SIX SIGMA THE COMPLETE REFERENCE USING STATISTICAL ANALYSIS
BY DR SURESH VIDYASAGAR MENON

Senior Consultant

Department-Quality, ISO Auditing

CONTROL CASE INTERNATIONAL PVT LTD

Abstract: This article gives the intricacies of the Entire framework of DMAIC of Six Sigma by applying the usage of statistical software tools like Minitab, Sigma XL & Quality Companion Software and Minitab workspace and discussing the intricacies of Define, Measure, Analyse, and Improve& Control Phase with examples

Index Terms : Defects, Standard Deviation, Define, Measure, Analyse, Control, Level, lean, Capability Analysis, Gauge, DOE.

1.INTRODUCTION

The Concept of Six Sigma begins with a process model and its implementation is called Business Process Management (BPM) and the process of Six Sigma began at Motorola in the 1980's. Six Sigma is the **letter σ** in the Greek alphabet used to denote Standard deviation, a statistical measurement of variation. Standard deviation can be thought of as a comparison between expected results or outcomes in a group of operations versus those that fail. Bill Smith of Motorola Coined the term Six Sigma and is also called the father of Six Sigma; The Quality leader responsible for the term Total Quality Management is Feigen Baum; robustness in quality management was pioneered by Dr Taguchi; quality leader who did extensive work in Japanese industry is Dr Deming who paved the way for Quality Management Concept; Walter She wart is also one of the contributors in Six Sigma, he is sometimes referred to as father of Statistical Control he introduced the concept of control charts in 1924. In 1920s, contributions by Walter Shewhart, who showed the relation of process corrections based on three sigma deviations from the mean and introduced the control chart and distinction of special versus common cause variation.

With Six Sigma Standard deviation we arrive at 3.4 defects per million opportunities or 99.9997 percent this would mean that at six sigma, an airline would only loose three pieces of luggage for every one million passenger that it handles. The Three primary elements of Six Sigma are Customers, Processes & Employees.

The Italian Sociologist Vilfredo Alfredo Pareto demonstrated the 80/20 rule which signifies that 80 percent of your outcomes come from 20 percent of your inputs. Pareto's rule is widely used in Six Sigma principles.
Dr. W. Edwards Deming worked for the Shewhart cycle and eventually developed the Plan-Do-Study-Act (PDSA) cycle.
Post world war II, Japan's condition was in bad shape. Several scholars, including Deming, were invited by Japanese Union of Scientists and Engineers (JUSE) to plan for the 1951 Japanese Census.

In 1950, Deming trained several engineers, managers, and scholars in SPC and concepts of quality. Deming's message to Japan's chief executives was that improvement in quality would result in the reduction of cost and increase in productivity and market share.

Many Japanese manufacturers applied his techniques and experienced high levels of quality and productivity. The improvement in quality coupled with the lowered cost created new international demand for Japanese products.
Pareto principle was specifically found on land holding of rich people in Italy as he noticed that 20% of the people were holding 80% of the land. The 80/20 rule was later popularized and generalized by Juran.

During Japan's reconstruction period of the 1950s, Dr. Joseph M Juran taught Quality Control concepts in Japan. The Philosophy of Total Quality Management started after 1960, first in Japan and then later spread to the rest of the world.
Dr. Juran created a trilogy for managing Quality. The three principles of the trilogy are based on planning, control, and improvement.
Dr. Juran studied the work of Vilfredo Pareto and applied the Pareto principle to reducing defects. The 80/20 rule states that 80% of the problems come from 20% of the causes.
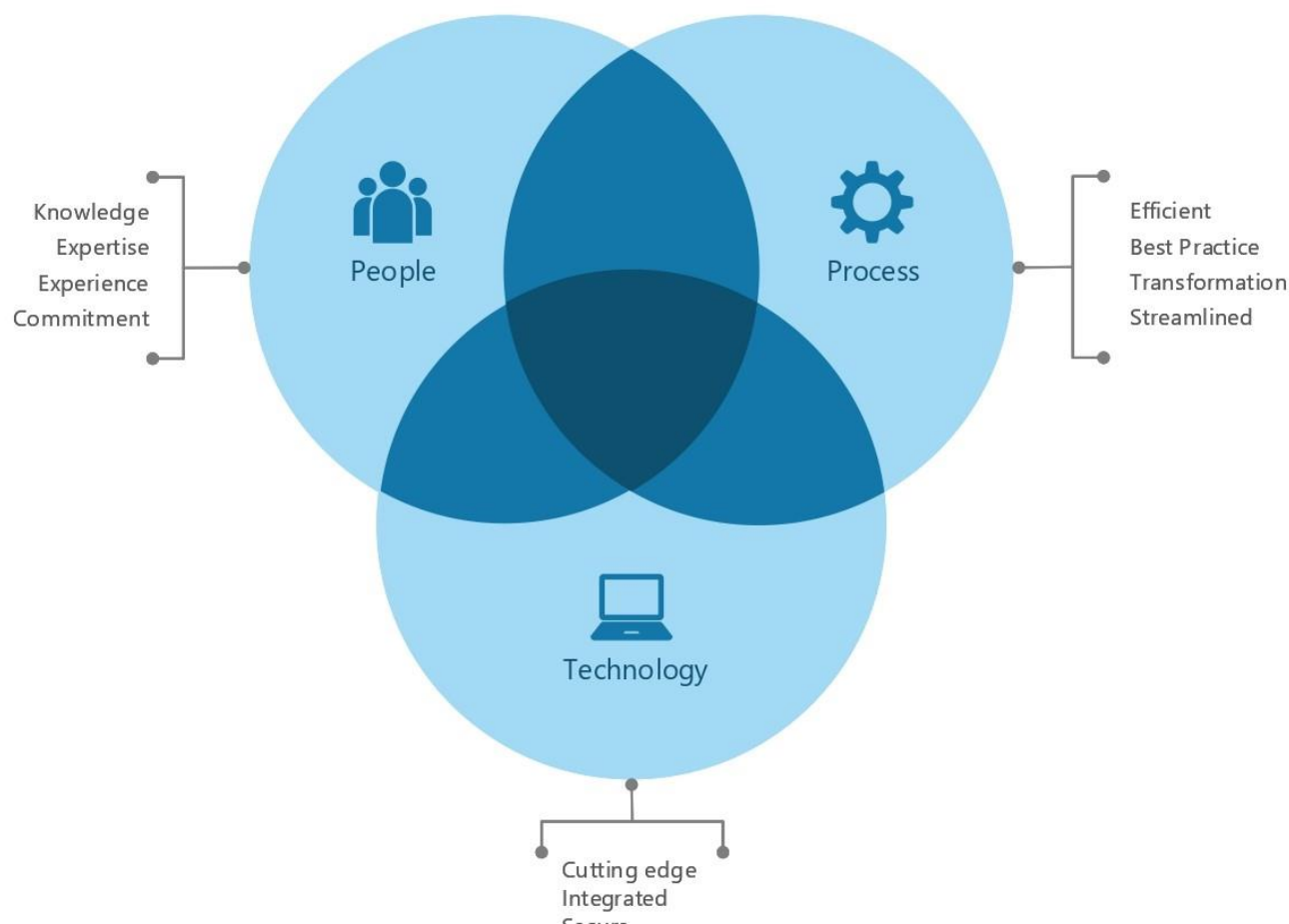Jack Welch launches Six Sigma at GE in 1995 and also Larry Bossidy of Allied Signal (now Honeywell), and Jack Welch of General Electric Company also contributed to the popularity of Six Sigma methodology in the way of doing business.

Six Sigma is basically the application of Statistical formulas and Methods to eliminate defects, variation in a product or a process. For example, if you want to find the average height of male population in India, you cannot bring the entire population of more than 2 billion into one room and measure their height for a scenario like this we take samples that is we pick up sample(people) from each state and use statistical formulas to draw the inference about the average height of male population in a population which is more than 2 billion. One more example would be say a company manufactures pistons used in motor cycles the customer demand is that the piston should not a diameter more than 9 cm and less than 5 cm anything manufactured outside this limits is said to be a variation and the six sigma consultant should confirm that the pistons are manufactured within the said limits else if there is variation in the range then the company is not operating at 6 sigma level it is operating at a very low level.

In statistics, the **standard deviation** (SD, also represented by the Greek letter **sigma** σ or the Latin letter s) is a measure that is used to quantify the amount of variation or dispersion of a set of data values.

The conceptual link between improved quality and business performance is well established. According to quality gurus W. Edwards Deming and Philip Crosby, "Producing high-quality products is always less costly per unit of good output than producing low quality products" (Fine 1986). They argue that zero defects is the optimal conformance level. Deming argued that quality improvement programs would improve organizational processes that would eventually lead to competitive advantage. Once this advantage was leveraged in the marketplace, he believed the competitive advantage would ultimately lead to improved performance.

Six Sigma also involves use of people, process and tools

People, Process and Technology

Knowledge
Expertise
Experience
Commitment

People

Process

Efficient
Best Practice
Transformation
Streamlined

Technology

Cutting edge
Integrated
Secure

One key innovation of Six Sigma involves the absolute "professionalizing" of quality management functions. Prior to Six Sigma, quality management in practice was largely relegated to the production floor and to **statisticians** in a separate quality department. Formal Six Sigma programs adopt a kind of elite ranking terminology (similar to some martial arts systems, like Kung-Fu and Judo) to define a hierarchy (and special career path) that includes all business functions and levels.

Six Sigma identifies several key roles for its successful implementation.

- *Executive Leadership* includes the CEO and other members of top management. They are responsible for setting up a vision for Six Sigma implementation. They also empower the other role holders with the freedom and resources to explore new ideas for breakthrough improvements by transcending departmental barriers and overcoming inherent resistance to change.
- *Champions* take responsibility for Six Sigma implementation across the organization in an integrated manner. The Executive Leadership draws them from upper management. Champions also act as mentors to Black Belts.
- *Master Black Belts*, identified by Champions, act as in-house coaches on Six Sigma. They devote 100% of their time to Six Sigma. They assist Champions and guide Black Belts and Green Belts. Apart from statistical tasks, they spend their time on ensuring consistent application of Six Sigma across various functions and departments.
- *Black Belts* operate under Master Black Belts to apply Six Sigma methodology to specific projects. They devote 100% of their valued time to Six Sigma. They primarily focus on Six Sigma project execution and special leadership with special tasks, whereas Champions and Master Black Belts focus on identifying projects/functions for Six Sigma.
- *Green Belts* are the employees who take up Six Sigma implementation along with their other job responsibilities, operating under the guidance of Black Belts.
- **Mikel Harry Coined the term Green Belt & Black Belt and is one of the Pillars of Six Sigma**
- **Deming on Processes states that eighty-five percent of the reasons for failure to meet customer expectations are related to deficiencies in systems and process…Rather than the employee, the role of the management is to change the process rather than badgering individuals to do better.**

Six Sigma Process Table

PPM / SIGMA / Cpk Conversion Table

RECALL: PPM may or may not = DPMO. Only if each part has one defect type will they be the same value. If one PART has >1 defect opportunity then these values can be drastically different.

*Converting to Cpk from a sigma level is an estimation since Cpk uses the USL or LSL, whichever is closest to the process mean. The opposite side that is not accounted for my have a tail that is unaccounted for.

SIGMA LIMITS (long-term)	% POPULATION WITHIN LIMITS	PPM DEFECTIVE OUTSIDE LIMITS	Cpk*
+/- .6745 Sigma	50.00%	500,000	
+/- 1.00 Sigma	68.27%	317,300	0.33
+/- 2.00 Sigma	95.45%	45,500	0.67
+/- 2.36 Sigma	98.00%	20,000	0.79
+/- 3.00 Sigma	99.73%	2,700	1.00
+/- 3.12 Sigma	99.82%	1,800	1.04
+/- 3.19 Sigma	99.86%	1,400	1.06
+/- 3.23 Sigma	99.88%	1,200	1.08
+/- 3.29 Sigma	99.90%	1,000	1.10
+/- 3.35 Sigma	99.92%	800	1.12
+/- 3.54 Sigma	99.96%	400	1.18
+/- 3.71 Sigma	99.98%	200	1.24
+/- 3.89 Sigma	99.99%	100	1.30
+/- 4.00 Sigma	99.9937%	63	1.33
+/- 4.26 Sigma	99.9980%	20	1.42
+/- 4.42 Sigma	99.9990%	10	1.47
+/- 4.50 Sigma	99.99966%	3.4	1.50
+/- 4.75 Sigma	99.9998%	2	1.58
+/- 4.89 Sigma	99.9999%	1	1.63
+/- 5.00 Sigma	99.99994%	0.6	1.67
+/- 5.20 Sigma	99.99998%	0.2	1.73
+/- 5.32 Sigma	99.99999%	0.1	1.77
+/- 5.61 Sigma	99.999998%	0.02	1.87
+/- 5.73 Sigma	99.999999%	0.01	1.91
+/- 6.00 Sigma	99.9999998%	0.002	2.00
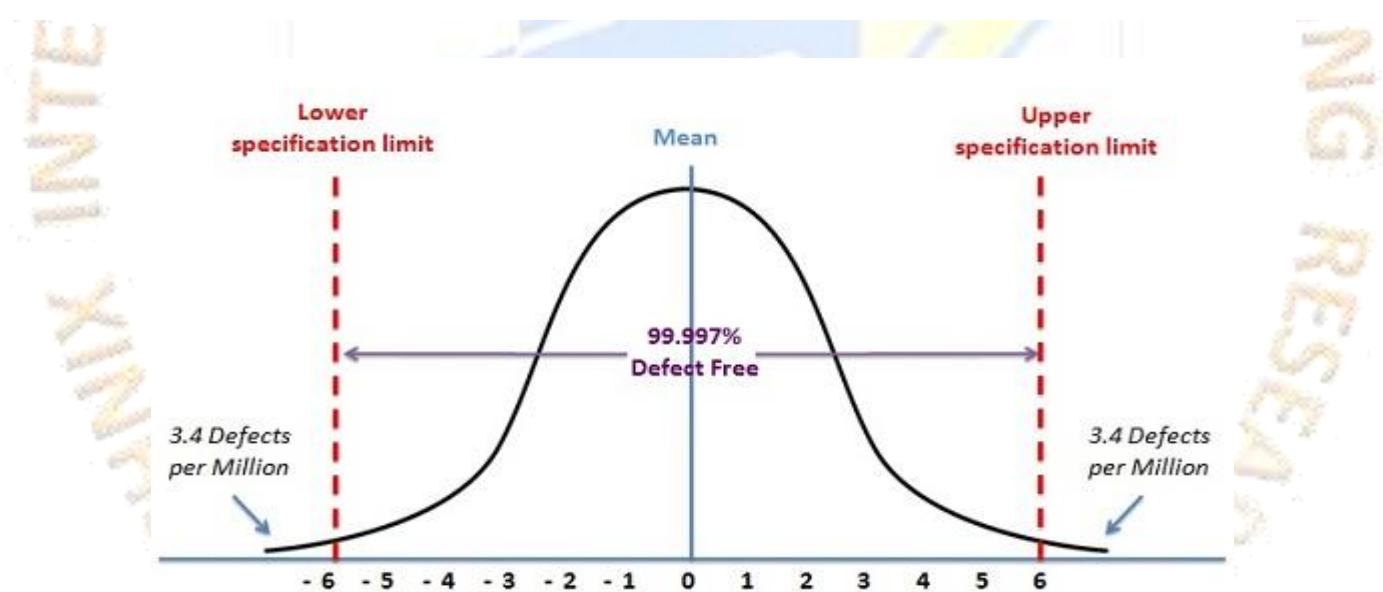
Waste Observation and Improvement Data Sheet: -

Gemba(Shop Floor Term in Japanese) Waste Observations and Improvement Suggestions					
Date:-		Team Work Area :			
Item	Waste, Defect or Flow Disruption	Suggested Improvement Area	TIMWOOD type	Assigned To	Due Date
TIMWOOD = Transportation, Inventory, Motion, Waiting, Overproduction, Over processing, Defects					

Equation Y=F(X)-Approaching the Problem

Understanding how to approach the problem – beginning to identify the problem and defining it with a statement – is critical to creating a foundation for successful Six Sigma projects, we're going to discuss the project in general, digging deeper via a series of why questions, and creating a general problem statement as a launching point for a project.

Problem Functions: $y = f(x)$

Because Six Sigma approaches things with a statistical mind-set, it considers all problems as a function. Using mathematical symbols, this looks like: The y=f(x) statement can be used in two ways. First, it is a general map for stating a problem. Y (the problem) occurs because some X (input or cause) is occurring. In reality, Y is usually occurring because of some group of causes or inputs, which means there are going to be more than one X inputs.

2.DEFINE PHASE

2.1 The objectives within the Define Phase which is first phase in DMAIC framework of Six Sigma are: -

The roadmap of Define phase consists of seven critical milestones: identifying your customer, identifying Voice of your Customer or VOC, determining Critical to Quality or CTQ parameters, defining a problem statement, developing a Project Charter, setting up a Six Sigma Deployment Team and Mapping the Process.

The first stage of the define phase is to know who your customers; customers can be internal or external; internal customers are customers within the project or organization and external customers are distributors, retailers and people who buy the product or service delivered by you.

The second stage of Define involves gathering voice of customer.
There are various sources for listening to the customer voices. Research, Formal transactions, Casual Contact, Inbound or Outbound communications, Internal Intelligence, Social Media etc.

The Voice of Customer or VOC is any data which reflects customer view on our process, product or service. It can be a rating, comments, verbatim of their feedback, preference, result of a survey or an interview.

The diagram given below is a excel template of the Project charter where each headers are discussed in detail below.

TEAM/PROJECT CHARTER

Project Name:	
Date (Last Revision):	
Prepared By:	Suresh Menon(Master Black Belt)
Approved By:	Nitesh Jain (Champion)

Business Case:	Opportunity Statement (High Level Problem Statement):
	Defect Definition:
Goal Statement:	Project Scope:
	Process Start Point:
	Process End Point:
Expected Savings/Benefits:	In Scope:
	Out of Scope:

Project Plan:				Team:		
Task/Phase	Start Date	End Date	Actual End	Name:	Role:	Commitment (%):
Define Phase				Suresh Menon	Master Black Belt	100
Measure phase					Green belt	60
Analyse					Green belt	60
Improve					Green belt	60
Control						

Project charters the charter documents the why, how, who and when of a project include the following elements

The business case is one of the elements of project charter which asks the following questions why is the project worth doing? Why is it important to do now? What are the consequences of not doing the project? What activities have higher or equal priority? How does it fit with business initiatives and targets? Business Case is the first stage towards developing a project charter. It captures the reasons for initiating an improvement project. Let's look at an example of a business case. A company is facing challenges in meeting a target of 97% for final process yield performance for the paint and polish area. Not meeting of target is causing floor space, shipment, and resource problems that are costing eight million US dollars per year to the company.

Problem Statement The second element of project charter is Problem or Opportunity Statement.
It defines what's wrong with the process, where is the problem appearing in the process, since when the problem is persisting, how big is the problem, and lastly the impact of the problem on the process.

The third component of the Project charter is the Goal Statement.

GOAL Statement is an operational definition of the desired state of the performance category. GOAL Statement describes the approach to solve the problem; as defined in the problem statement. It should be specific, measurable, achievable, realistic, and time bound. Consider a Goal Statement which says: "Reduce customer complaints by 20 percent within the next two months"; Here, the goal is specific that is to reduce customer complaints. The goal is measurable which is defined as 20 percent. It is achievable as well as realistic, and it is to be accomplished within two months. This implies that it is time-bound as well. Thus, the Goal Statement is SMART (Specific, Measurable, Achievable, Realistic, and Time-bound

The fourth component of the Project Charter is the Project Scope.
Project Scope determines what is in and out of the project scope.

Project scope refers to the detailed set of deliverables that are derived from a project's requirements.

The fifth component of a project charter is Process Boundaries.
Process boundaries are the beginning and end points of a business process.
Project boundaries clearly define the extent of the project scope and are important for implementing a project.

The sixth component of a project charter is milestone or project plan.
It contains a chart or graph indicating major milestones of the project. The project plan shows the ''Why'' and the ''How'' of a project.
GANTT chart or Microsoft Project can be used to plan the project milestones and track the progress and variances.
A project plan is documented and shared with all the team members and champion of the project.
Based on the project's progress, the document is updated regularly.

