on how many groups are compared.
Tree Diagram	
	The tree diagram is used to break down broad categories into different levels of detail. It starts with one item or issue that branches into two or more ….The tree diagram helps to break down and get to the details of a general idea.

Prioritizing Matrix	
	A prioritization grid is used to make decisions involving multiple criteria and multiple alternatives. This tool prioritizes issues based on weights by performing a pair-wise evaluation based on ....
Process Decision Program Chart	
	The Process Decision Program Chart (PDPC) is a tool for contingency planning. This tool can be used to implement a plan or a program, or improve a program. It helps to brainstorm possible problems and identify ....
Activity Network Diagram	
	The Activity Network Diagram is also known as the PERT (Program Evaluation and Review Technique) network, and CPM - the Critical Path Method (CPM) network. The CPM and PERT networks are widely used in planning, scheduling, and ....

The Affinity diagram

Affinity diagram is a tool used to gather large amounts of data in the form of ideas, opinions, or issues and organize them into groupings based on their relationships.

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Finished Affinity Diagram of Poor Product Performance

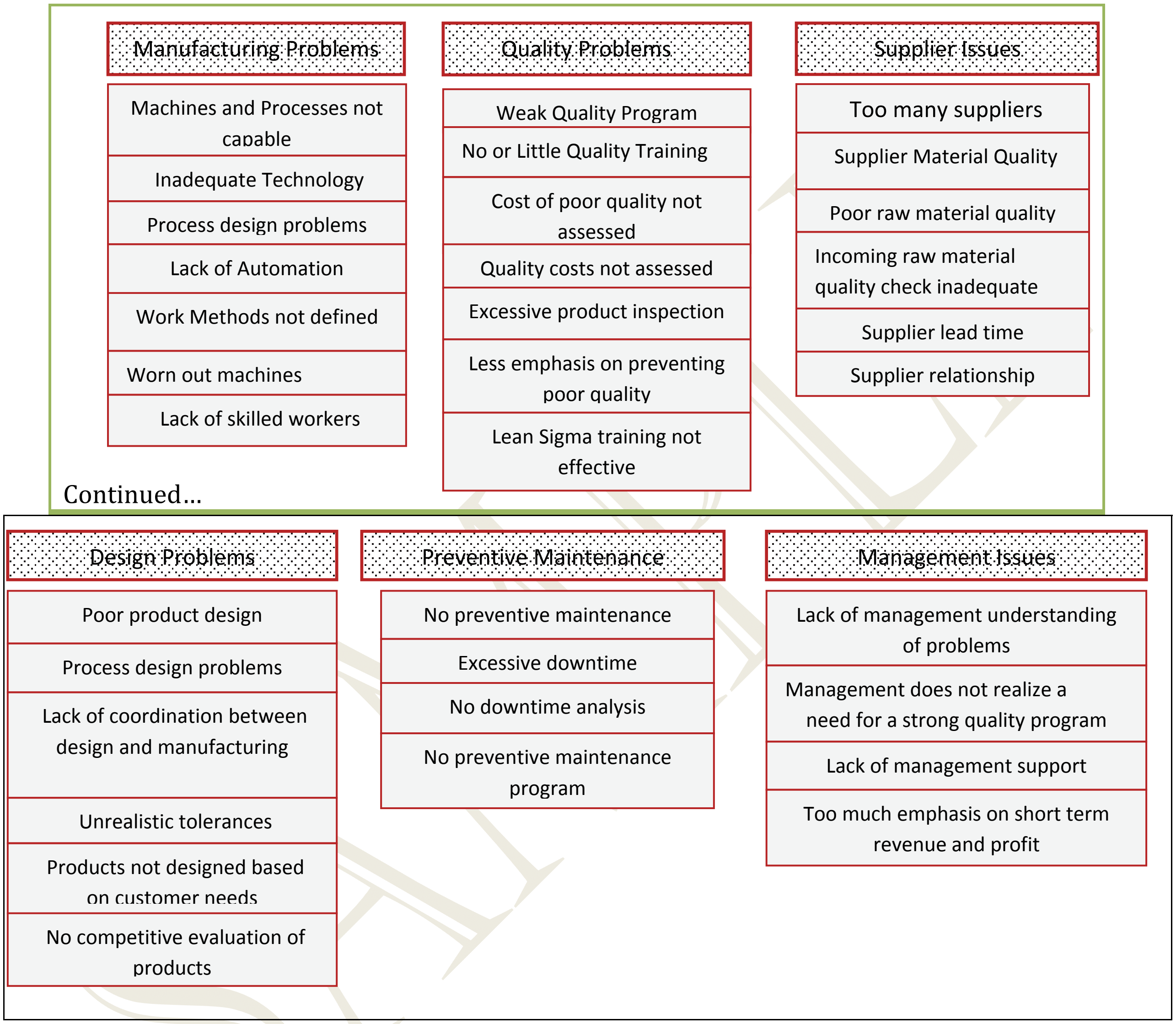

Figure 5.45: The Finished Affinity Diagram

Interrelationship Digraph

The purpose of the interrelationship digraph is to identify the *relationships* between different issues relating to a problem. This graph may be used as an extension to the affinity diagram and can be used in conjunction with ….

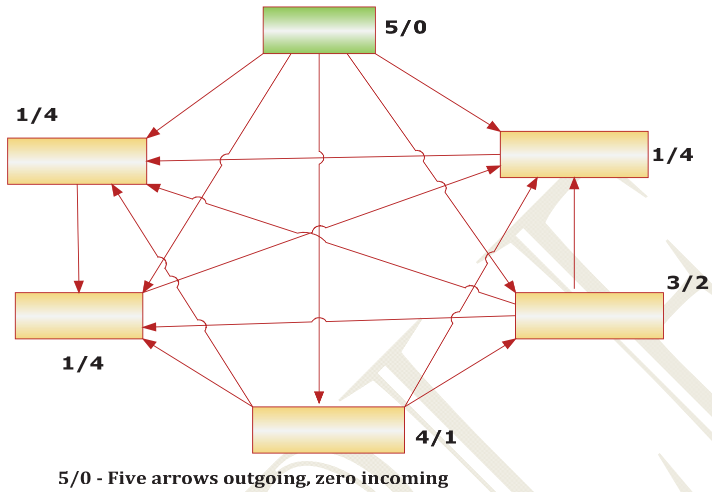

Figure 5.46: Interrelationship Digraph

Tree Diagrams

The tree diagram may be used to identify the steps needed to solve a problem. It is used to break down broad categories into different levels of detail and starts with one item branching into two or more forming new branches that can be viewed as the next level.