Below is an illustration of GANTT Chart preparation using Minitab Workspace.
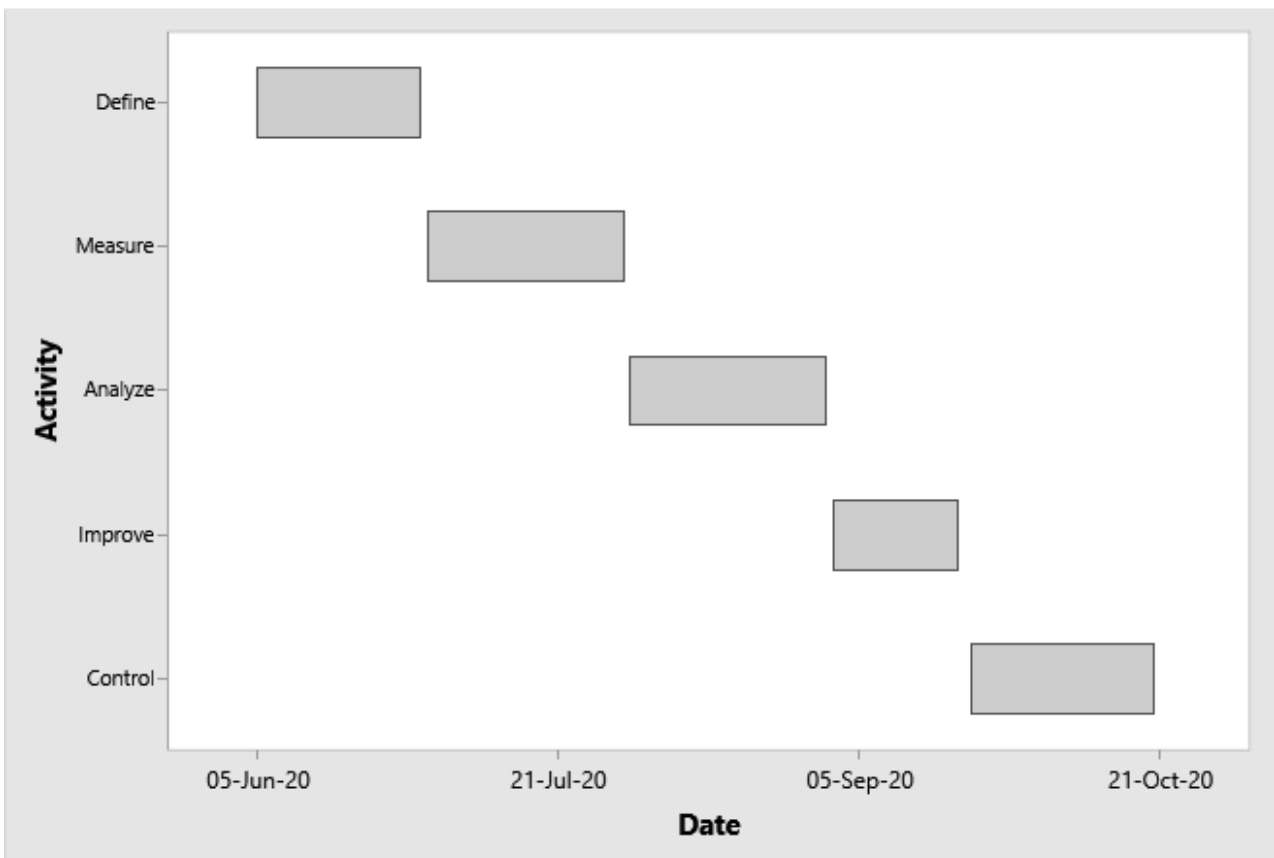
Gantt Chart

Project Name:

Project

Prepared By:

Suresh Menon

Prepared Date:

05-Jun-20

Gantt Chart

Activities

Activity	Start Date	Due Date	Progress	Footnote
Define	05-Jun-20	30-Jun-20		
Measure	01-Jul-20	31-Jul-20		
Analyze	01-Aug-20	31-Aug-20		
Improve	01-Sep-20	20-Sep-20		
Control	22-Sep-20	20-Oct-20		

Milestones

Milestone	Date

Summary

Objective:

Conclusion:

The seventh component of the project charter is Resource or Team Members Roles.

It is a resource plan for the project. The plan contains a list of all key stakeholders involved in the project and their roles.

It Contains of the Apex Council or the Six Sigma Steering Committee than the→ Champion or the Senior Manager→Process Owner(Functional Heads)→Master Black Belt→Black belt(Facilitator)→Green Belt(project team leader)→Team Member(Process Experts). The Top Management forms the Apex Council, who is accountable for Six Sigma business results. It plays a pivotal role in implementing the Six Sigma program in an organization. Champion or Sponsor refers to the Senior Manager, who sponsors a Six Sigma project. He directs company's objective towards successful deployment of Six Sigma program and ensures process improvement in an organization. He is accountable to the Apex Council. The Senior Manager defines business strategy for a Six Sigma project and approves changes in project definitions. He also ensures availability of resources (time, support, money) for projects and helps the team to overcome roadblocks. The Six Sigma Coach is a Master Black Belt, who provides technical support to the Six Sigma management. He advises the business unit, and mentors Black Belts and teams. He communicates with the Apex Council and manages inter-project communication. He resolves team conflicts in an efficient manner, and helps to estimate, measure, and validate savings. The Master Black Belt deals with resistance to Six Sigma. Furthermore, he analyses business operation and adheres to a schedule for projects.

The Team members of a Six Sigma project are the Process Experts. They possess good knowledge of product, process, and customer. They collect data actively and are responsible for process improvement. They work willingly in teams to meet the deadline. Thus, their active participation plays a crucial role in a Six Sigma project to attain the business goal.

In the seventh component we can also use the RACI Matrix as shown below where each resource is given the roles of Responsible(R), Assign(A), Consultation(C), Inform(I)

RACI (Responsibility Assignment Matrix)

Project Name:

Project

Prepared By:

Suresh Menon

Prepared Date:

05-Jun-20

RACI

Role	Name	Suresh Menon	Nitesh Jain	ABC
		Master Black Belt	Champion	Process Owner
Activity				
DMAIC implementation		R	R	A
Resource Allocation		R	R	A

Instructions   open

Cost – Benefit is the last component of the project charter.

It is a decision-making technique to compare Costs and Benefits of a proposed change in the process. The objective here is to find out whether project benefits outweigh costs incurred.

Top Management must approve funding for Projects that require significant financial resources, therefore before a proposed project is initiated, a cost-benefit analysis using projected revenues, costs and net cash flows is performed to determine the project's financial feasibility. The analysis is based on estimates of the project's benefits and costs and the timing thereof. The result of the analysis is a key factor in deciding which projects will be funded. Upon project completion accounting data are analyzed to verify the projects financial impact on the organization. In other words, the management must confirm whether the project added to or detracted from the company's financial wellbeing.
A cost-benefit analysis attempts to evaluate the benefits and costs associated with a project or initiative. Two types of benefits can be evaluated: direct or indirect. Direct benefits are easily measured and includes issues such as increased production, higher quality, increased sales, reduced delivery costs and lower warranty costs. Indirect benefits are more difficult to measure and include such items as improved quality of work life, increased internal customer satisfaction and better trained employees.
The Simple formula for computing benefit-cost ratio is:
$\sum$ NPV of all Benefits anticipated/ $\sum$ NPV of all costs anticipated
Note: NPV Stands for Net Present Value where NPV is calculated using the formula $P = F(1+i)^{-n}$ where P = Net Present Value, F = Amount to be received n years from now also called as Future value: and I = Annual interest rate expressed as decimal the formula assumes that the money is compounded annually and n stands for number of years.

Stake Holder Analysis is a very important roadmap in a six sigma project because they are the entities or people who are going to be affected in doing the six sigma project and the problems faced within the organization which if persists can affect them directly or indirectly.

The process steps to complete stakeholder analysis are as follows:
- Determine who the stakeholders are.
- Determine how the stakeholders affect the project with the help of a brainstorming session.
- Agree upon the final list of concerned stakeholders.
- Sub-divide all stakeholders into groups; according to their domain of interest.
- Determine which stakeholder benefits or hinders the project outcome or execution.
- Assess every stakeholder's positive or negative impact on the project and grade that impact.
- Determine what can be done to lessen the negative impact and improve the positive contribution.

SIPOC (Supplier Input Process Output Customer) Diagram and Explanation

The SIPOC is often presented at the outset of process improvement efforts such as **Kaizen** events or during the "define" phase of the **DMAIC** process. It has three typical uses depending on the audience:

- To give people who are unfamiliar with a process a high-level overview
- To reacquaint people whose familiarity with a process has faded or become out-of-date due to process changes
- To help people in defining a new process

Several aspects of the SIPOC that may not be readily apparent are:

- Suppliers and customers may be internal or external to the organization that performs the process.
- Inputs and outputs may be materials, services, or information.
- The focus is on capturing the set of inputs and outputs rather than the individual steps in the process.

SIPOC deals with the existing process. It can be called an advanced level process overview of an existing process.
There is another diagram, called COPIS which is nothing but the opposite of SIPOC. It too is an advanced level process overview but of an improved or optimized process.

COPIS always puts the customer first. It is referred to as an inside-out approach of streamlining the process.

SIPOC

Project Name:

Project

Prepared By:

Prepared Date:

SIPOC

Suppliers	Inputs		Process	Outputs		
	Description	Requirements		Description	Requirements	Customers
Tirupur Mills	Raw Cotton Yarn		Washing	Readymade Shirt		ABC (USA)
			Bleaching			
			Dyeing			
			Sewing			
			Buttoning			
			Ironing			
			Quality Control			
			Packing			

Instructions   open

Process Maps

■ Before Process Mapping starts, you have to learn about the different level of detail on a Process Map and the different types of Process Maps. Fortunately, these have been well categorized and are easy to understand.

■ There are three different levels of Process Maps. You will need to use all three levels, and you most likely will use them in order from the macro map to the micro map. The macro map contains the least level of detail, with increasing detail as you get to the micro map. You should think of and use the level of Process Maps in a way similar to the way you would use road maps. For example, if you want to find a country, you look at the world map. If you want to find a city in that country, you look at the country map. If you want to find a street address in the city, you use a city map. This is the general rule or approach for using Process Maps.

■ The Macro Process Map, what is called the Level 1 Map, shows the big picture, you will use this to orient yourself to the way a product or service is created. It will also help you to better see which major step of the process is most likely related to the problem you have, and it will put the various processes that you are associated within the context of the larger whole. A Level 1 PFM, sometimes called the "management" level, is a high-level process map having the following characteristics:

- Combines related activities into one major processing step

- Illustrates where/how the process fits into the big picture

- Has minimal detail

- Illustrates only major process steps

- Can be completed with an understanding of general process steps and the purpose/objective of the process

■ The next level is generically called the Process Map. You will refer to it as a Level 2 Map, and it identifies the major process steps from the workers' point of view. In the pizza example above, these are the steps the pizza chef takes to make, cook, and box the pizza for delivery. It gives you a good idea of what is going on in this process, but could can you fully understand why the process performs the way it does in terms of efficiency and effectiveness, could you improve the process with the level of knowledge from this map?

■ Probably not, you are going to need a Level 3 Map called the Micro Process Map. It is also known as the improvement view of a process. There is however, a lot of value in the Level 2 Map because it is helping you to "see" and understand how work gets done, who does it, etc. It is a necessary stepping stone to arriving at improved performance.

■ Next, we will introduce the four different types of Process Maps. You will want to use different types of Process Maps, to better help see, understand, and communicate the way processes behave.

Level 1 Process Map is Given Below it is at Macro Level
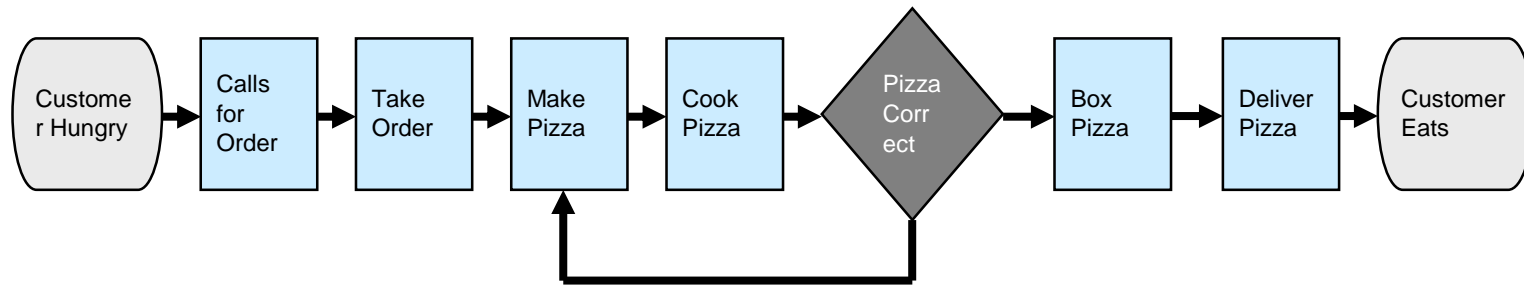
Level 2 Process Map is Given Below it is Much More In Detail
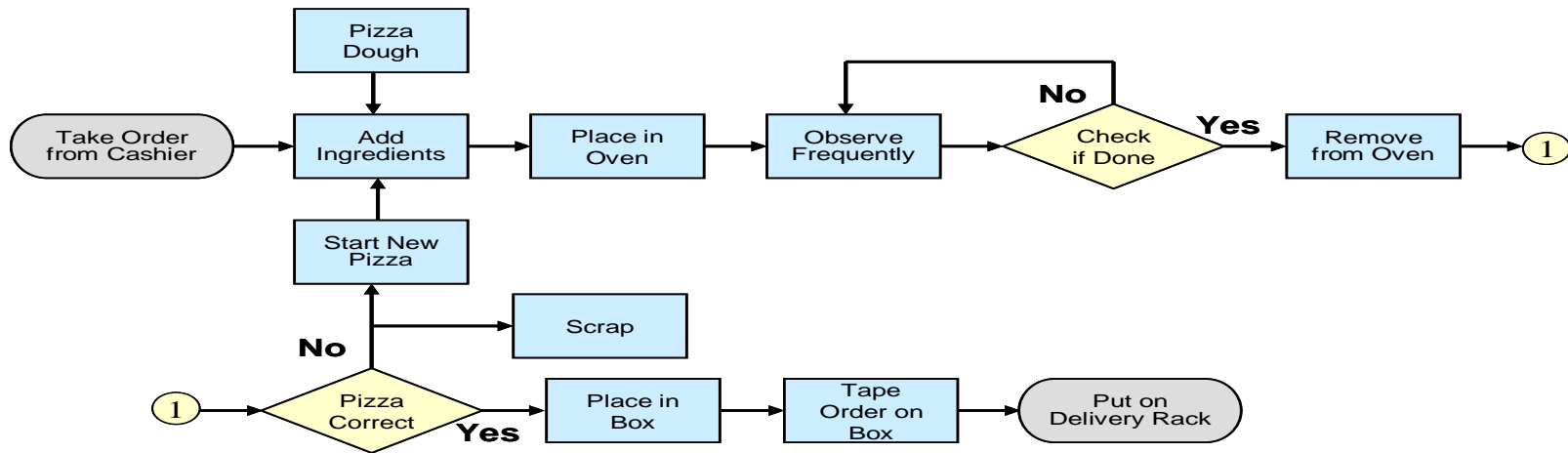
Level 3 – The Micro Process Map, sometimes called the Improvement level or viewpoint. Similar to a level 2, it will show more steps and tasks and on it will be various performance data; yields, cycle time, value and non-value added time, defects, etc.

There is another type of flowchart known as deployment flowchart that explains both 'What' and 'Who' of the process. For example, in the process flow given above the concerned department name or the name of the person would be included in the flow charting activity

Quality Function Deployment

Quality function deployment (QFD) is a customer driven process for planning innovation in products or services. It starts with the voice of customer which becomes the basis of requirements. QFD Matrices are sometimes referred to as "House of Quality". In its simplest form QFD involves a matrix that represents customer requirements as rows and product or service features as columns. The Cell where the row and column intersect shows the correlation between individual customer requirements and the product or service requirement. The matrix is sometimes called as the "requirement matrix".

	Customer Weight	Feature 1	Feature 2	Feature 3	Feature 4
Requirement 1	1	1			
Requirement 2	2		1		
Requirement 3	3			1	
Requirement 4	4				1
Raw Score		1	2	3	4
Relative Weigth		10%	20%	30%	40%

.**Hoshin Kanri is known as shining metal in Japanese** (also called Policy Deployment) is a method for ensuring that the strategic goals of a company drive progress and action at every level within that company. This eliminates the waste that comes from inconsistent direction and poor communication.

Hoshin kanri, a Japanese term, is a top-down, bottom-up, systematic and structured strategic planning process that engages all levels of the organization while creating measurable and aligned goals that imbue the concept of continuous improvement through use of the *plan–do–check–act cycle*. (Note: Some sources will cite the *plan–do–study–act* [PDSA] cycle.) The term *hoshin kanri* has been translated many different ways. For example, Akao (2004) decomposes "hoshin kanri" into its four basic syllables to help explain its meeting:
• Ho—direction
• Shin—focus
• Kan—alignment
• Ri—reason
He further indicates that "ho + shin" translates to "shining metal," "compass, "or "point the direction." Similarly, "kan + ri" means "management" or "control. "Perhaps the loose translation is that it aligns an organization toward achieving a common goal. Although King (1989) agrees that "hoshin" means "shining metal" and "pointing the direction," he does not mention, "compass." However, he states that "hoshin" is translated as "policy" or "target and means." Likewise, he agrees that "kanri" means "management" or "control" and translates it as "planning." King suggests another literal translation for "hoshin kanri" as "target and means management."

He further notes that "hoshin kanri" is sometimes referred to as "policy management," "policy control," or "management by policy." As is evident from the above, "hoshin kanri" is known by many different names:
• Hoshin planning
• Policy deployment
• Policy management
• Policy control
• Management by policy

Formulas Used In Six Sigma-Define Phase

Takt time = Available time for production/customer demand.

Takt is a German Word for Baton which is used by Music Directors to Control the flow of Music.

Available production time = Scheduled time – Break time – Meeting time.

Production time is the time required in producing a product so for example if available production time is 400 minutes and customer demand is 20 units then Takt time = 400/20 =20 minutes so the production has to make 1 unit every 20 Minutes.

Cycle time is split into four components:

• Auto time – Time spent by machines running unattended;

• Manual time – Time spent in loading, unloading, and adding components during the same process;

• Delay time – Time spent waiting for operator or other process to finish, or parts or raw material availability; and

• Machine time – Time spent by machine working on the part.

Process time + Delay time = Total Cycle time

Staff Required on the Production Line = Total cycle time/Takt Time

In an ideal production process, the cycle time must be as close to the takt time as possible.

Lead time is the time between customer order and delivery of the product.
For Example, in Delivering a Burger of Mc Donald's to the customer the company takes 30 minutes so 30 minutes is the lead time.
Reducing lead time should be the target, but to do so, you should reduce cycle time, set up time, and wait time. Lead time will automatically get impacted.

Solution

Step 1 – Production time needed

Production time needed = No. of machines * cycle time per part * average daily demand

Time available for set up = Available production time – production time needed

Example: A product works on a takt of 100 minutes and has production cycle time of 400 minutes. What is the crew size?

Solution:
•Crew Size = 400/100 = 4

Staff Required on the Production Line = Total cycle time/Takt Time

•4 staff are needed on the line to ensure takt target is met.

ROI = PROFITS DIVIDED BY INVESTMENTS * 100

An Average american company operates at four Sigma Level.

Noise factors are referred to as random variation or common cause variation.

Common cause variation is a source of variation caused by unknown factors.