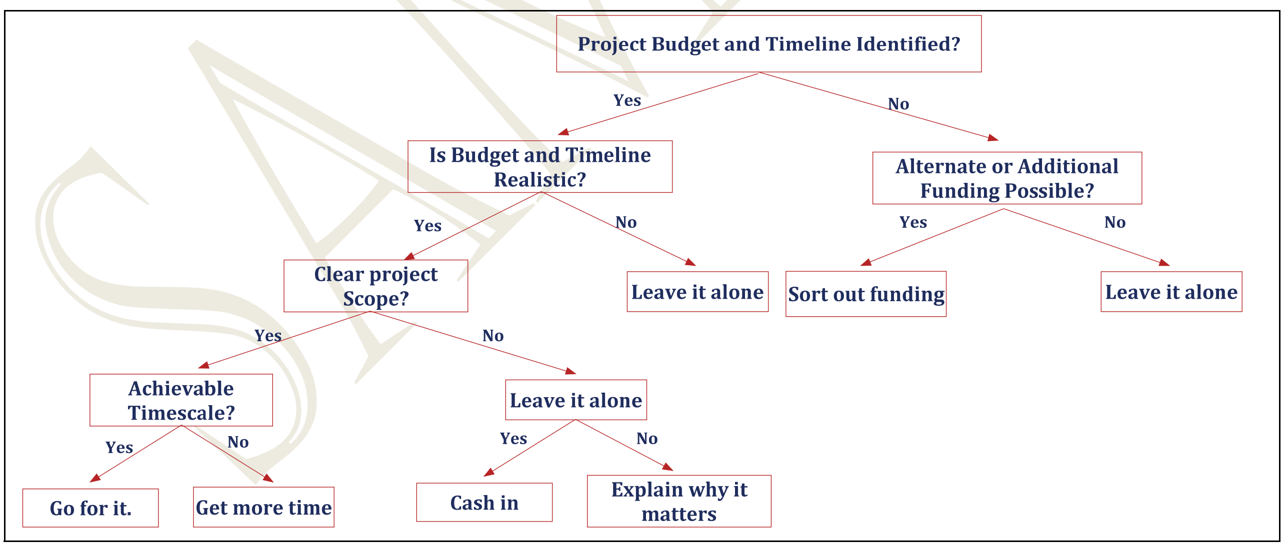

Figure 5.48: Decision Tree for Project Development

Prioritization Grid or Matrix

A prioritization grid is used to make decisions involving multiple criteria and multiple alternatives. This tool prioritizes issues based on weighted criteria. Prioritization grid or matrices are particularly useful for evaluating and prioritizing alternatives by weighting the criteria. The problem involving prioritization grid usually has several options or alternatives that need to be compared and several criteria that need to be evaluated. The objective is to rank the options from the most desirable to least desirable.

The steps to select the best alternative using the prioritization matrix are outlined below.

Step 1: ***Identify and state the goal statement through consensus***. For this example, the stated goal is: ***select the best machine among the five available testing machines.***

Step 2: ***Select the criteria by which a decision is to be made.*** The criteria for this decision problem are:

- Completion Time (or, time to complete the job)
- Automation
- Cost
- Useful life, and
- Maintenance

Step 3: ***Weigh Criteria for the options.*** In order to determine which criteria are most important, weigh each criterion against the other criteria using an L-shaped matrix. We have evaluated the criteria weight for the options (the machines) using the weights below. Each criterion is weighed against the other using these weights. The results are shown in Table 5.27.

Equally important	1
Moderately important	5
Highly important	10
Less important	0.3
Least important	0.1

The steps for weighing the criteria for each option in Table 5.27are explained below.

:

:

: continued…

Example below shows the last iteration:

Table 5.33

SUMMARY MATRIX	***Machine 1***	***Machine 2***	***Machine 3***	***Machine 4***	***Machine 5***
Completion Time	0.31*0.22= 0.07	0.12*0.22= 0.03	0.18*0.22 =0.04	0.35*0.22= 0.08	0.03*0.22= 0.01
Automation	0.29*0.29= 0.08	0.11*0.29= 0.03	0.37*0.29= 0.11	0.09*0.29= 0.03	0.14*0.29= 0.04
Cost	0.26*0.15= 0.04	0.11*0.15= 0.02	0.26*0.15= 0.04	0.25*0.15= 0.04	0.12*0.15= 0.02
Useful Life	0.03*0.13= 0.00	0.08*0.13= 0.01	0.37*0.13= 0.05	0.21*0.13= 0.03	0.31*0.13= 0.04
Maintenance	0.03*0.20= 0.01	0.04*0.20= 0.01	0.23*0.20= 0.05	0.37*0.20= 0.07	0.32*0.20= 0.06
COLUMN SUM	***0.20***	***0.10***	***0.29***	***0.25***	***0.17***

Step 6: Choose the best option across all criteria. Compare the relative decimal values in Table 5.33 to decide the best option. Figure 5.50 shows a bar chart that shows relative decimal values for each option plotted from Table 5.33. From this figure we can see that machine 3 has the largest relative decimal value. The ranking is done from the largest to smallest relative decimal value. The largest relative value gets the highest ranking. In our example, machine 3 should be selected as the best option.