Dr Taguchi's Loss Equation :

Taguchi Constructed a loss equation to determine how much society loses every time when the parts produced do not match the specified target the loss function is given below :-

L(y) = k(y-T) ^ 2

Where k = Δ / m^2

Δ = Cost of a defective product

M= | USL – T|

Example : Suppose a manufacturer specifies the target for the diameter of a given rivet(A rivet is a permanent mechanical fastener**. Before being installed, a rivet consists of a smooth** cylindrical **shaft with a head on one end. The end opposite to the head is called the** *tail*) **to be 6 inches and the lower and upper limits to be 5.98 and 6.02 inches respectively. A bolt measuring 5.99 inches is inserted in its intended hole of a machine. Five months after the machine was sold it breaks down as a result of loose parts . The cost of repair is estimated at $95. Find the loss to society incurred because of the part not matching its target.**

We must first determine the value of the constant k

Now the equation l(y) = k (y-T)^2

Where k = Δ / m^2

T = 6 inches (which is the target)

Y = 5.99 (the bolt which is actually inserted)

USL = 6.02 (Upper Specification Limit)

m = | USL – T | = 6.02 – 6 = 0.02

Δ = $95 (Δ = Cost of Repair)

k = ($95/0.0004) = $237,500

(y-T)^2 = (5.99 – 6) ^2 = 0.01 ^2 = 0.0001

Therefore

L(y)= k (y-T)^2 =$237,500 * 0.0001 = $23.75

Not producing a bolt that matches the target would have resulted in a financial loss to the society that would amount to $23.75.

The 25 patient/day capacity of a hospital is the result of truly remarkable little law, referred convininiantly as little law.Little law was proved by John .C.Little of MIT.

That is throughput (TH) is equal to work in process(WIP) divided by cycle time.

TH =WIP/CT

In our hospital example , WIP is the number of patient the hospital accomadates and cycle time is the average length of the stay.

According to little's law TH can only be increased if

1] WIP the amount of work the system can process at one time is increased.

2] CT is decreased example length of stay in haspital.

3] Both

Defects per Million Opportunies (DPMO)

A very simple product may have only one CTQ characteristic. For Example, a paper clip may have only have one opportunity for defect whether it holds the paper or not. Complex products have more than one CTQ characteristic and therefore have more opportunities for defects. Let Us consider that a computer has 10 opportunities for defects bad drives, system crashes display flickers etc.

Example a Paper Clip has one opportunity for defect we find 7 clips defective in 1000 clips produced so the Defect per Opportunity and the DPMO can be calculated as follows

DPO = Defects / Opportunities * total items produced

So DPO = 7 / 1 * 1000= 0.007

DPMO = DPO * 1 Million(10 ^6)= 0.007 * 10^6= 7000.

Example: - A process produces 40,000 pencils, three types of defect can occur the number of occurrences of each defect type are:

1]   Blurred printing: 36

2]   Wrong Dimension: 118

3]   Rolled Ends: 11

Total number of defects is = 165 so DPU = Number of defects/ Number of Units = 165/40,000 = 0.004125

Defects per Million Opportunities (DPMO)

To calculate the number of opportunities it is necessary to find the number of ways the defect can occur for each item.

For this product blurred printing occurs in only one way so there are 40,000 opportunities for this defect to occur ; there are 3 independent places where the dimensions are checked so there are 3 * 40,000=120,000 opportunities for dimensional defects ; rolled ends can occur at the top or bottom of the pencil so there are 2 * 40,000=80,000 opportunities for this defect to occur thus the total number of opportunity for defects is

40,000 + 120,000+ 80,000 = 240,000

There Defects per million opportunities is calculated as

DPMO = (Number of defects)(1,000,000)/Total number of opportunities = 165,000,000/240,000 = 687.5

So DPMO = 687.5

PPM (Parts per Million is defined simply as PPM=DPU * 1,000,000 from the above example of Pencils PPM= 0.004125 * 1000,000 so PPM= 4125

PPM is also used to refer to contaminants as seen in the following example

Example:- Suppose 0.23 Grams of Insect parts is found in 25 Kilograms of Product so PPM=(0.23/25,000) * 1,000,000

So PPM= 9.2

Throughput Yield

For a process, throughput is a measure of the productivity of the process in producing error free product or service. For a product, throughput is a measure of the quality of the product of the entire product as a function of the quality of its various features.

The throughput yield is calculated based on the defects per unit (DPU) for each process step

DPU = #errors / # items

Throughput Yield = 1- DPU or e ^ -dpu = 10 ^ -dpu

For example if there are 74 errors in products and 600 products DPU = 74/600 = 0.12 and Y = 1-0.12 = .88= 88%

DPO = Defects per Opportunity = total defects/ total opportunity.

DPMO= DPO * 1 Million

Throughput (T) is the rate at which an organization generates money through sales.it is based on the total sales minus the variable cost, which includes the cost of material's used to produce the goods sold.

Inventory (I) Money invested in purchasing things intended for sales.

Operational Expense (OE) is Money Spent to turn inventory into throughput it includes salaries and wages paid to workers, rent, utilities etc.

Net profit = T-OE

Return on Asset = (T-OE)/I

Productivity = T/OE

Asset Turn = T/I

Overall Equipment efficiency is calculated based on availability * performance * Quantity

OEE = A *P * Q

A = actual operating time / planned time

P = Ideal Cycle time / Actual cycle time

Q = Acceptable output/ Total output

Staff Required on the Production Line = Total cycle time/Takt Time

2.3.3 Rolled Throughput Yield (RTY)

RTY summarises stepwise throughput yields for a multiple step process or multiple featured product. RTY is the measure of the overall quality level rolled throughput yield RTY for a N

Step process is calculated using the formula RTY = Y1 * Y2* Y3 *… Yn

The First Pass Yield is also first time yield = Units Passing Without Rework/ Input Yield

Final Yield = Final Yield (Including Rework)/Input Yield.

Net Present Value

The net present value (NPV) of an amount to be received in the future is given by the formula $P = A(1+i)^{-n}$

Where P = net present value; A = Amount to be received n years from now; i= annual interest rate expressed as decimal ; this formula assumes that the money is compounded annually.

Example:-
In four years $2500 will be available; what is the NPV of that money assuming an annual interest rate of 8% ?

$P= 2500(1+0.08)^4$
P= 1837.57

Therefore $1837.57 invested at 8% compounded annually will be worth $2500 after 4 years

For example, in the table given below the NPV of Cost Column is $10,523 and the NPV of the Benefits Column is $18,824, the project NPV can be found by subtracting the Cost NPV from the Benefits NPV.

Rate	12%		
Year	Cost	Benefit	Net
1	$10,000	$0	$10,000
2	$2,000	$500	$1,500
3	$0	$5,000	$5000
4	$0	$10,000	$10,000
5	$0	$15,000	$15,000
NPV	$10,523	$18,824	$8,301

Cost of Quality

The standard categories of quality costs are as follows
- **Appraisal Cost** – Expenses involved in the inspection process.
- **Prevention Cost**- Cost of all activities whose purpose is to prevent failures.
- **Internal failure Cost**- Costs incurred when a failure occurs in-house.
- **External Failure Cost**- Costs incurred when a failure occurs when the customer owns the product.

Cost of Poor Quality(COPQ) – The parameters which affect the COPQ are excess inventory, excess employee turnover, rework, idle time of machines, over processing and overproduction.

3. COMMON FINANCIAL MEASURES

Revenue growth is the projected increase in income that will result from the project that is calculated as the increase in gross income minus the cost. Revenue growth may be stated in dollars per year or as percentage per year.

Conceptually margin refers to the difference between income and cost however there are multiple financial concepts of margin which is used to measure the efficiency and effectiveness of an organization's financial capabilities and finesse.

➤**Percent profit margin : This metric provides and overall sense of how efficiently an organization converts sales into profits it is computed as given below :-**

➤**Percent profit margin= (Sales of a product or service- Cost of a product or service/ Sales of a Product or Service) * (100)**

= (Net Profit/Net Sales) * 100

➤**Percent Gross Margin: This metric measures the efficiency of producing sales. It is computed as Follows**

Percent Gross Margin = (Gross profit/Net Sales) * 100

➤**Percent Operating Margin: This Metric Measures how effectively an Organization Controls Cost not related to production and sales of a product or service**

It is Computed as Percent Operating margin = (Operating profit/Net Sales) * 100

➢ **Gross Profit = Net Sales – Cost of Goods Sold**

➢ **Cost of Goods Sold = Cost of Raw Goods + Cost of Labour + Cost of Inventory**

➢ **Net Profit = Net Income = Net Earnings = Bottom Line = Total revenue – Total Expenses**

➢ **Operating Profit = Operating Income = Earnings = Gross Profit – Operating Expenses**

Strategizing

The components of Strategic Management model are given below:

Company Mission

The Mission of the company is the unique purpose that sets it apart from other companies of its type and identifies the scope of its operations. IN short the company mission describes company's product, market and technological areas of emphasis in a way that reflects the values and priorities of the strategic decision makers.

Internal Analysis

The Company analyses the quantity and quality of the company's financial, human and physical resources. It also assesses the strengths and weaknesses of the company's management and organizational structure. Finally, it contrasts the company's past success and traditional concerns with the company's capabilities in an attempt to identify the company's future capabilities.

External Environment

A firm's external environment consists of all conditions and forces that effect its strategic options and define its competitive situation. The strategic management model shows the external environment as three interactive segments: remote, industry and operating environments.

Strategic Analysis and Choice

Simultaneous assessment of the external environment and the company profile enables a firm to identify a range of possibly interactive opportunities. The opportunities are possible avenues for investment.

Long Term Objectives

The results that an organization seeks over a multiyear period are its long term objectives in the areas of profitability, return on investment, competitive position, technological leadership, productivity, employee relations, public responsibility and employee development.

Action Plans

Action Plan translates generic and grand strategies into action by incorporating four elements. First they identify specific action to be undertaken in the next year or less as part of the business's effort to build competitive advantage. Second they establish a clear time frame for completion of each action. Third action plans to create accountability by identifying who is responsible for each action. Fourth each action has one or more specific immediate objectives that the action should achieve.

Strategic Control and Continuous Improvement

Strategic Control is concerned with tracking a strategy as it is being implemented, detecting problems or changes in its underlying premises and making necessary adjustments. In Continuous Improvement the Companies can implement Six Sigma by using a consultant or train their middle management staff on Six Sigma.

Finally, to conclude that it would be very sensible to mention that the topic of strategic management is too vast like an ocean to comprise in a short article, this is a framework on which strategic management processes are build on.

SWOT

A *SWOT analysis* is an effective strategic planning tool applicable to an organization or project objective. SWOT stands for: *strengths*, *weaknesses*, *opportunities*, and *threats*. It is attributed to Albert Humphrey from Stanford University during the 1950s and 1960s.
Strengths and weaknesses are identified with respect to the internal capabilities of an organization. They provide an introspective view. Strengths and weaknesses should not be considered opposites. This will become apparent in the example below.
Strengths address what the organization does well. This might be: research and development, production, marketing, acquisitions, partnering, and so on. Strengths need to be assessed fairly and objectively to bring credibility to the SWOT analysis.
Weaknesses address the organization in terms of skills, capabilities, and competencies. For example, an organization continually fails to deliver its products to its customers on time. This might be due to a lack of skill, incapable processes, or poor training of employees. Note: A weakness should never be improved at the expense of a strength! On the other hand, *opportunities* and *threats* provide the organization with an external view. Quite simply, we are trying to identify opportunities for the organization to grow to new levels, and threats to the organization that will impede its progress. Threats are often barriers to an organization's growth and can represent a competitive disadvantage. When analysing a SWOT, the question to ask is, "How can the organization leverage its strengths and improve its weaknesses to take advantage of the opportunities while mitigating or eliminating the threats?"

PEST

An analysis similar to SWOT is the *PEST analysis*, which brings together four environmental scanning perspectives that serve as useful input into an organization's strategic planning process:

•   *Political*. This perspective looks at political stability, threats of wars, regulatory issues, tax considerations, labour problems, laws, and so forth. For example, as this book is being written, we have:

Political stability. Mid-term congressional elections have shifted the dominating party from Democratic to Republican in the U.S. House of Representatives.

Threat of wars. The war in Afghanistan continues; arguably, the war in Iraq is over; an unstable ruler of North Korea recently died and leadership was assumed by his hardliner son; Iran is clamouring for its own nuclear weapons and attempting to threaten the world's oil supply; and terrorist bombings are rampant.

Regulatory issues. The recent financial meltdown has resulted in strengthening the power and authority of regulatory agencies.

Tax considerations. In an attempt to stimulate the economy, the federal government has proposed special depreciation considerations designed to motivate organizations to purchase capital equipment.

Labour problems. Eight and a half percent unemployment continues to strain our government welfare systems, and public pension legacy issues continue to mount.

Laws. Broad-sweeping healthcare and financial reform laws were passed that will have significant impact to both organizations and individuals.

Economic. This perspective looks at currency exchange rates, market conditions, unemployment rates, inflation factors, interest rates, and so forth. Current examples include: the U.S. dollar against other major international currencies, rates of unemployment in the United States and in other major countries of the world, almost zero percent inflation, low GDP growth rates in the developed world, outsourcing to low-cost nations such as India, China, and those of Southeast Asia, and, in some cases, negative interest rates on bonds.

Social. This perspective looks at education considerations, demographics, health factors, cultural implications, and so forth. Current examples include: the widening educational gap between the United States and other first-world countries, and shifting demographics such that "baby boomers" are now the largest group, and consequently place the biggest strain on the U.S. healthcare system.

Technological. This perspective looks at new technology developments, rate of technological change, cost impact of technology, and so forth.

Aligning Training to Strategy: If training is to be positioned as supporting the needs of the organization senior leaders must be involved with and stand behind the training plans. Technically training plans are action plans that support the strategic plans of the organization, if the plans do not have strategic outcomes, then the organization should not be supporting the training so the following sequence should be followed 1]Strategic plan→Human Resource Strategic Plan→Training Plan→Training Needs Analysis.

Training Plans Are Not a Panacea: Often poor Performance is attributed to a skill or knowledge deficiency that can be corrected by training. Nonetheless many times the root cause of poor performance is not skill related at all. However, training cannot remedy a situation caused by poor performance or other root causes that are not skill related. For example, to expect training can fix operating systems problems is unrealistic. Consider the following points below where training would not be beneficial. Increased defects in a manufacturing environment caused by outdated or inadequate equipment 2] unsatisfactory help desk customer support resulting from poor morale and compensation issues 3] Mistakes caused by employees working overtime on a sustained basis.

There are many elements necessary to ensure a successful deployment. Key among them are the following:
• Governance
• Assessment
• Resource planning
• Resource development
• Execution
• Measure and improve the system

4.DFSS

While DMAIC may be traditionally viewed as the foundation for Lean Six Sigma, its application is primarily limited to improving existing processes; it does little to Address the design of new products or processes that's what DFSS does it is used for designing new products and processes. This concept is illustrated in the flowchart given in Figure 1.0

Fortunately, several additional structured methodologies exist. Several of the common methodologies are depicted in Figure 1.0. Each of these methodologies has its usefulness as long as the nuances of each are fully understood. Table 1.1 has been created to provide a loose comparison between the DMAIC and DFSS methodologies. These comparisons are not exact, but do provide a sense of how the methodologies align. This table may be beneficial for readers who may be required to use multiple methodologies or find themselves in need of selecting one suitable for a particular project.
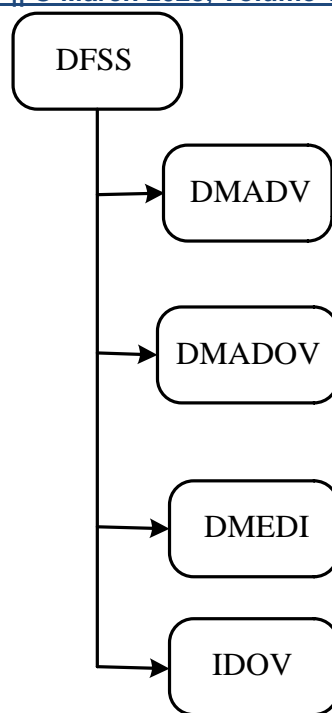
Figure 1.0   The DFSS family of methodologies.

Table 1.1 Comparing DMAIC and DFSS methodologies.

| DMAIC | DFSS | | | |
	DMADV	DMADOV	DMEDI	IDOV
Define	Define	Define	Define	Identify
Measure	Measure	Measure	Measure	
Analyse	Analyse	Analyse	Explore*	Design
Improve	Design	Design	Develop	
		Optimize		Optimize
	Verify**	Verify**	Implement	Validate***
Control				

DMADV is a well-recognized Design for Six Sigma (DFSS) methodology and an acronym for *define*, *measure*, *analyse*, *design*, and *verify*. Note that the ASQ Black Belt Body of Knowledge replaces "verify" with "validate." The difference is likely because, although different, "verify" and "validate" are often used synonymously.
Design. Quite simply, this means carrying out the process of designing a product or process. Many organizations have well-established policies and procedures for their respective design processes. One valuable Lean Six Sigma technique that supports the design process is quality function deployment (QFD). Additional tools useful in this phase include pilot runs, simulations, prototypes, and models.
Verify. This phase is directed at ensuring that the design output meets the design requirements and specifications and is performed on the final product or process. Basically, *verification* speaks to the design meeting customer requirements and ensures that the design yields the correct product or process. By contrast, *validation* speaks to the effectiveness of the design process itself and is intended to ensure that it is capable of meeting the requirements of the final product or process.
Both verification and validation are necessary functions in any design process. As such, this suggests that DMADV might be more appropriately named DMADVV.

Differences between Six Sigma and DFSS

- Six Sigma is reactive to problems, removing defects and DFSS is proactive avoiding problems in the first place.
- Six sigma aims for fast return and DFSS is long term strategy with pay-out down the road.
- Six sigma focusses on improvement projects and DFSS focusses on products and processes.
- Six Sigma Improves the current process and DFSS optimizes new designs and processes.

80% of the quality problems are design related.

5. SIX SIGMA (SARBANES OXLEY ACT-2002)

The Sarbanes–Oxley Act of 2002 changed many of the rules under which corporations and executives were required to provide information to investors and to others. In many respects, the Act defined a customer service approach that corporations would be required to adopt (in addition to attempting to prevent a repeat of many abuses among corporate executives, accounting firms, and analysts that came to light in 2001 and 2002). For example, the new law "requires steps to enhance the direct responsibility of senior corporate management for financial reporting and for the quality of financial disclosures made by public companies."4 This "direct responsibility" means that the officers of companies are required to *personally* certify the accuracy of financial statements. In a very real sense, this represents a government-enforced form of customer service. If we recognize that the investor is a customer of the company whose stock he or she owns, then what are the customer requirements and expectations?

Where Lean Six Sigma meets Sarbanes-Oxley

A key requirement of Sarbanes-Oxley is that of internal control over financial reporting, which is covered under section 404 of the act further, the SEC has established rules that such internal controls satisfy the following three functions
Recordkeeping: This function addresses the processes associated with transactions an dispositions of a company's assets.it Requires that a sufficient level of detail should be kept that is accurate and detail.
Compliance: This function addresses the processes that ensure transactions are actually recorded and receipts and expenditures are accurate and made only when authorized by the management. Also financial statements must be prepared according to the generally accepted accounting principles (GAAP).
Prevention and detection this function addresses the processes that ensure the prevention and/or detection of unauthorized use or disposition of company assets.

From the above discussion, it should be clear that lean Six Sigma and Sarbanes-Oxley relate to each other through two central ideas
Processes: For Sarbanes- Oxley to be Successful, processes need to be inventoried, mapped and improved. Simplified process facilitate the compliance function
Control: Sustaining the gains is what improvement is all about consequently, tools like mistake proofing and control plans are beneficial and support prevention and detection of functions

6.MEASURE PHASE

The roadmap of Measure phase consists of seven major events: Knowing types of data, using Minitab to perform various statistical tests and analyses, distributing data, developing sampling strategy, preparing a data collection plan,

analysing measurement system, and determining the process capability.

Before proceeding ahead, a brief recap of the Measure phase. Every organization measures various performance parameters during the course of the day to access whether their plans are working and achieving the desired results. If there are no measurements it will be not possible to know whether the organization is meeting customer requirement and making profits. At the same time, it is not economical to measure every activity and control all the parameters. When there is a specific problem in the organization to be eliminated the first step is to measure the extent of the problem. Measurement of key performance parameters of any process is a key to find solutions and eliminate the problem in the process. During measure phase the performance of the current process is measured to identify the problem area.

We ask the following questions given below in measure phase:

✓ What needs to be measured?

✓ How to measure it?

✓ What is the customer requirement?

✓ What is the variation between the customer requirement and the current level of performance?

✓ Is there any additional measurement required to precisely know the problem?

✓ What measurements are required after the process is improved?

A factor rarely discussed in the ranks of Six Sigma is the raw cost of collecting data. Unfortunately promising projects may be abandoned simply because of the high cost of acquiring the necessary data.

In Measure phase we will be faced with 2 types of Data that is 1] Continuous Data 2] Discrete Data.

Continuous data are the data which are measured to the finer elements and expressed in units of physical property such as length, height, diameter, temperature and weight and Discrete data is that data which cannot be measured these are data regarding characteristics like colour, odour, and count data such as pass/fail.

To measure data to improve the process of a part manufacturing factory we should also determine the sampling plan from the sampling types such as 1] Simple random Sample here the lot we collect is homogeneous that is from the same category. 2] Stratified Sample this is a refined method of random sampling where the lot is segregated based on certain criteria from a heterogeneous lot. 3] Systematic Sample in this samples are taken after every fixed interval of time when the machine produces the part 4] Rational Sample is done when the team finds there are large numbers of data already existing, it is possible to identify a critical area from the past records and collect samples only from specific area.

Dr Kaoru Ishikawa Diagram or Fishbone Diagram or Cause and Effect Diagram is used to find the cause related to a problem which is causing the variation in the process. It is ideally done by having meetings with the process owners and other stake holders along with the six sigma team of black belts and green belts.

Love it or hate it, brainstorming is something we've all done at some point in our lives. Those sessions may have been disorderly at times with ideas coming from every direction or totally structured with the help of a particular diagram.

Since the late 1960's, Ishikawa Diagram has helped millions of people through the process of brainstorming potential causes of an effect or problem and mapping those relationships.

Due to their focus, shape and design, these diagrams are more commonly known as cause-and-effect or fishbone diagrams.

Fishbone diagrams give you a great way to brainstorm within a well-defined structure, but do you know how to fully use them and the types of diagrams that are available?

Each fishbone diagram starts the same: a central problem or effect is placed on the far right of the diagram. Then a line, which is called the "spine", is drawn straight to the left and branches are added off shooting both above and below it. These branches become known as "affinities" or types of causes from the spine of the central problem or effect. Then specific causes are added to each of the affinities while you are actively brainstorming. This continues until your brainstorming session is complete and you feel satisfied with your fishbone diagram.

Since nearly everyone can use a fishbone diagram to help them brainstorm and there are so many industries and uses, there are a few types different types of fishbone diagrams available. Below are the four most popular:

The Simple Fishbone

In its most basic form, the fishbone diagram has no predetermined affinities or categories of causes, so you can set and create the affinities that may be unique to your organization or industry.

For example, a health care system may have affinities that wouldn't be applicable to a manufacturer and vice versa. Even manufacturers could have different affinities due to the array of products they are producing, like food, automotive parts or electronics to name a few.
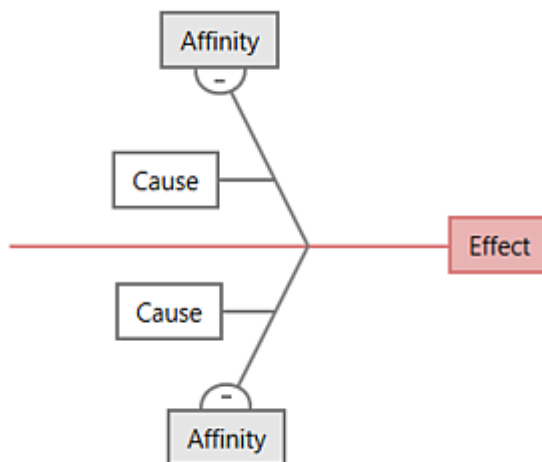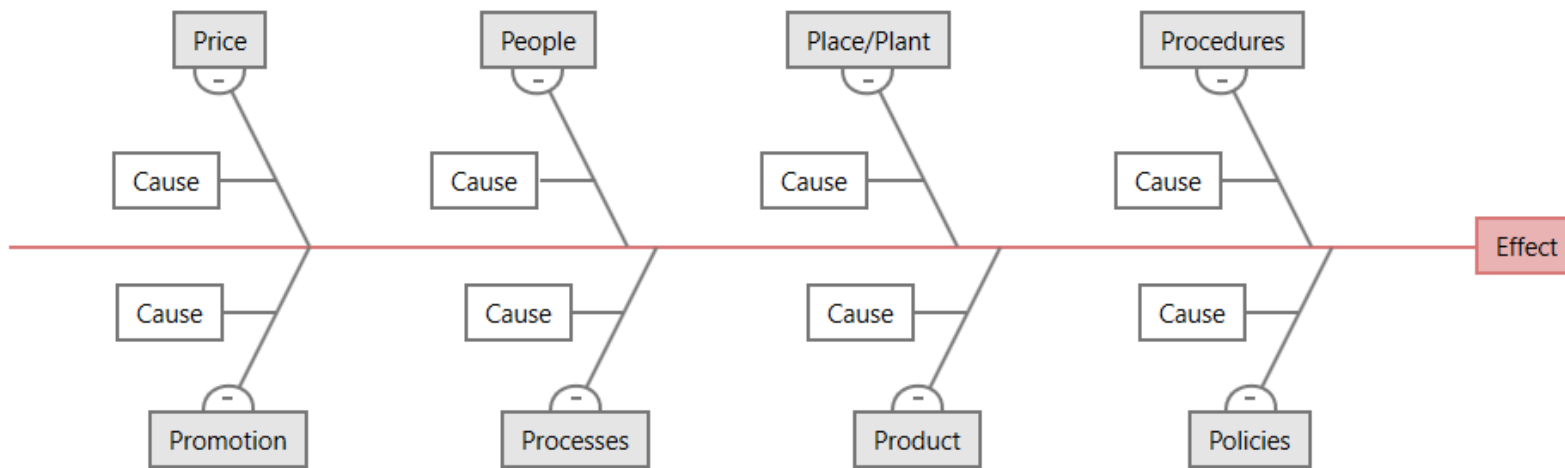

The 4S Fishbone

This type of fishbone diagram gets its name from the way it organizes information about potential causes into four common categories: Suppliers, Systems, Surroundings and Skills. It is commonly used in the service industry, but could be used in nearly any industry.
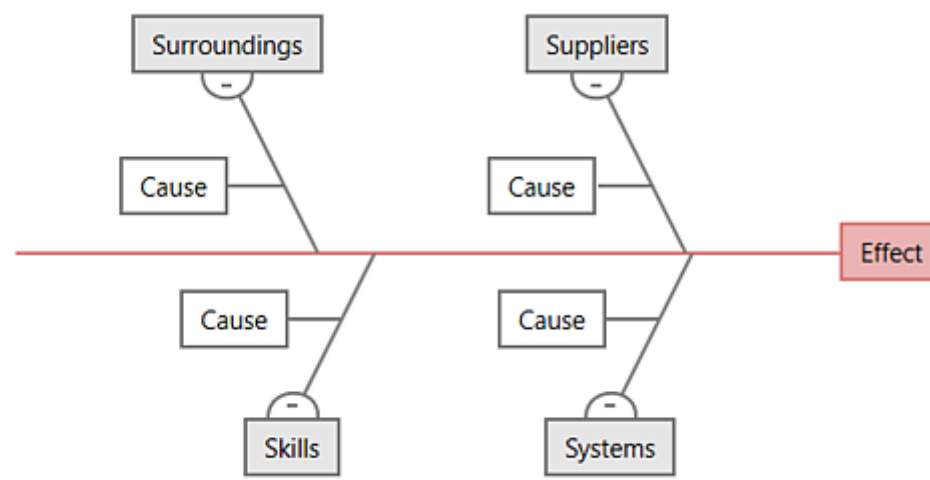
The 8P Fishbone

This type of fishbone is named after the 8 categories that make it up: Procedures, Policies, Place, Product, People, Processes, Price and Promotion. This variation is also commonly used in the service industry, but can be applied in nearly any type of business or industry.


The Man Machines Materials Fishbone

This fishbone diagram variation is most commonly used in manufacturing and allows you to organize potential causes of a problem into these categories: Man, Materials, Machine, Methods, Measurements and Environment. In some cases, two additional categories are included: Management/Money and Maintenance.
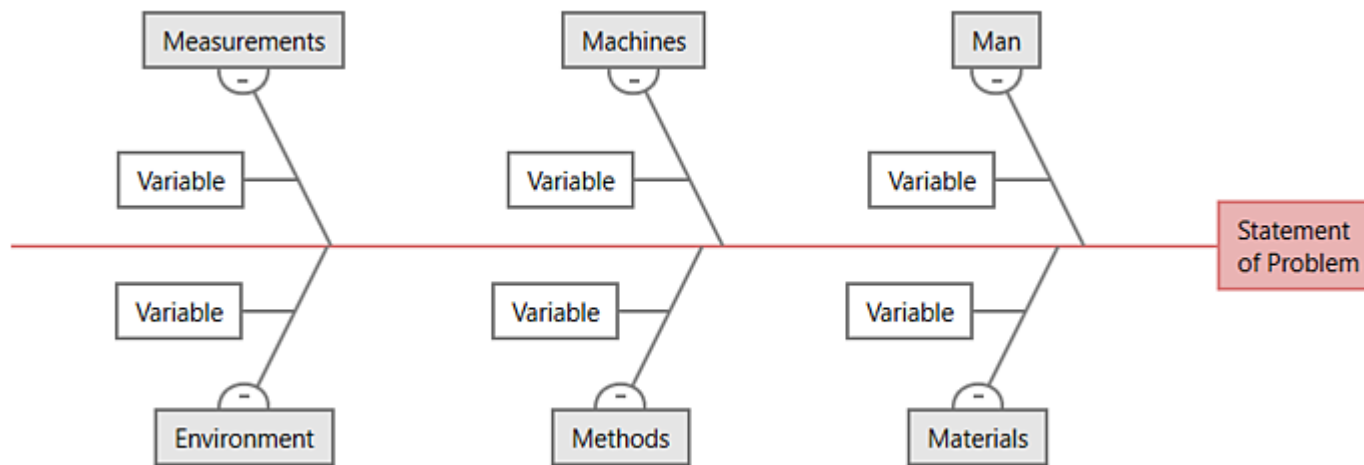
Cause and Effect diagram is a visual tool used to brainstorm and logically organize possible causes for a specific problem or effect. Cause and Effect diagram is also known as, Fishbone diagram or Ishikawa diagram. It's called as Fishbone diagram as the structure is similar to the skeleton of a fish. It's called as Ishikawa diagram because Dr. Kaoru Ishikawa was the person who developed the first Cause and Effect diagram in the year 1943. Cause and Effect diagrams are created to arrange ideas or inputs in proper categories, understand the relationship between possible causes and an effect, stimulate thinking for brainstorming on all possible causes, develop a list of possible causes for a problem, and guide concrete action and track the potential causes for an investigation effort.

5 why's is a tool used that is often used in conjunction with cause and effect diagram; the idea of 5 why's is to take potential causes of a problem and to dig deeper by asking "Why" upto 5 times. The goal is to get something that is actionable.
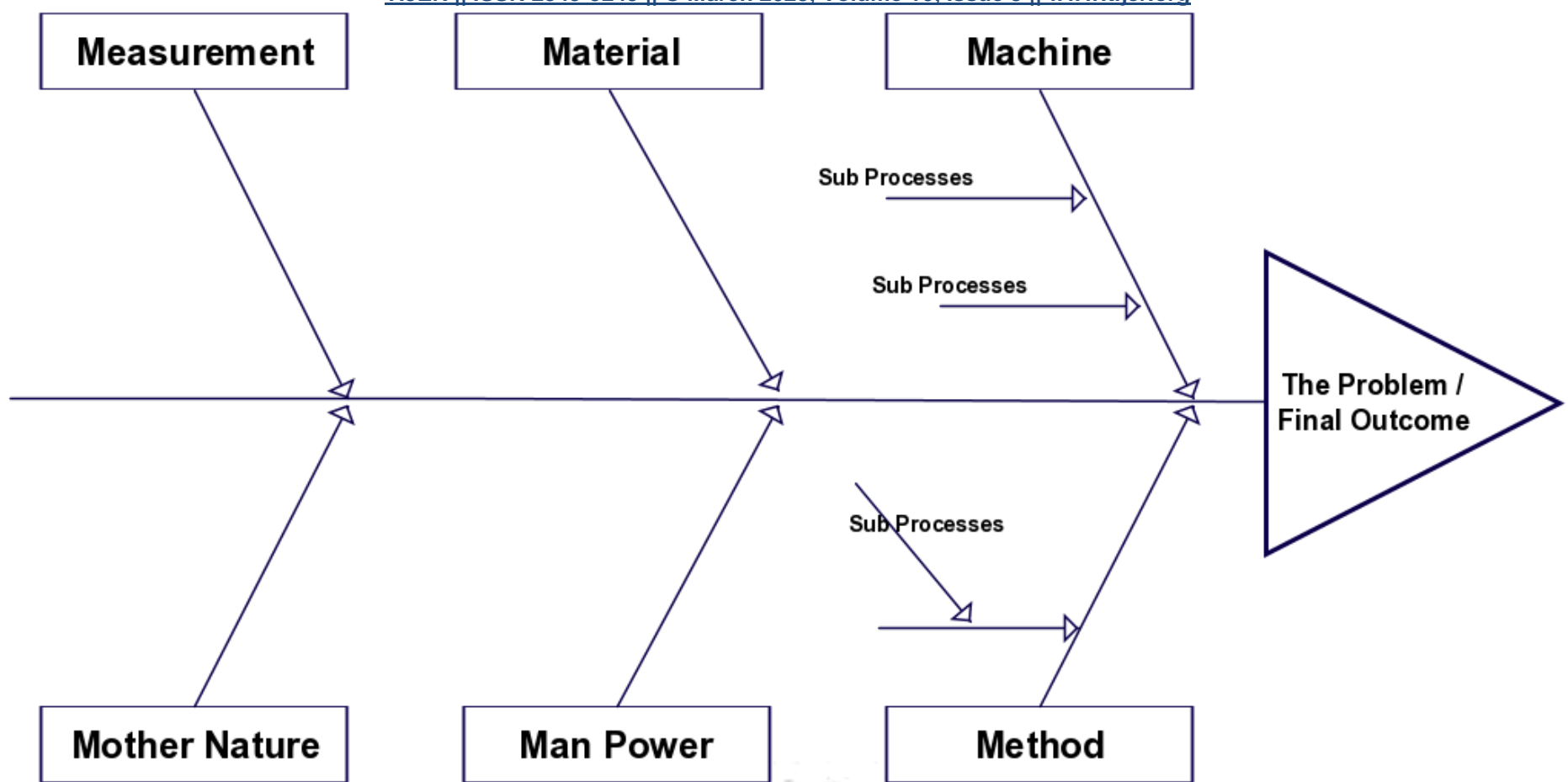
The essence of Measure phase revolves around understanding the degree of process variation.

Sampling

Sampling strategy should involve an accurate way of incorporating the voice of the entire population by selecting samples, randomly or strategically. Sampling is carried out with the intent to mirror the opinion of the population. Population study is both time consuming as well as costly. Thus, to deal with the constraints such as time and money, sampling technique is utilized to measure a high volume process. The number of samples taken from the population or the sample size helps to provide judgment of the entire population and thus helps to measure a high-volume process

Approaches for Sampling: -

1] Systematic Sampling where samples are collected after a particular period of time. For Example, Collecting samples after every nth period of time.

2] Collecting sample in Groups

3] Random Sampling that is randomly pick up samples from the assembly line. Random Sampling refers to the sampling technique in which each element of the population has an equal chance of being selected in the sample. In this technique, samples are drawn at random.
For example, cycle tyres produced in the assembly line have a random check of 10 percent on daily production as a part of quality control
4] Stratified sampling. Stratified Sampling refers to the sampling technique in which the population is divided into different groups or strata and then the samples are drawn proportionately over the full operating range of the process.
For example, tyres produced in different batches are checked for quality inspection.

5] Stratified Random Sampling Stratified Random Sampling refers to the method in which the population is divided into subgroups and sampling is done at random from proportional subgroups of the population.
For example, to calculate average cycle time for LC insurance process of different countries, where each country is strata, random data was collected from each strata.

The steps for creating a data collection plan are: -

- List down all the relevant process steps in a separate row.
- Record the primary project metric for each process step.
- Prepare a list of CTQs for each process step and/or metric.
- Record the applicable data type for each process step.
- Record Operational Definitions for each "Small Y". An Operational Definition can be used here.
- Make a note of upper specification limit and lower specification limit for each process step.
- Enter the sample size. Consider the cost and practicality of sampling, how representative the sample is, and the variability of the population.
- Determine logistical issues, for example, who will collect data, when will it be collected, and how it will be collected.
List what will be done with the data.

Formulas used in Measure Phase

Some Little Statistics

Central tendency is defined as the tendency for the values of a random variable to cluster round its mean, mode, or median.

Central Tendency	Population	Sample
Mean/Average is the average of a set of data values	$\mu = \sum (X_i)^2/N$	$XBar = \sum (X_i)^2/n$
Median	Middle value of Data	
Mode	Most occurring value in the data	
Dispersion		
Variance	$\sigma^2 = \sum(X - \mu)^2/N$	$S^2 = \sum(X_i - XBar)^2/n-1$
Standard Deviation	$\sigma = \sqrt{\sum(X_i - \mu)^2/N}$	$S = \sqrt{\sum(X_i - XBar)^2/n-1}$
Range	Max value – Min value in a set of data	

Standard deviation is a mathematical tool to help us assess how far the values are spread above and below the mean.

Central Limit Theorem: The Central Limit Theorem states that the sampling distribution of the sample means approaches a normal distribution as the sample size gets larger — no matter what the shape of the population distribution. This fact holds especially true for sample sizes over 30. All this is saying is that as you take more samples, especially large ones, your graph of the *sample means* **will look more like a normal distribution.**

A high standard deviation shows that the data is widely spread (less reliable) and a low standard deviation shows that the data are clustered closely around the mean (more reliable).

Standard deviation is simply the square root of variance. It is one of the most important measures of Dispersion. It is also a measure of how spread-out numbers are from the mean. The best measurement of variation is standard deviation.

The **standard deviation** is a measure of the spread of scores within a set of data. Usually, we are interested in the **standard deviation** of a **population**. However, as we are often presented with data from a **sample** only, we can estimate the **population standard deviation** from a **sample standard deviation**.

Variance

The square of standard deviation is known as Variance. Why did we need to define one more parameter, when standard deviation appears to be the right answer? It has some interesting and useful properties. Prominent one is the addition property for two independent data sets or observations. In other words, variance of the sum of independent data sets or observations (also referred random variables) is the sum of their variances.

Z is the Z score, or Sigma score. A low Z score means that a significant portion of the tail of the distribution is extending past the specification limit. A high Z score means that not much of the distribution is extending past the specification limit. The table below shows Z scores related to defects per million opportunities. Notice that the Sigma values we identified earlier are represented here.

You may also see the z score formula shown to the left. This is exactly the **same** formula as $z = x - \mu / \sigma$, except that $\bar{x}$ (the sample **mean**) is used instead of μ (the population **mean**) and s (the sample **standard deviation**) is used instead of σ (the **population standard deviation**).

Gage Repeatability& Reproducibility (R&R) Study

Repeatability also Known as Equipment variation and Reproducibility also known as appraiser variation.

Attribute R&R study is for conducting study on discrete variables and not continuous variables which can be measured on a measuring scale.

The MSA Manual published by Automotive Industry Action Group (AIAG) specifies the following Norms:

✓ **IF GRR is less than 10 percent the measurement system is acceptable**

✓ **If GRR is between 10 and 30 percent equipment may be accepted based upon the importance of application, cost of measurement, device, cost of repair etc.**

✓ **Measurement System is not acceptable for GRR beyond 30 percent.**

We can use Minitab to execute GAGE R&R Studies by Clicking on Assistant option then→ Click on Gage R&R.

Kindly note Gage R&R Variable MSA is for Continuous Data and Gage Attribute MSA is for Categorical Data or discrete data.

Gage Attribute MSA is for Categorical data (Good, Bad) to do this in Minitab Go to Assistant Menu -> Click on MSA(Measurement System Analysis) and Select Attribute Agreement Worksheet then select number of operators , how many times to repeat this procedure , number of items , Standard of items whether good or bad then you get worksheet created by Minitab in that enter in the results column the 2 categories (Good, Bad) then click on Attribute Analysis and select the relevant columns and you get the thermometer graph which tells us accurately what the percentage variation from the reference data.