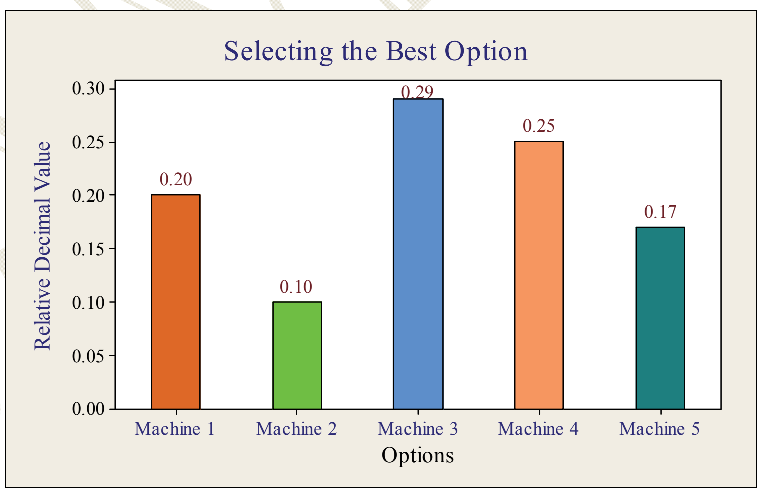

Figure 5.50: Selecting the Best Option

Activity Network Diagrams

The Activity Network Diagrams are also known as the PERT (Program Evaluation and Review

Technique) network, or CPM (Critical Path Method) network. The CPM and PERT networks are widely used in planning, scheduling, and controlling projects. These network diagrams are used to determine the project completion time (the time it takes from the beginning of a project to the end) and determine the critical path of the project. The critical path identifies the project completion time and the slack times for activities. These networks are also used for project crashing - what can be done to reduce or expedite a project time.

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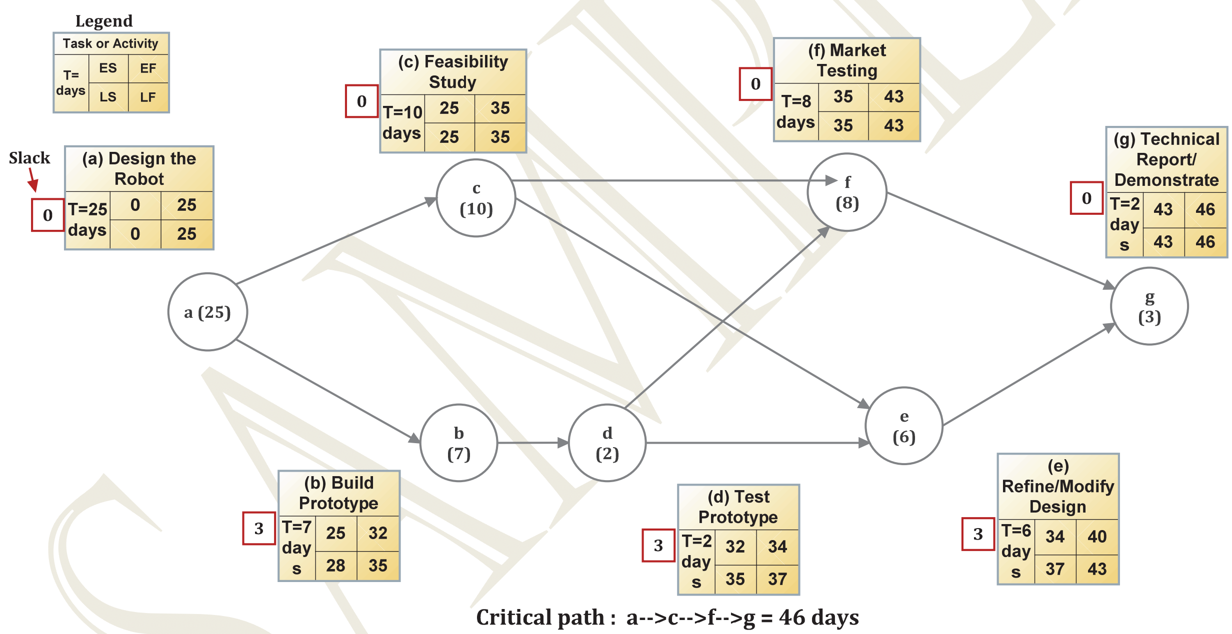


Figure 5.60: Activity-on node Network Diagram

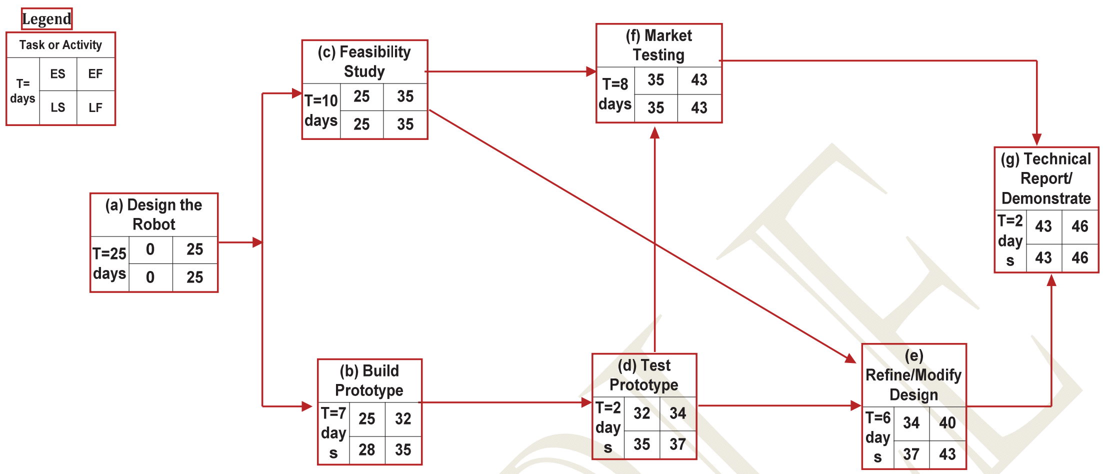


Figure 5.61: Variation of Activity on Node Network

Continued...

Multi-Vari Charts and Other Plots Useful to Investigate Relationships Before Running the Analysis of Variance

This section presents several plots that can be used to present the information in the form of graphs and charts in the preliminary stages of data analysis. These plots can be very helpful in visualizing the data, and provide invaluable information for a formal analysis of variance. The graphs and chart include

● Multi-vari Chart ● Box plot

● Main effects plot ● Interaction plot ● Marginal plot

Some of these plots-for example the box plot and marginal plot-were explained earlier. Here we explain how to construct all of the above plots. Next, we will analyze the resulting graphs to get further insights. The analyses can be helpful in determining the type of statistical tests to be used for the data.

Example 17: A Multi-vari Chart for a Two-factor Design

The marketing manager of a departmental store chain is interested in studying the effect of store location and store size on the profit. Four different locations (A, B, C, and D) and three different store sizes (small, medium, and large) were selected for the study. For each store location a random sample of two stores of each size was selected and the monthly profits (in thousands of dollars) were recorded. Table 5.18 shows the data. Note that this problem can be formulated as a two-factor ANOVA (analysis of variance) with **Store Size** as **Factor A** with three levels (small, medium and large); **Store Locations** as **Factor B** with four levels (A, B, C, and D), and the **Profit** as the response variable.

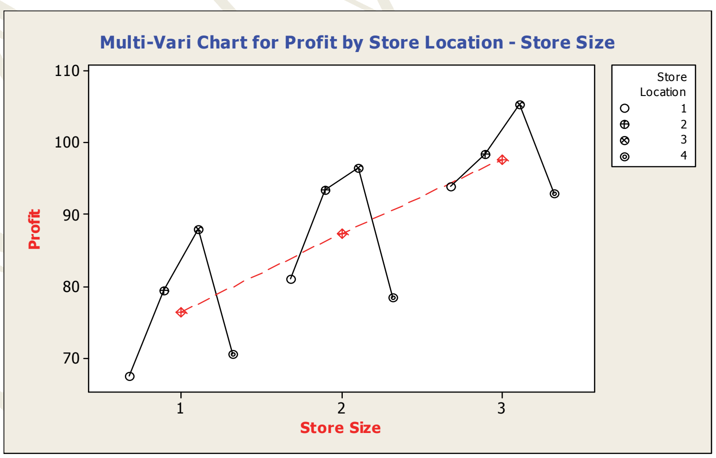
Table 5.18

	Store Location					
Store Size	**A**	**B**	**C**	**D**	**Totals**	**Means**
Small	60 65	76 83	85 91	68 73	**611**	**76.375**
Medium	: :				**699**	**87.375**
Large		95 102	102 109	91 95		
Totals			**580**	**484**		
Means	**80.83**		**96.67**			

Multi-Vari Chart

This chart displays the mean values at each factor level for every factor. For our example, there are two factors: store size and store location. The multi-vari plot will display the average profit for each level of store size: small (1), medium (2), large (3) and each level of store location: A(1), B(2), C(3), and D(4).