Reproducibility: Variation is average of measurement made by different operators using the same *gage* measuring the same object. ... *Repeatability*: The random variations in measurement when one operator uses the same *gage* to measure the same part at several times

In Gage Repeatability & Reproducibility for Variable/Continous data you should have minimum 10 parts and 3 operators in the study to get a favourably precise output.

Example of Gage R&R for Continuous data

In Minitab you have to go to assistant menu and select Gage Study and then enter the number of operators and their names and also the number of parts and their names and then enter the measurements of each manually and then select from the assistant option analyse.

We have to use a minimum of 3 operators and 10 parts to get a reasonably precise output in the output below we have used 10 parts and 3 operators and from the horizontal thermometer graph we can see that the measurement system equals to 14.7 % of variation and from the vertical bar graph it can be found that the repeatability has crossed the 30% mark so the variation in the equipment is more than the rules laid down by the automotive industry action group and we have to recalibrate the equipment or change the equipment but operator to operator variation is less and fits the AIAG standard.

Repeatability is variation caused by one operator measuring one part multiple times and reproducibility is multiple operators measuring parts multiple times.
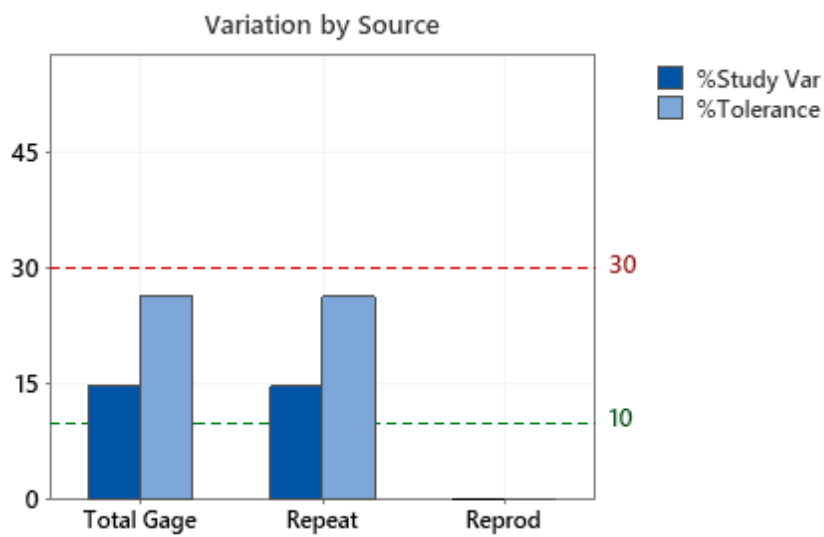
Gage R&R Study for Measurements
Summary Report

Can you adequately assess process performance?

| 0% | 10% | 30% | | 100% |

Yes ▮ 14.7% No
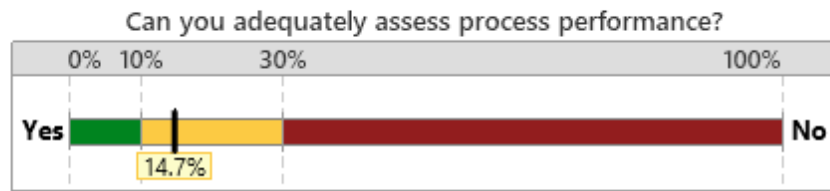
The measurement system variation equals 14.7% of the process variation. The process variation is estimated from the parts in the study.

Can you sort good parts from bad?

| 0% | 10% | 30% | | 100% |

Yes ▮ 26.4% No
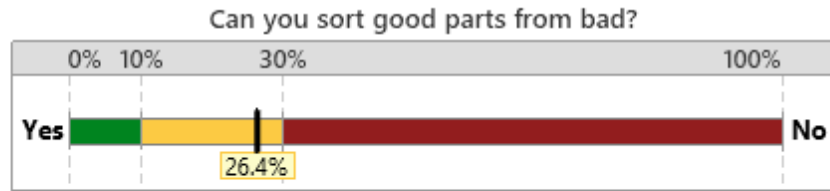
The measurement system variation equals 26.4% of the tolerance.

Variation by Source

Legend: ■ %Study Var ■ %Tolerance

Study Information

Number of parts in study	10
Number of operators in study	3
Number of replicates	2

(Replicates: Number of times each operator measured each part)

Comments

General rules used to determine the capability of the system:
  <10%: acceptable
  10% - 30%: marginal
  >30%: unacceptable

Examine the bar chart showing the sources of variation. If the total gage variation is unacceptable, look at repeatability and reproducibility to guide improvements:
• Test-Retest component (Repeatability): The variation that occurs when the same person measures the same item multiple times. This equals 100.0% of the measurement variation and is 14.7% of the total variation in the process.
• Operator component (Reproducibility): The variation that occurs when different people measure the same item. This equals 0.0% of the measurement variation and is 0.0% of the total variation in the process.

Gaga R&R Attribute or Discrete Data Example: -

Inspectors at a textile manufacturing plant rate samples of dyed fabric as go or no-go (pass or fail) based on the absence or presence of white specks. To assess the consistency and correctness of the inspectors' ratings, a quality engineer asks two inspectors to rate print quality on 60 samples of fabric twice. Fabric samples were randomly presented.

You can use this data to demonstrate **Attribute Agreement Analysis**. Because the data include only two levels, it is useful for demonstrating the **Assessment Disagreement** table of the **Attribute Agreement Analysis**. The data also include a known standard for each sample, so that you can assess the consistency and correctness of ratings compared to the standard in addition to compared with other appraisers.

Worksheet column	Description
Appraiser	The identification number of the inspector evaluating the fabric
Response	The inspector's evaluation for the sample (*go* or *no-go*)
Samples	The sample identifier
Standard	The known rating for each fabric sample (*go* or *no-go*)

Attribute Agreement Analysis for Response
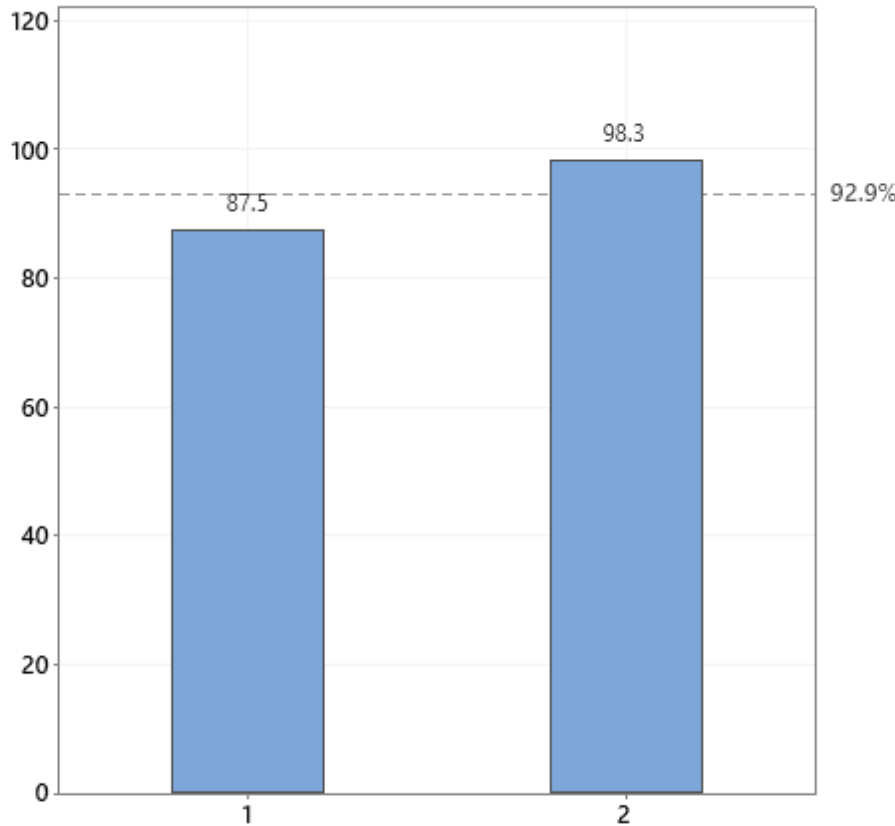### Summary Report

Is the overall % accuracy acceptable?

< 50%   100%

No ▯▯▯▯▯▯▯▯▯ Yes

92.9%
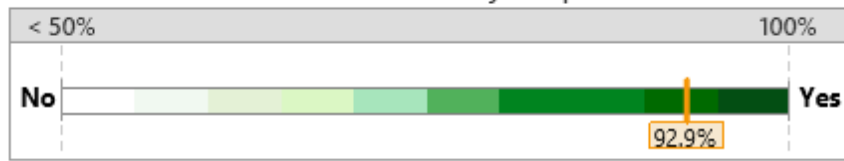
The appraisals of the test items correctly matched the standard 92.9% of the time.

Misclassification Rates

Overall error rate	7.1%
go rated no-go	9.8%
no-go rated go	4.7%
Mixed ratings (same item rated both ways)	4.2%

% Accuracy by Appraiser

98.3 (appraiser 2)
87.5 (appraiser 1)
92.9%

Comments

Consider the following when assessing how the measurement system can be improved:
• Low Accuracy Rates: Low rates for some appraisers may indicate a need for additional training for those appraisers. Low rates for all appraisers may indicate more systematic problems, such as poor operating definitions, poor training, or incorrect standards.
• High Misclassification Rates: May indicate that either too many go items are being rejected, or too many no-go items are being passed on to the consumer (or both).
• High Percentage of Mixed Ratings: May indicate items in the study were borderline cases between go and no-go, thus very difficult to assess.

Gage R&R for Attribute data is just the reverse of Continuous here the vertical bar graph above for both the operators are crossing 80% which is fairly accurate and appraiser 2 is more accurate than appraiser 1. The horizontal thermometer graph above also depicts that the visual inspections of attribute data at the textile company is equal to 92.9%

Attribute Agreement Analysis for Response
Report Card

Check	Status	Description
Mix of Items	i	It is good practice to have a fairly balanced mix of go and no-go items. Your data shows that you have 47% go items and 53% no-go items. If you have a small percentage of items of one type, you reduce your ability to assess how well the appraisers rate that type of item.
Accuracy and Error Rates	i	The accuracy and error rates are calculated across all appraisals. Suppose you test 50 items, 25 Good and 25 Bad, and 3 appraisers test each item 2 times.

To calculate the accuracy and error rates, you need to determine the total number of appraisals:
• Overall accuracy and error rates: (50 items x 3 appraisers x 2 trials) = 300 appraisals
• Good items rated as Bad: (25 items x 3 appraisers x 2 trials) = 150 appraisals
• Bad items rated as Good: (25 items x 3 appraisers x 2 trials) = 150 appraisals
• Items rated both ways: (50 items x 3 appraisers) = 150 appraisals

Overall % Accuracy: If 240 appraisals match the standard, the accuracy rate is:
(240/300) x 100 = 80%

Overall Error Rate: If 60 appraisals do not match the standard, the error rate is:
(60/300) x 100 = 20%

Good rated Bad: If appraisers rate a Good item as Bad 30 times, the misclassification rate is:
(30/150) x 100 = 20%

Bad rated Good: If appraisers rate a Bad item as Good 15 times, the misclassification rate is:
(15/150) x 100 = 10%

Rated both ways: If appraisers rate 15 items inconsistently across trials, the misclassification rate is:
(15/150) x 100 = 10% |

It is very important to know that if the process is found to be stable using Capability Analysis formulas and by Gage R&R Study we can directly move to the Improve or control Phase else we have to start again from Define Phase.

Gage Run Chart

Example of Gage Run Chart

An engineer selects 10 parts that represent the expected range of the process variation. Three operators measure the 10 parts, three times per part, in a random order.

The engineer creates a gage run chart to assess the differences in measurements between different operators and parts.

1.   Open the sample data, **GageData.MTW**.

2.   Choose **Stat** > **Quality Tools** > **Gage Study** > **Gage Run Chart**.

3.   In **Part numbers**, enter *Part*.

4.   In **Operators**, enter *Operator*.

5.   In **Measurement data**, enter *Measurement*.

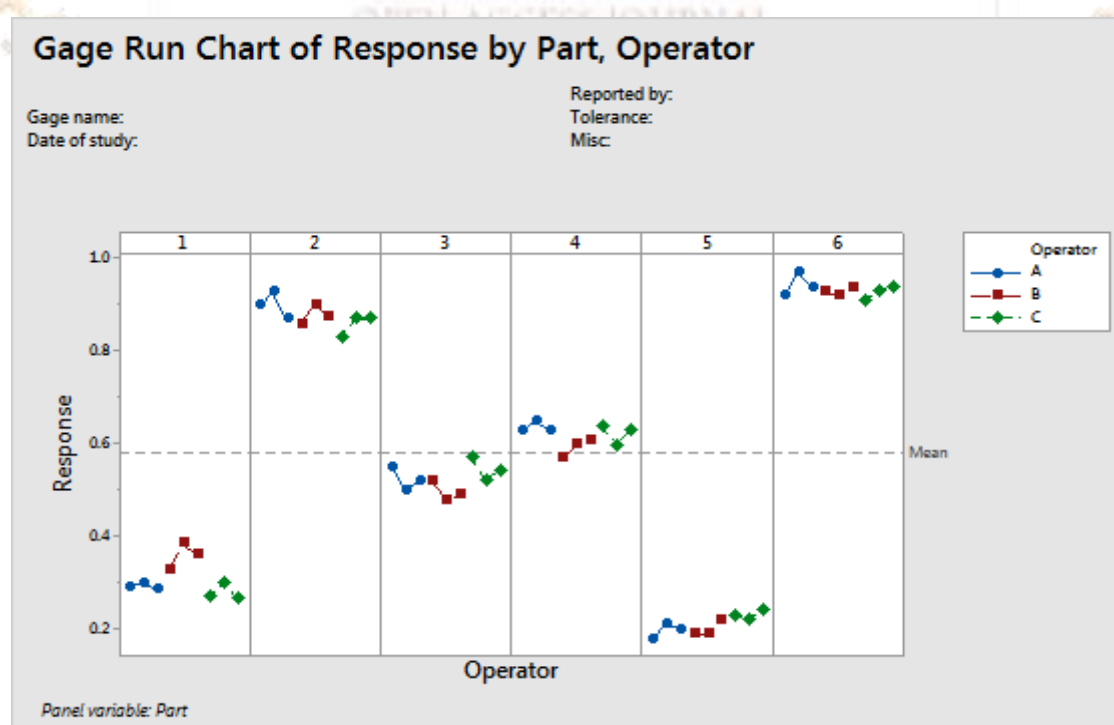6.   Click **OK**.

Interpret the results

For each part, you can compare the variation between measurements that were made by each operator and examine the differences in measurements between operators. You can also view the measurements in relationship to the horizontal reference line. By default, the reference line is the mean of all the observations.

Most of the variation is due to differences between parts. Some smaller patterns also appear. For example, Operator B does not measure consistently, and Operator C usually measures lower than the other operators.
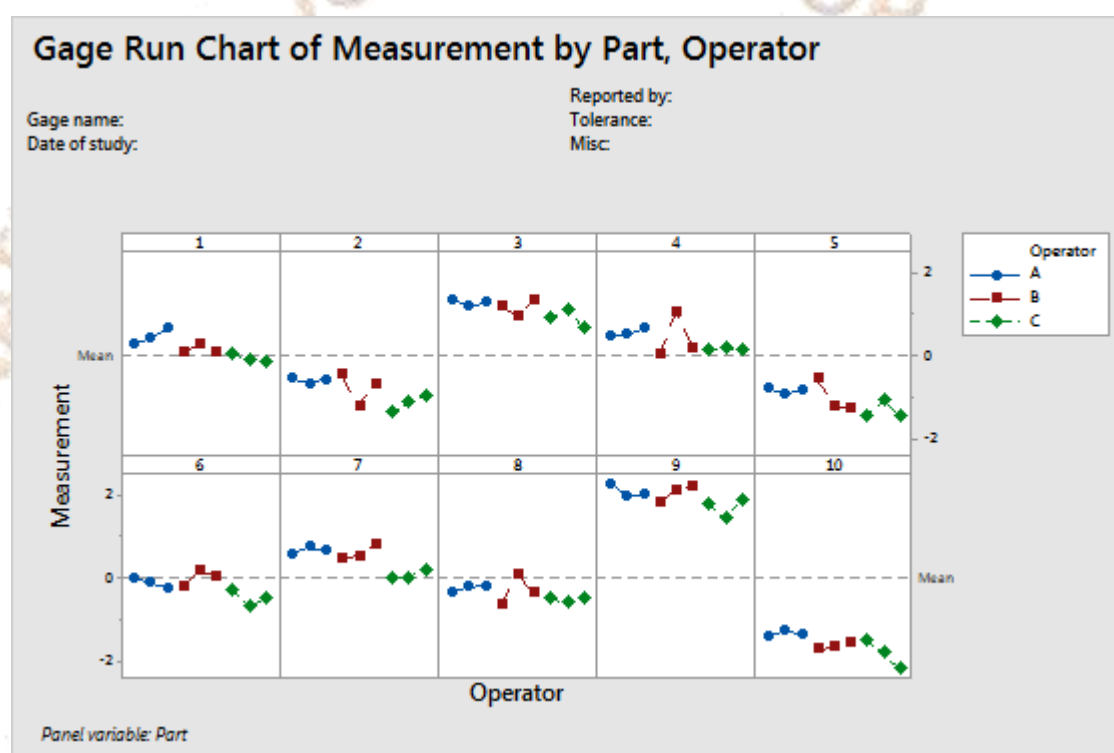
Use a gage run chart to assess the variation in the measured values for each measured part. The gage run chart helps you see how much measurement variability is due to operators or parts.
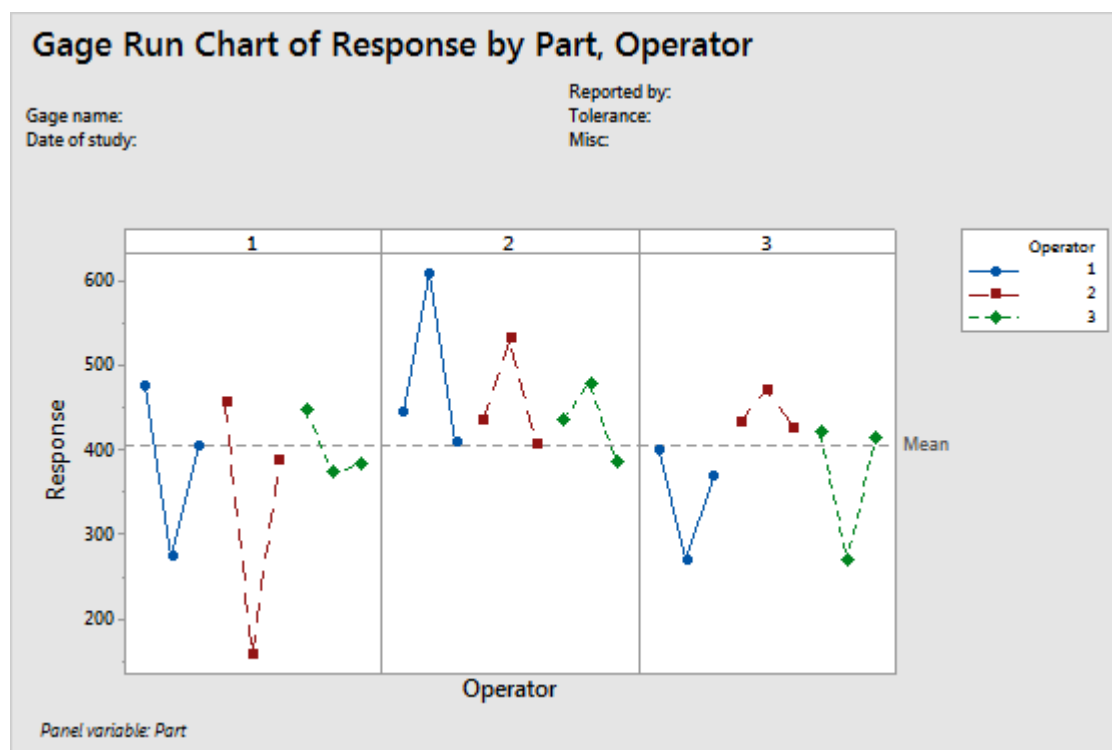
This gage run chart shows the measurements of 6 parts that are selected from a manufacturing process. The parts represent the normal variation of the process. 3 operators measure each part with the same gage 3 times in a random order.


The part-to-part variation is quite noticeable in this chart—Part 2 and Part 6 have higher measurements than Part 1 and Part 5.

Step 2: Assess the variation between measurements from each operator

For each part, you can compare both the variation between measurements made by each operator, and differences in measurements between operators. You can also look at the measurements in relationship to the horizontal reference line. By default the reference line is the mean of all observations.

This gage run chart shows that the operator's measurements do not have good repeatability. Each operator measures each part 3 times (3 trials). When the same operator measures the same part, the differences between the measurements are large. Oscillations could indicate that the operators adjust how they measure between measurements.
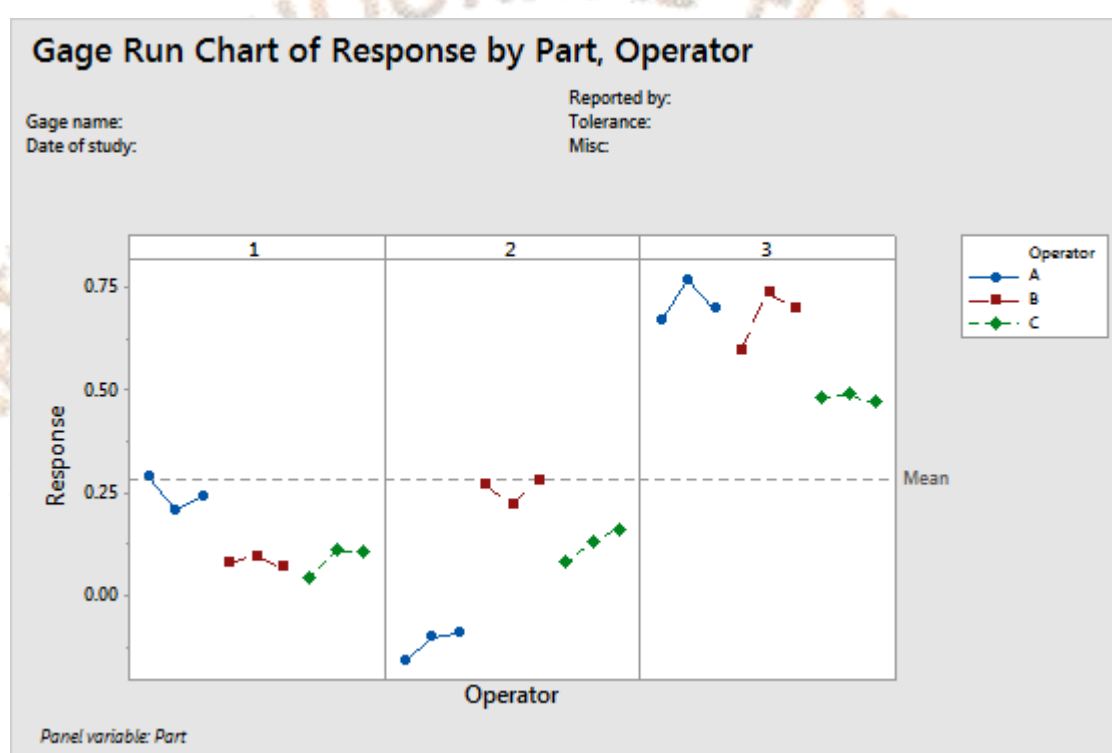
This gage run chart shows that the operators measure more consistently for each part, but the differences in the measurements between operators for the same part are large

Example of Crossed Gage R&R Study

An engineer selects 10 parts that represent the expected range of the process variation. Three operators measure the 10 parts, three times per part, in a random order.

The engineer performs a crossed gage R&R study to assess the variability in measurements that may be from the measurement system.

1.   Open the sample data, **GageData.MTW**.

2.   Choose **Stat** > **Quality Tools** > **Gage Study** > **Gage R&R Study (Crossed)**.

3.   In **Part numbers**, enter *Part*.

4.   In **Operators**, enter *Operator*.

5.   In **Measurement data**, enter *Measurement*.

6.   Under **Method of Analysis**, select **ANOVA**.

7.   Click the **Options** button. Under **Process tolerance**, select **Upper spec - Lower spec**, and enter *8*.

8.   Click **OK** in each dialog box.

Interpret the results

The two-way ANOVA table includes terms for the part, the operator, and the part-operator interaction. If the p-value for the interaction is ≥ 0.05, Minitab omits the interaction from the full model because it is not significant. In this example, the p-value is 0.974, so Minitab generates a second two-way ANOVA table that omits the interaction from the final model.

Use the variance components (VarComp) to compare the variation from each source of measurement error to the total variation. In these results, the %Contribution column in the Gage R&R table shows that the variation from Part-To-Part is 92.24%. This value is much larger than Total Gage R&R, which is 7.76%. Thus, much of the variation is due to differences between parts.

Use %Study Var to compare the measurement system variation to the total variation. The Total Gage R&R equals 27.86% of the study variation. The Total Gage R&R %Contribution might be acceptable depending on the application.

For this data, the number of distinct categories is 4. According to the AIAG, you need at least 5 distinct categories to have an adequate measuring system.

The graphs also provide the following information about the measurement system:

- In the Components of Variation graph, the %Contribution from Part-To-Part is larger than that of Total Gage R&R. Thus, much of the variation is due to differences between parts.

- The R Chart by Operator shows that Operator B measures parts inconsistently.

- In the Xbar Chart by Operator, most of the points are outside the control limits. Thus, much of the variation is due to differences between parts.

- The By Part graph shows that the differences between parts are large.

- In the By Operator graph, the differences between operators are smaller than the differences between parts, but are significant (p-value = 0.00). Operator C's measurements are slightly lower than the measurements of the other operators.

- In the Operator* Part Interaction graph, the lines are approximately parallel and the p-value for the Operator*Part interaction found in the table is 0.974. These results indicate that no significant interaction between each Part and Operator exists.

Gage R&R Study - ANOVA Method

Two-Way ANOVA Table With Interaction

Source	DF	SS	MS	F	P
Part	9	88.3619	9.81799	492.291	0.000
Operator	2	3.1673	1.58363	79.406	0.000
Part * Operator	18	0.3590	0.01994	0.434	0.974
Repeatability	60	2.7589	0.04598		
Total	89	94.6471			

α to remove interaction term = 0.05

Two-Way ANOVA Table Without Interaction

Source	DF	SS	MS	F	P
Part	9	88.3619	9.81799	245.614	0.000
Operator	2	3.1673	1.58363	39.617	0.000
Repeatability	78	3.1179	0.03997		
Total	89	94.647			

Gage R&R

Variance Components

Source	VarComp	%Contribution (of VarComp)
Total Gage R&R	0.09143	7.76
Repeatability	0.03997	3.39
Reproducibility	0.05146	4.37
Operator	0.05146	4.37
Part-To-Part	1.08645	92.24
Total Variation	1.17788	100.00

Process tolerance = 8

Gage Evaluation

Source	StdDev (SD)	Study Var ($6 \times$ SD)	%Study Var (%SV)	%Tolerance (SV/Toler)
Total Gage R&R	0.30237	1.81423	27.86	22.68
Repeatability	0.19993	1.19960	18.42	14.99
Reproducibility	0.22684	1.36103	20.90	17.01
Operator	0.22684	1.36103	20.90	17.01
Part-To-Part	1.04233	6.25396	96.04	78.17
Total Variation	1.08530	6.51180	100.00	81.40

Number of Distinct Categories = 4

Gage R&R for Measurement
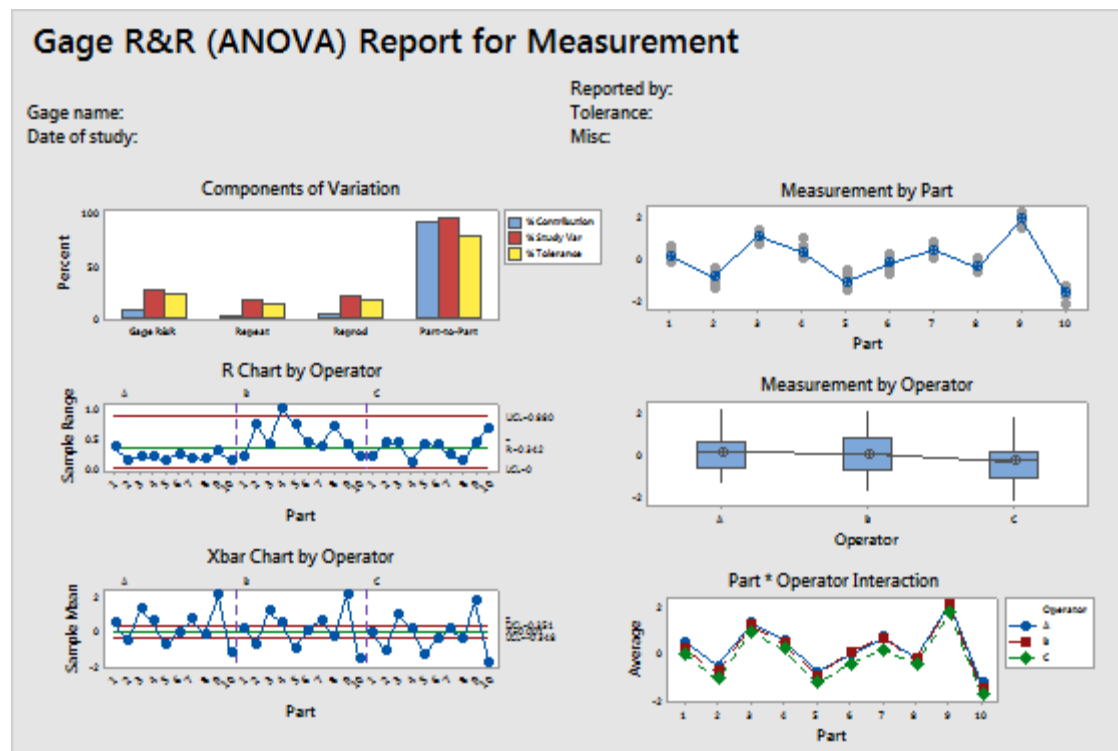
Example of Gage Linearity and Bias

Linearity: a measure of how the size of the part affects the bias of a **measurement** system. It is the difference in the observed bias values through the expected range of **measurement**.

Bias is a quantitative term describing the difference between the average of **measurements** made on the same object and its true value.

Use Gage Linearity and Bias Study to assess the accuracy of your measurement device across its operating range. Select parts that span the operating range of the gage. Each part must have a reference value.

An engineer wants to assess the linearity and bias of a measurement gage that is used to measure inner diameters of bearings. The engineer chooses five parts that represent the expected range of measurements. Each part was measured by layout inspection to determine its master measurement, and then one operator randomly measured each part 12 times. The engineer performed a crossed gage R&R study previously, using the ANOVA method, and determined that the total study variation is 16.5368.

1.   Open the sample data, **BearingDiameter.MTW**.

2.   Choose **Stat** > **Quality Tools** > **Gage Study** > **Gage Linearity and Bias Study**.

3.   In **Part numbers**, enter *Part*.

4.   In **Reference values**, enter *Master*.

5.   In **Measurement data**, enter *Response*.

6.   In **Process variation**, enter *16.5368*.

7.   Click **OK**.

Interpret the results

%Linearity (absolute value of the slope * 100) is 13.2, which indicates that the gage linearity explains 13% of the overall process variation. The p-value for the slope is 0.000, which indicates that the slope is significant and that linearity is present in the measurement system.

Because linearity is significant, the engineer must use the individual bias values and not the average overall bias value. The individual bias values vary from 0.2 to 3.7, and their p-values vary from 0.000 to 0.688. Reference values 2, 8, and 10 have bias. Values 4 and 6 do not have bias.
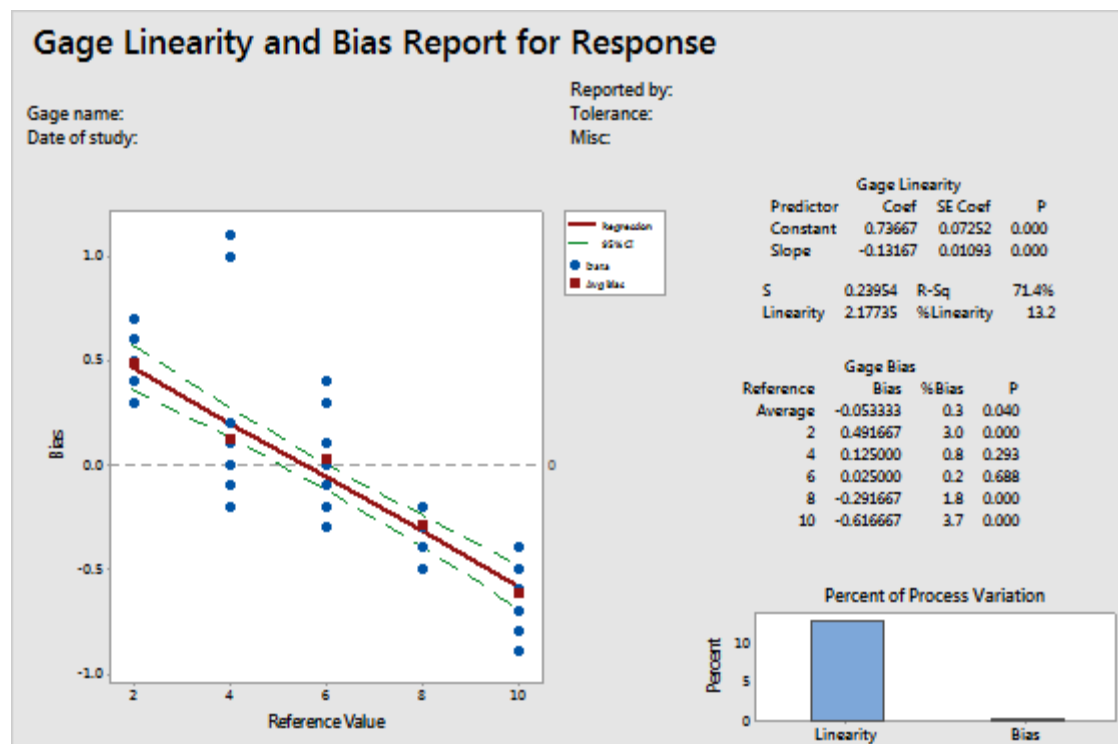
Box Plot

A box plot sometimes called a box and whisker plot is an alternative to the histogram , it shows the location,spread , shape of the data it may also show outliers.

A box plot consists of 2 tails the length of the box describes the middle 50% of the data it is called as interquartile range , the two tails extend out to the expected range of measurements the middle line in the box is the median.

A plant fertilizer manufacturer wants to develop a formula of fertilizer that yields the most increase in the height of plants. To test fertilizer formulas, a scientist prepares three groups of 50 identical seedlings: a control group with no fertilizer, a group with the manufacturer's fertilizer, named Grow Fast, and a group with fertilizer named Super Plant from a competing manufacturer. After the plants are in a controlled greenhouse environment for three months, the scientist measures the plants' heights.

As part of the initial investigation, the scientist creates a boxplot of the plant heights from the three groups to evaluate the differences in plant growth between plants with no fertilizer, plants with the manufacturer's fertilizer, and plants with their competitor's fertilizer.

1.   Open the sample data, **PlantGrowth.MTW**.
2.   Choose Graph > Boxplot > One Y > With Groups.
3.   In Graph variables, enter Height.
4.   In Categorical variables for grouping (1-4, outermost first), enter Fertilizer.
5.   Click OK.

Interpret the results

Grow Fast produces the tallest plants overall. Super Plant also increases plant height, but its variability is greater, and Super Plant does not have a positive effect on a large proportion of the seedlings. The graph shows that Grow Fast causes a greater and more consistent increase in plant height.
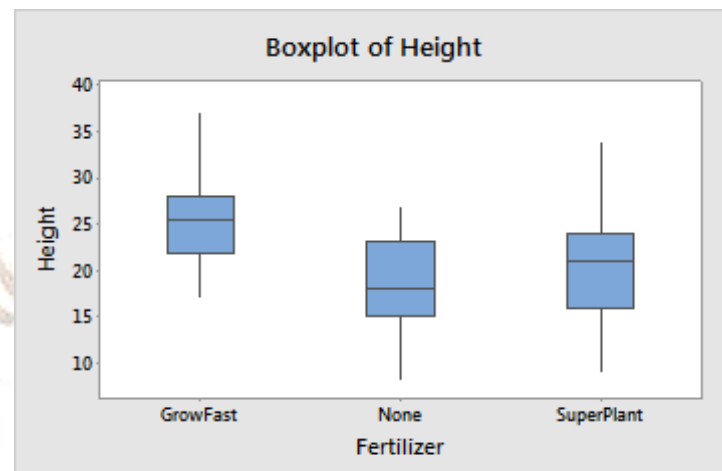
Now let's see how you can calculate the Inter Quartile Range (IQR) in a box plot. To calculate IQR, first you need to locate Upper Quartile and Lower Quartile values in a box plot. Post that, you need to calculate the difference between both quartiles to calculate Inter Quartile Range. The Inter Quartile Range is nothing but the difference between the upper quartile and lower Quartile. An Illustration of Box Plot is given below.
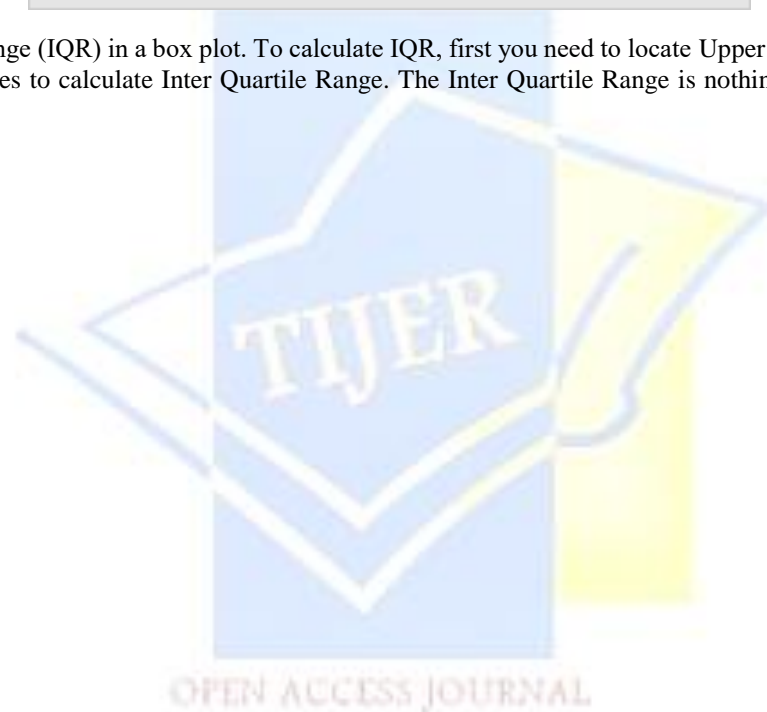
Diagram of
Box-Plot Graph
Used in
detecting
outliers in a set
of data given

Outlier

Largest
Observed
Value

75th Percentile

Median 50th
Percentile

25th Percentile

The Line
represents
smallest observed
Value

Outlier

Extreme
Values

OPEN ACCESS JOURNAL
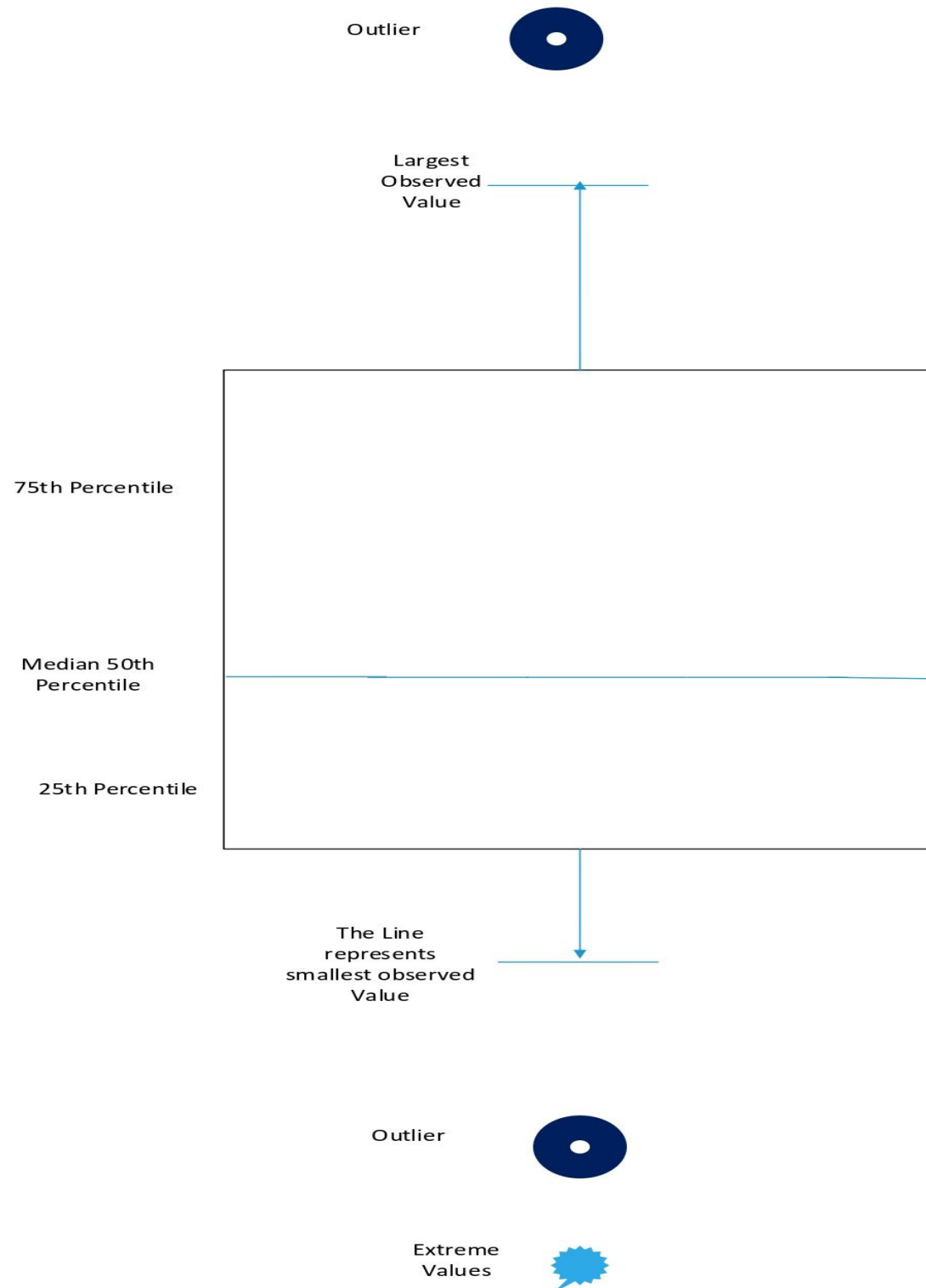
Time Series Graph

Employment trends data

An employment analyst studies the trends in employment in three industries across five years (60 months).