The multi-vari chart is shown below.



A Multi-Vari Chart for Profit by Store Location and Store Size

In this figure, we have plotted the two factors. The solid lines connect the means of factor B (store location) levels (at each level of factor A, store size). The dotted line connects the means of factor A (store size) levels.

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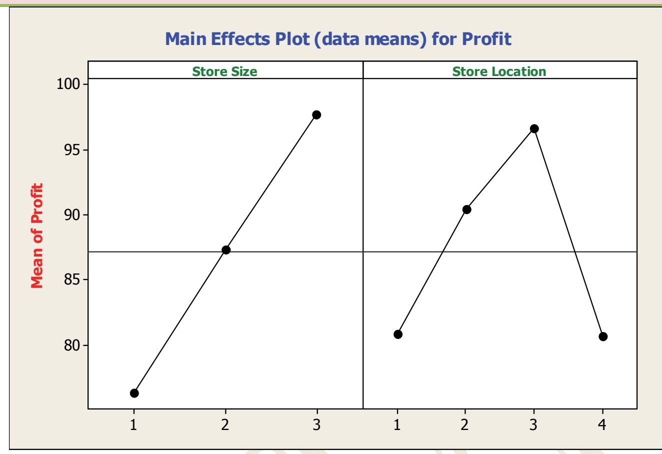
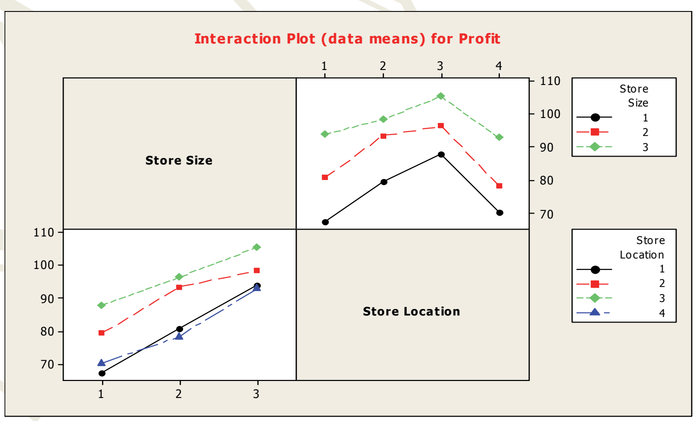
Main Effects Plot



Main Effects Plot for Profit

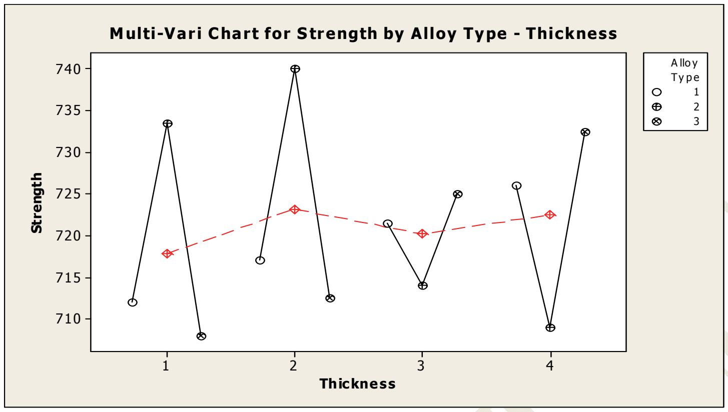
Interaction Plot

Interaction plots are used to assess the interaction effects between the variables. For our example, the response variable is Profit, and there are two factors of interest; Store Size and Store Location. Our objective is to determine how profit is affected by store size and location and also by their combination. In cases where there are two or more factors are involved, the interaction effects are critical.