You can use this data to demonstrate **Area Graph** and **Time Series Plot**. It is used to find the trends in the industry of trade, food, metals from the graph below we can find out that the trend in the food industry is very highly fluctuating whereas in metal industry it is fairly stable.

Worksheet Column	Description
Trade	The monthly employment rate in thousands for the wholesale and retail trade industry
Food	The monthly employment rate in thousands for the food products industry
Metals	The monthly employment rate in thousands for the fabricated metal products industry
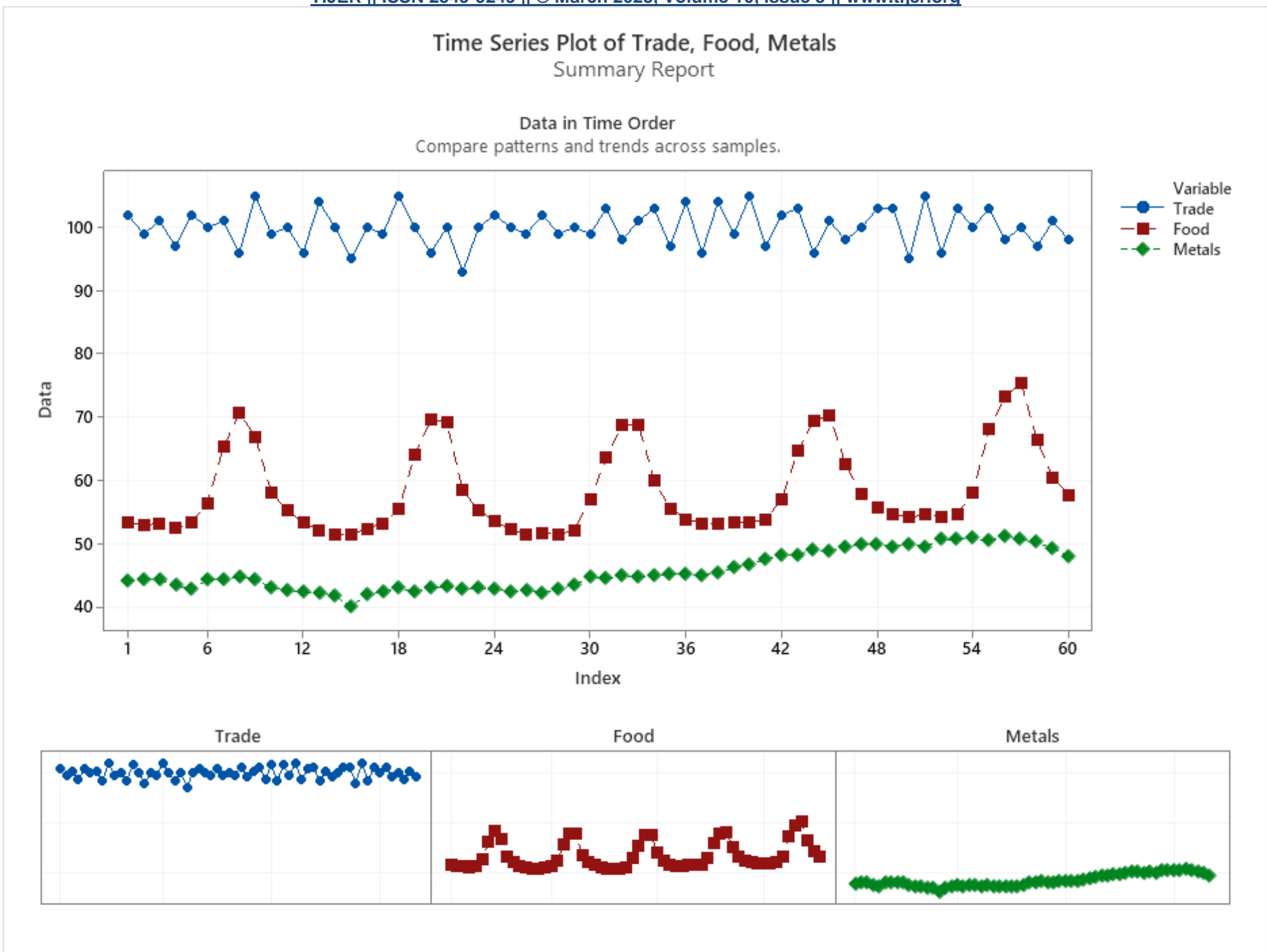
Example of Scatter plot: -

Overview

Use Scatterplot to investigate the relationship between a pair of continuous variables. A scatterplot displays ordered pairs of x and y variables in a coordinate plane.

A medical researcher studies obesity in adolescent girls. Because body fat percentage is difficult and expensive to measure directly, the researcher wants to determine whether the body mass index (BMI)—a measurement that is easy to take—is a good predictor of body fat percentage. The researcher collects BMI, body fat percentage, and other personal variables of 92 adolescent girls.

As part of the initial investigation, the researcher creates a scatterplot of the body fat percentage vs. BMI to evaluate the relationship between the two variables.

1.   Open the sample data, **BodyFatPercentage.MTW**.

2.   Choose **Graph** > **Scatterplot** > **Simple**.

3.   Under **Y variables**, enter *%Fat*.

4.   Under **X variables**, enter *BMI*.

5.   Click **OK**.

Interpret the results

The scatterplot of the BMI and body fat data shows a strong positive and linear relationship between the two variables. Body mass index (BMI) may be a good predictor of body fat percentage.
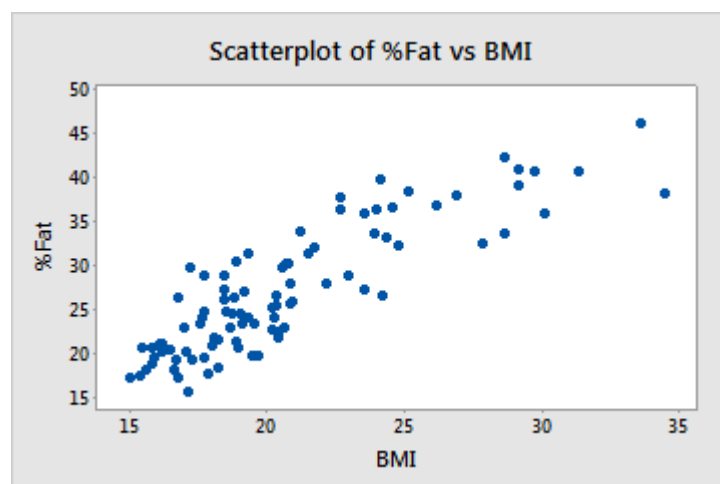
Example of a scatterplot with regression and groups

A quality engineer for a camera manufacturer wants to shorten the flash recovery time. Flash recovery time is the least amount of time that is required between flashes. The engineer wants to determine whether a relationship exists between the voltage that remains in the camera battery immediately after a flash and the flash recovery time. The engineer also wants to determine whether there are differences in flash recovery time between old and new formulations of the battery. The engineer collects random samples of batteries made with the old and new formulations. The engineer measures the volts remaining immediately after a flash and the flash recovery time for each.
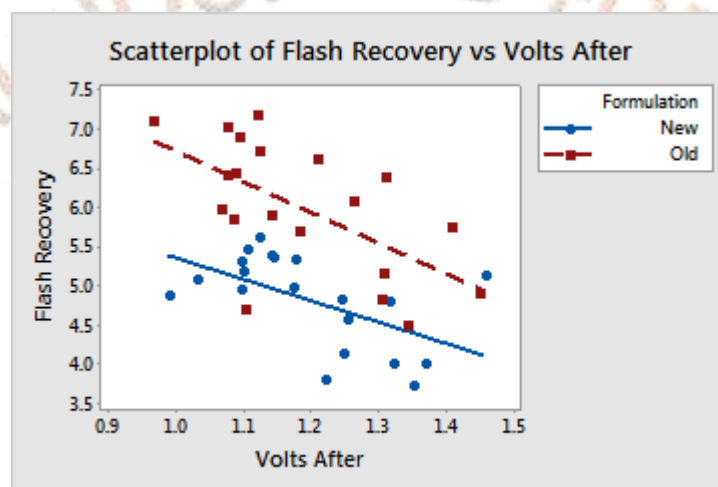
As part of the initial investigation, the engineer creates a scatterplot of volts remaining after a flash versus flash recovery time, grouped by battery formulation, to assess the relationship between the two variables for the two formulations.

1.   Open the sample data, **FlashRecoveryTime.MTW**.

2.   Choose **Graph** > **Scatterplot** > **With Regression and Groups**.

3.   Under **Y variables**, enter *Flash Recovery*.

4.   Under **X variables**, enter *Volts After*.

5.   In **Categorical variables for grouping (0-3)**, enter *Formulation*.

6.   Click **OK**.

Interpret the results

The scatterplot shows a negative linear relationship between the volts after and the flash recovery time. As the amount of volts after the flash increases, the recovery time decreases. The new formulation appears to require a shorter flash recovery time than the old formulation.

Example of Pie-Chart: -

A quality engineer for an automotive supply company wants to decrease the number of car door panels that are rejected because of paint flaws. As part of the initial investigation, the engineer creates a pie chart to compare the counts of flaws in each category.

1.   Open the sample data, **PaintFlaws.MTW**.

2.   Choose **Graph** > **Pie Chart**.

3.   Select **Chart counts of unique values**.

4.   In **Categorical variables**, enter *Flaws*.

5.   Click **OK**.

Interpret the results

This pie chart shows that Peel is the most common paint flaw and that Smudge and Other are the least common paint flaws.
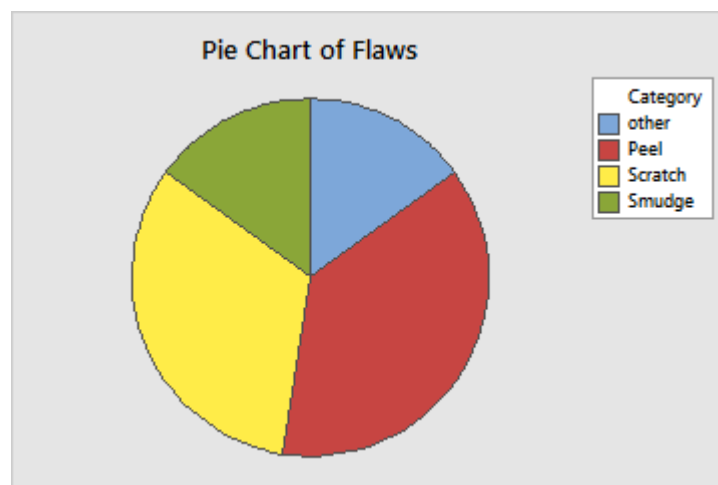
what is the difference between standard normal distribution and normal distributions?

Both are **normal distributions** but **standard normal distribution** is a particular case **of Normal distribution** when the mean is 0 and **standard** deviation or variance is 1. This makes Y a "**Standard "distribution**. So basically X is Normally **distributed** and Y is "**Standard**" normally **distributed**.

what is the difference between z distribution and normal distribution?

The **'z' distribution** is a special case of the **normal**, whose mean is zero and standard deviation is one. ... It is a statistic of data generally known as **z**-statistic for **normal distribution** and the value of **z** is defined as $z = (x\text{-mean})/s.d.$ that makes the mean and variance of given data to zero (0) and 1 respectively.

CAPABILITY ANALYSIS

Normal Capability Analysis requires the data to be normal you can check the normality of the data in Minitab 18 using Anderson-Darling test and then convert the data into normal form using Box-Cox Transformation or Johnson Transformation.

Calculate the Process Capability – Process Capability is measured by comparing the variation in the product to the upper and lower specification limits, assuming that the product mean value is exactly centred between the upper and lower specification limits

The process capability is calculated using the formula CP = USL-LSL/6 * Standard Deviation where CP = process capability index, USL = Upper Specification Limit and LSL = Lower Specification Limit.

The Process capability measures indicates the following

1. Process is fully capable

2. Process could fail at any time

3. Process is not capable.

When the process is spread well within the customer specification the process is considered to be fully capable that means the CP is more than 2. In this case, the process standard deviation is so small that 6 times of the standard deviation with reference to the means is within the customer specification

Example: The Specified limits for the diameter of car tires are 15.6 for the upper limit and 15 for the lower limit with a process mean of 15.3 and a standard deviation of 0.09. Find Cp and Cr what can we say about Process Capabilities?
Cp= USL-LSL/ 6 * Standard deviation = 15.6 – 15 / 6 * 0.09 = 0.6/0.54 = 1.111
Cp= 1.111
Cr = 1/ 1.111 = 0.9
Since Cp is greater than 1 and therefore Cr is less than 1; we can conclude that the process is potentially capable.
Long term Potential Performance
The long term process performance is calculated using the similar methods as Cp and Cpk with the difference being that the standard deviation used in this case applies to long term variations.
Formula is Cp = USL-LSL/ 6 * Long term Standard Deviation.
Cpk= USL-XDouble-Bar/3 * Standard deviation or Cpk = X double bar – LSL/ 3 * standard deviation.

The process is said to be stable and centred when Cp=Cpk.

Example of Normal Data Capability Analysis from Minitab: -

An engine manufacturer uses a forging process to make piston rings. The quality engineers want to assess the process capability. They collect 25 subgroups of five piston rings and measure the diameters. The specification limits for piston ring diameter are 74.0 mm ± 0.05 mm.

You can use this data to demonstrate **Normal Capability Analysis** or other analyses that use normally distributed data.

Worksheet column	Description
Diameter	The diameter of each piston ring. Every 5 rows represent a subgroup.

Reference

Data are from Douglas C. Montgomery (2005). Introduction to Statistical Quality Control. John Wiley & Sons, New York.

In the output from Minitab below we find that the vertical bar graph is well within the lower and upper limit; the lower limit is 73.95mm and upper limit is 74.05 mm and forms a perfect bell shaped curve; Ppk is also greater than 1 and Cpk is also greater than which depicts that the process is capable. The Z bench which is a statistical term is greater than 3 which also depicts that the process is capable.

Capability Analysis for Diameter
Summary Report

How capable is the process?

0   6

Low   Z potential = 4.80   High

Z actual = 4.73

Actual (Overall) Capability
Are the data inside the limits?

LSL ... USL
73.950 73.965 73.980 73.995 74.010 74.025 74.040
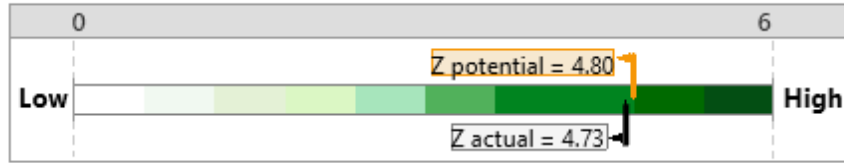
Customer Requirements

Upper spec	74.05
Target	*
Lower spec	73.95

Process Characterization

Mean	74.001
Standard deviation (overall)	0.010199

Actual (overall) capability	
Pp	1.63
Ppk	1.60
Z.Bench	4.73
% Out of spec	0.00
PPM (DPMO)	1
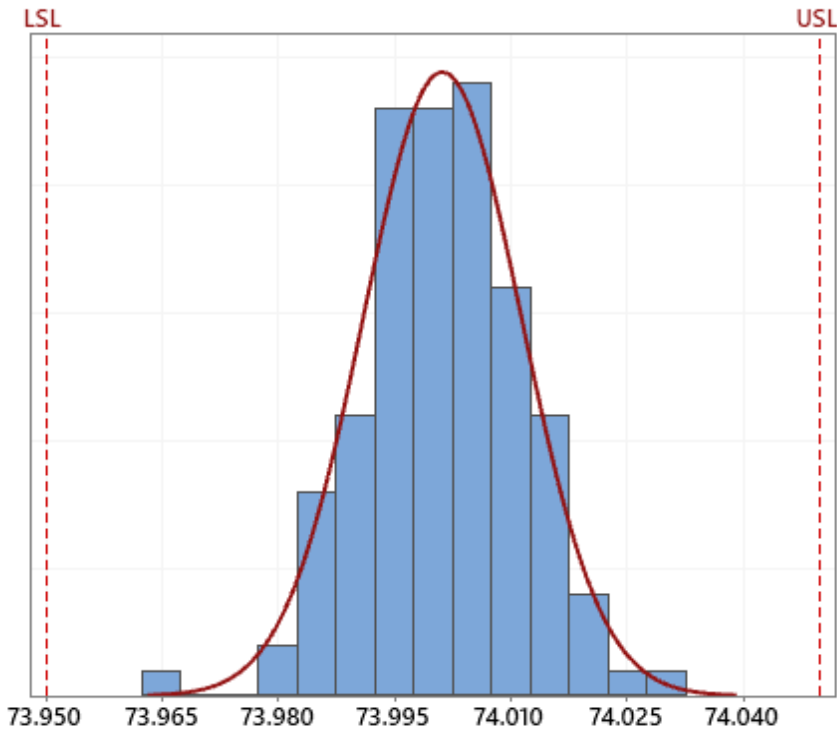
Comments

• The defect rate is 0.00%, which estimates the percentage of parts from the process that are outside the spec limits.

Actual (overall) capability is what the customer experiences.

Potential (within) capability is what could be achieved if process shifts and drifts were eliminated.

Capability Analysis for Diameter
Process Performance Report

Capability Histogram
Are the data inside the limits?