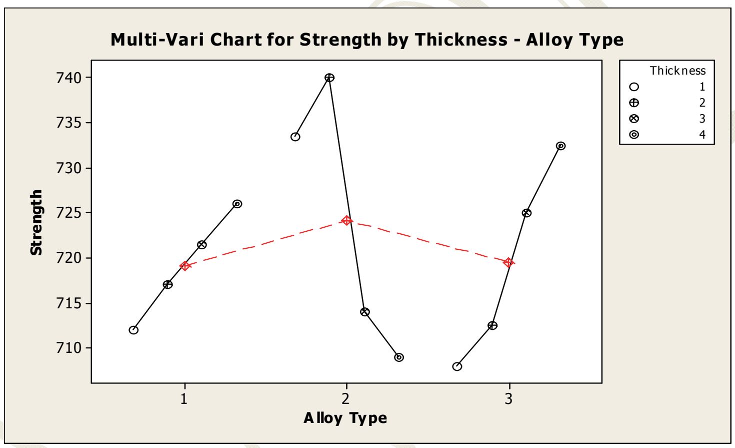


Interaction Plot of Profit vs. Store Size and Store Location

The presence or absence of interaction can be determined from the above interaction plot.

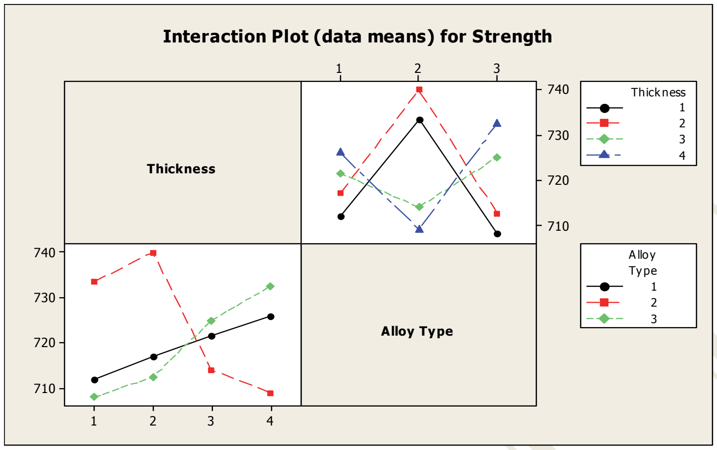


A Multi-Vari Chart for Strength by Alloy Type and Thickness



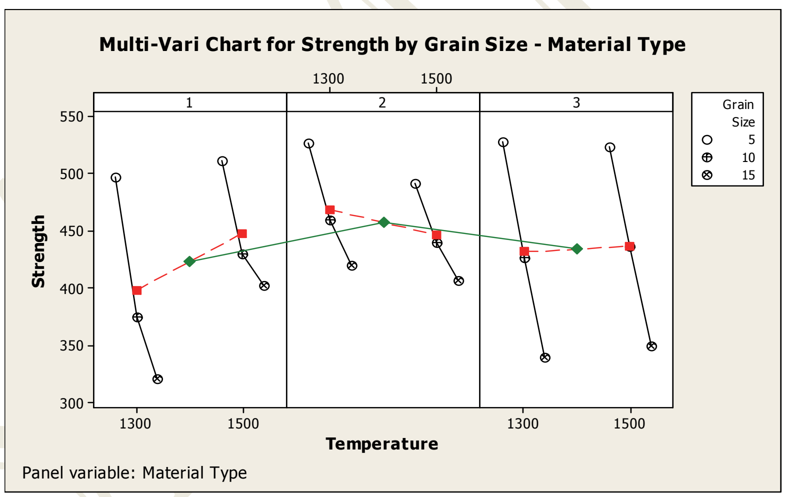
A Multi-Vari Chart for Strength by Thickness and Alloy Type

Both the plots above show that alloy type 2 and thickness 2 has the maximum strength. Also, there is an indication of interaction between the alloy type and thickness because the response variable is not a linear function of the combinations of the levels of the two factors.



Interaction Plot of Strength by Thickness and Strength by Alloy Type

Example 19: Multi-vari Chart for a Three-factor Design



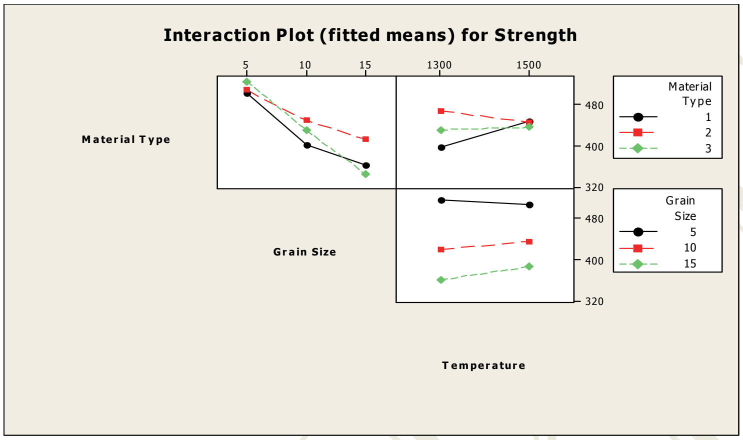
Multi-Vari Chart for Strength by Grain Size, Temperature, and Material Type

In this figure:

- Factor 1 is Grain Size, Factor 2 is Temperature, Factor 3 is Material Type
- Black lines connect the means of factor 1 levels (at each combination between factor 2 and 3 levels).
- Red lines (dotted lines) connect the means of factor 2 levels (at each level of factor 3).
- A green line (the solid line from the center of columns 1, 2, and 3) connects the

means of factor 3 levels.

For 3 and 4 factors, the multi-vari chart is paneled. The panel variable is the 3rd factor for a 3 factor chart……….



Interaction Plot: Material Type & Grain Size, Material Type & Temperature, and Grain Size & Temperature

Summary and Applications of Plots

TYPE OF CHART/GRAPH	APPLICATIONS	NUMBER OF VARIABLES PLOTTED
Scatterplot **Marginal Plot**	**In a scatterplot, two variables usually denoted by X and Y are examined. A sample of n observations is collected and the bivariate data (x1, y1), (x2, y2),…., (xn, yn) are plotted. The plot is used to extract the relationship between x and y.** **Types of Scatterplot: (a) scatterplot with histograms, box plots, or dot plots of x and y variables along with the x,………** **(b) Scatterplot with Fitted Line or Curve: these scatterplots show if the relationship between x and y is linear or nonlinear. The plot is also used to determine the correlation or degree of association ……..**	**Two variable plotted (Bivariate data)**
Multi-vari Chart	**Mult-vari charts can be used as clue generation techniques. The charts have several applications. They can be used in preliminary stages of data**	**Up to four factors can be plotted using MINITAB**

	analysis to investigate the relationships between the main factors and their interactions. Two-to four factor analysis of variance data can be plotted using multi-vari chart……. **:** **In a discrete manufacturing environment these charts can be used to detect part-to-part variation, within part variation, and also variation between time periods etc. In a continuous manufacturing, the chart can be used to detect shift-to-shift, day-to-day or week-to-week variation in the response variable.**	
Type of Chart/Graph	**Applications**	**Number of Variables Plotted**
Interaction Plot	**Interaction plots are used to assess the interaction effects between the variables. In the initial stages of data analysis, interaction plots can be used to see the interactions between variables. These plots can visually show the interaction effects without formally running the analysis of variance (ANOVA). However, the interaction plot may be misleading in ……………………**	Interaction plot matrix of several factors can be generated using MINITAB.
Symmetry Plot	**Symmetry plots are a quick and easy way to check if the data follows a symmetrical distribution. The symmetry plot is generated by first calculating the median of the data and then forming the first pair of values that are closest to the median: one above and one below the median. The second pair is formed using the two values that …….**	One variable plotted at a time

The detailed treatment of all the above plots with computer instructions and data files can be found in Chapter 5.