LSL ... USL
73.950 73.965 73.980 73.995 74.010 74.025 74.040
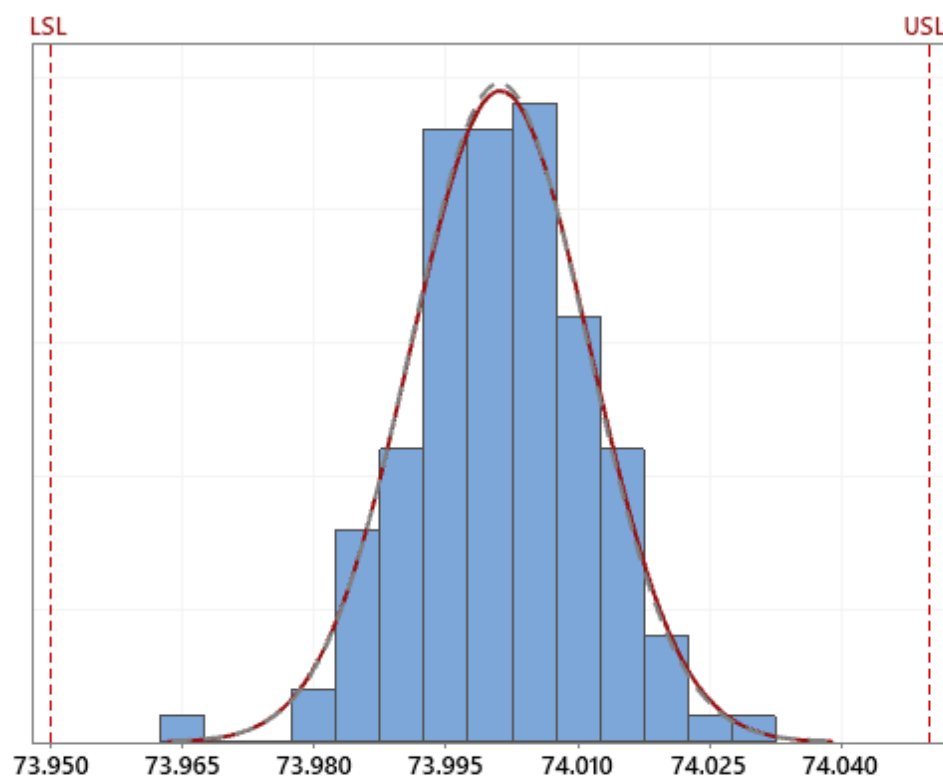
Process Characterization

Total N	125
Subgroup size	25
Mean	74.001
Standard deviation (overall)	0.010199
Standard deviation (within)	0.010067

Capability Statistics

Actual (overall)	
Pp	1.63
Ppk	1.60
Z.Bench	4.73
% Out of spec (observed)	0.00
% Out of spec (expected)	0.00
PPM (DPMO) (observed)	0
PPM (DPMO) (expected)	1
Potential (within)	
Cp	1.66
Cpk	1.62
Z.Bench	4.80
% Out of spec (expected)	0.00
PPM (DPMO) (expected)	1

—— Actual (overall) capability is what the customer experiences.

– – – Potential (within) capability is what could be achieved if process shifts and drifts were eliminated.

The report card below doesn't show a yellow triangle which is a warning sign, which means that the process is stable.

Capability Analysis for Diameter
Report Card

Check	Status	Description
Stability	✓	The process mean and variation are stable. No points are out of control.
Number of Subgroups	i	You only have 5 subgroups. For a capability analysis, it is generally recommended that you collect at least 25 subgroups over a long enough period of time to capture the different sources of process variation.
Normality	✓	Your data passed the normality test. As long as you have enough data, the capability estimates should be reasonably accurate.
Amount of Data	✓	The total number of observations is 100 or more. The capability estimates should be reasonably precise.

Capability Analysis for Attribute Data (Defective Items or items having 2 finite possibilities like good-bad, reject, no-reject basically visual inspection)

Example The supervisor for a call center wants to evaluate the process for answering customer phone calls. The supervisor records the total number of incoming calls and the number of unanswered calls for 21 days.

Because this data contains counts of defectives, you can use it to demonstrate **P Chart** and **Binomial Capability Analysis**.

Worksheet column	Description
Total Calls	The total number of calls each day. This column contains the subgroup sizes.
Unanswered Calls	The total number of unanswered calls each day. Each unanswered call is a defective.

Binomial Capability Analysis for Unanswered C
Summary Report

Is the % defective at or below 10%?

| 0 | 0.05 | 0.1 | | > 0.5 |

Yes ▮▮▮▮ No

P = 0.150
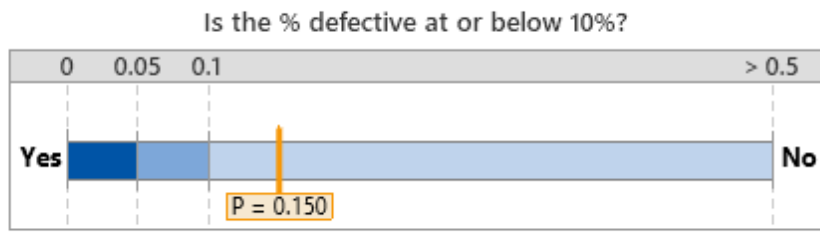
Process Characterization

Number of subgroups	21
Average subgroup size	254.381
Total items tested	5342
Number of defectives	511

Observed % Defective per Subgroup
Where are the data relative to the acceptable level?

10%

Process Capability (Overall)

% Defective	9.57
95% CI	(8.79, 10.39)
PPM (DPMO)	95657
Process Z	1.31
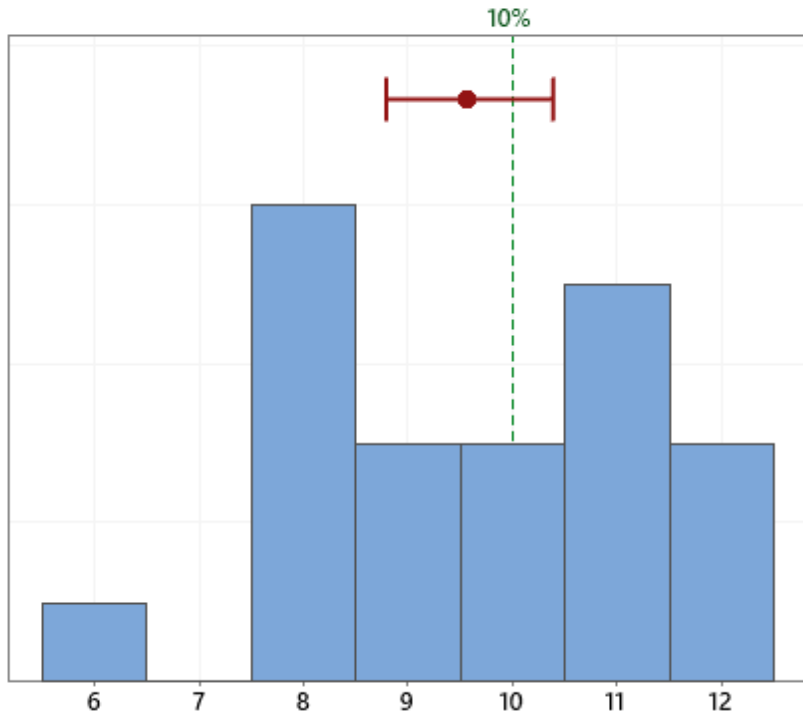
Comments

Acceptable % defective: 10%

The process % defective is not significantly less than the maximum acceptable level (p-value > 0.05).

From the output above we see that the percentage defectives which can be tolerated by the organization is 10% which is the threshold now from the horizontal thermometer graph we can depict that the percentage defective of 10% is not significantly less than the threshold laid by the company so we should improve the process and try to bring the number of unanswered calls less than 10% which would be in the interest of the organization.

Formulas for Cp Cpk and Pp Ppk are Similar

People often get confused about the difference between Pp/Ppk and Cp/Cpk.

Cp, Cpk Formula & Calculations

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

$$CpU = \frac{(USL - \bar{X})}{3\hat{\sigma}}$$

$$CpL = \frac{(\bar{X} - LSL)}{3\hat{\sigma}}$$

$$Cpk = Min(CpU, CpL)$$

(Cpk > 1.33 is desirable)

$\hat{\sigma}$

Pp, Ppk Formula & Calculations

$$Pp = \frac{(USL - LSL)}{6\sigma}$$

$$PpU = \frac{(USL - \bar{X})}{3\sigma}$$

$$PpL = \frac{(\bar{X} - LSL)}{3\sigma}$$

$$Ppk = Min(PpU, PpL)$$

(Ppk > 1.33 is desirable)

C_{pk} measures how close you are to your target and how consistent you are to around your average performance. A person may be performing with minimum variation, but he can be away from his target towards one of the specification limit, which indicates lower C_{pk}, whereas C_p will be high. On the other hand, a person may be on average exactly at the target, but the variation in performance is high (but still lower than the tolerance band (i.e., specification interval).

In such case also C_{pk} will be lower, but C_p will be high. C_{pk} will be higher only when you are meeting the target consistently with minimum variation."

The rationale for considering 1.5 sigma shift is based on the Motorola experience that the mean of the process does not remain constant but varies depending on factors such as tool wear , temperature changes, material variation, drift in measuring instruments, changes in chemical concentration.

Difference between Cp & Cpk :

Cp is the potential capability indicating how well the process would be if it were centred on the target; this is not necessarily it's actual performance because it does not consider the location of the process, only the spread it doesn't take into account closeness of the estimated process mean to the specification limits.

Another metric used in conjunction with Cp is Cpk the formula for Cpk = min[USL-Xbar/3 standard deviation , X bar – LSL/3 Standard Deviation].

Cpk does take into account the location of the data by considering the closeness of the mean to the specification limits.

If Cpk > 1.5 then it is Motorola 6 Sigma Capability and as per Motorola university Cp ,Cpk, Ppk , Pp are interpreted in the same manner.

You must have a C_{pk} of 1.33 [4 sigma] or higher to satisfy most customers.

In the Six Sigma quality methodology, process performance is reported to the organization as a sigma level. The higher the sigma level, the better the process is performing.

The process capability index is a dimensionless number (Number without unit of measure) that is used to represent the ability to meet customer specification limits. The index compares the variability of a characteristic to the specification limit. Two basic process capability indices are Cp,Cpk.
Cp = USL-LSL/6 * standard deviation or Cp = Voice of Customer/Voice of the process= VOC/VOP= Tolerance/Natural process variation
However the Cp index is limited in its use since it does not address the centering of the process relative to the specification limits for that reason Cpk was developed; it is defined as Cpk= Min(Cpku,Cpkl)

Where Cpku is the upper process capability index and given by Cpku = USL- Mean/ 3 * Standard Deviation

Cpkl is the lower process capability index and given by Cpkl = Mean-LSL/ 3* Standard Deviation where Mean is the process average.

The Cpk can be easily Converted into a sigma level using Sigma Level = 3 * Cpk

In Cpk the K is called the k-factor; it measures the level of variation of the process mean from the specified target.
Cpk= (1-k)Cp

Where k = (USL+LSL)/2- Xbar the whole / (USL-LSL)/2
If K=0 it means that the process is perfectly centred and therefore Cpk = Cp

Cp and Cpk represent long term capability while Pp and Ppk represent short term capability. The AIAG suggests that using Ppk for less than 30 day production run(that is short term) and Cpk for everything thereafter (That is long term).

Long term variability = short term variability + 1.5 sigma Shift.

If the data is Normal and you have multiple set of variables you can do a Capability Analysis using the option Stat→Quality Tools→Capability Analysis→Multiple Variables Normal.

Example A manufacturer uses two machines to produce connector pins. A quality engineer wants to compare the process capability of each machine. The engineer randomly samples five pins per box from each machine. The specification range for the length of the pin is 13 mm to 25 mm.

You can use this data set to demonstrate **Normal Capability Analysis for Multiple Variables**.

Worksheet column	Description
Length	The length of each connector pin
Machine	The machine that produced the pin: 1 or 2

From the output below we find the Cpk of Machine 1 is 1.081 which is capable whereas the Cpk of Machine 2 is 0.869 which is less than 1 , so we can conclude that machine 1 is capable than machine 2.

Process Capability Report for Length by Machine

Machine = 1

Within
Cp   *
CPL   1.081
CPU   *
Cpk   1.081

Overall
Pp   *
PPL   1.079
PPU   *
Ppk   1.079
Cpm   *

Machine = 2

Within
Cp   *
CPL   0.869
CPU   *
Cpk   0.869

Overall
Pp   *
PPL   0.879
PPU   *
Ppk   0.879
Cpm   *
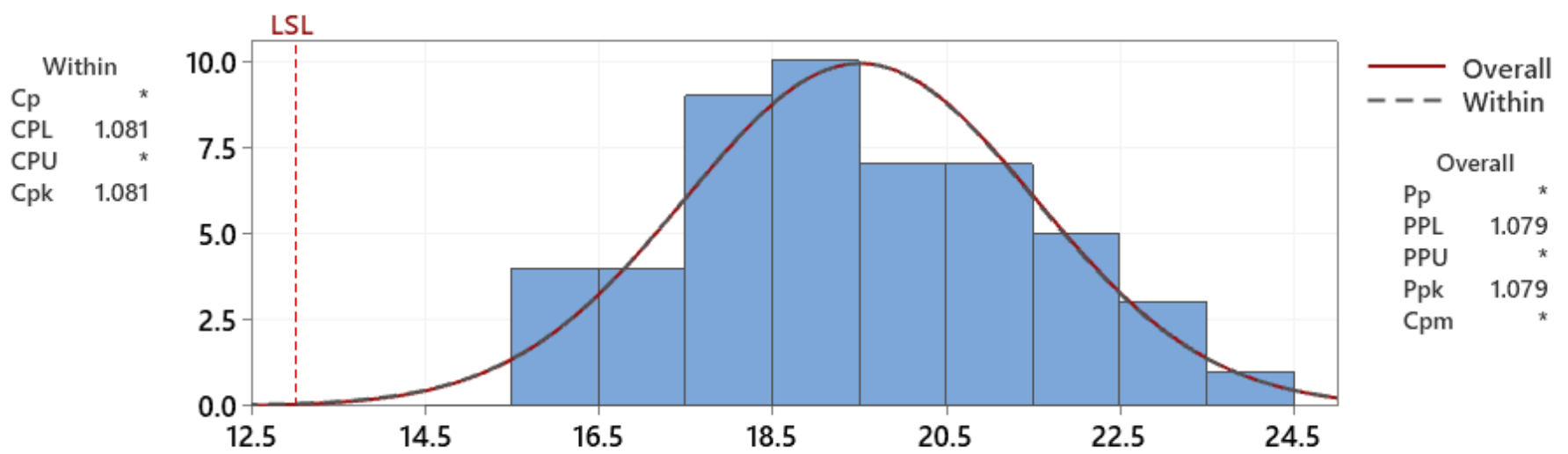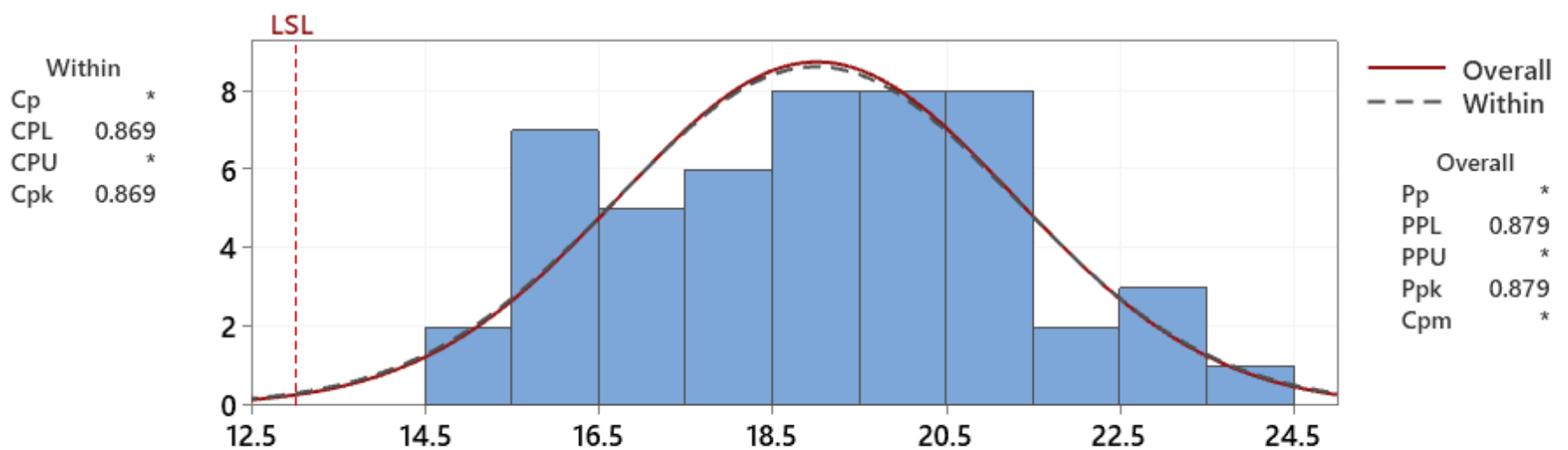
The actual process spread is represented by 6 sigma.

If the data is Non-Normal and you have multiple set of variables you can do a Capability Analysis using the option Stat→Quality Tools→Capability Analysis→Multiple Variables Non-Normal.

Example A manufacturer uses two machines to package its product. A quality engineer wants to assess the process capability of each machine. The engineer randomly samples 50 packages from each machine and records the weight of each package. The specification range is 31 oz ± 4 oz. The engineer knows that the distribution of weights follows the largest extreme value distribution.

You can use this data to demonstrate **Non normal Capability Analysis for Multiple Variables**.

In this example we have lower specification limit as 27 and the data is non normal that is the mean and median are not equal in the data given and multiple variable is machine; from the output we can find that the Ppk is 0.62 which is less than 1 , so using the current machine the process is unstable , now we check the Ppk of New Machine purchased by the organization and find that it is 0.62 which is less than 1 so purchasing a new machine has not changed the capability of the process in any way .

Worksheet column	Description
Packaging Weight	The weight of each package
Machine	The machine identifier: *Current* or *New*

Process Capability Report for Packaging Weight by Machine

Machine = Current
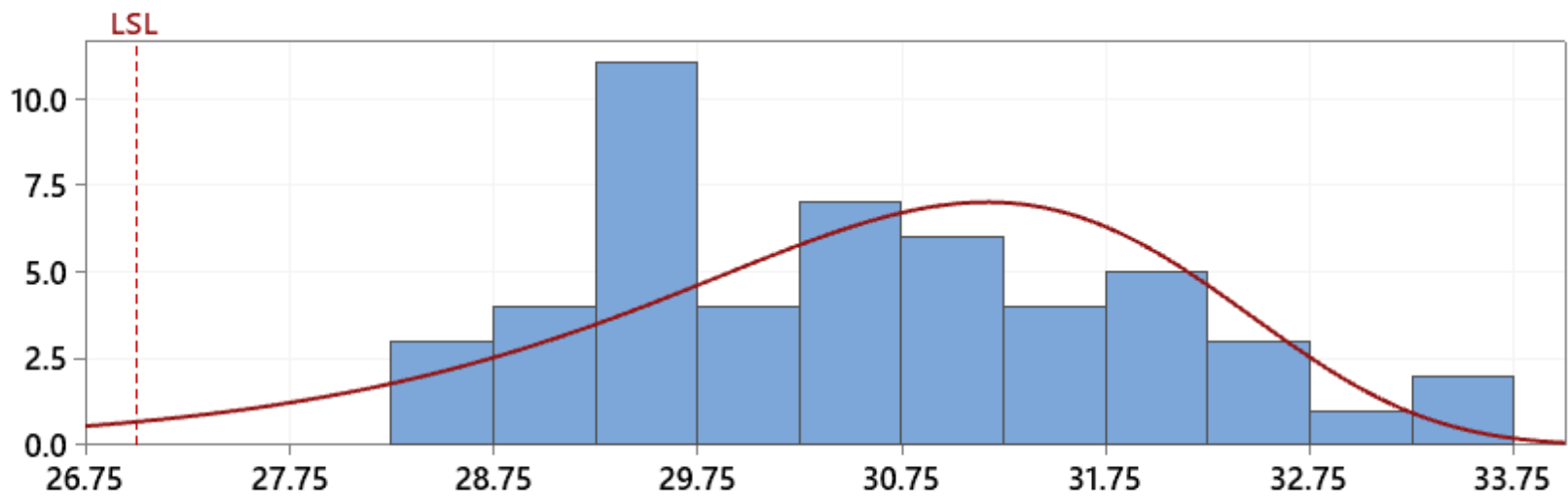
Machine = New
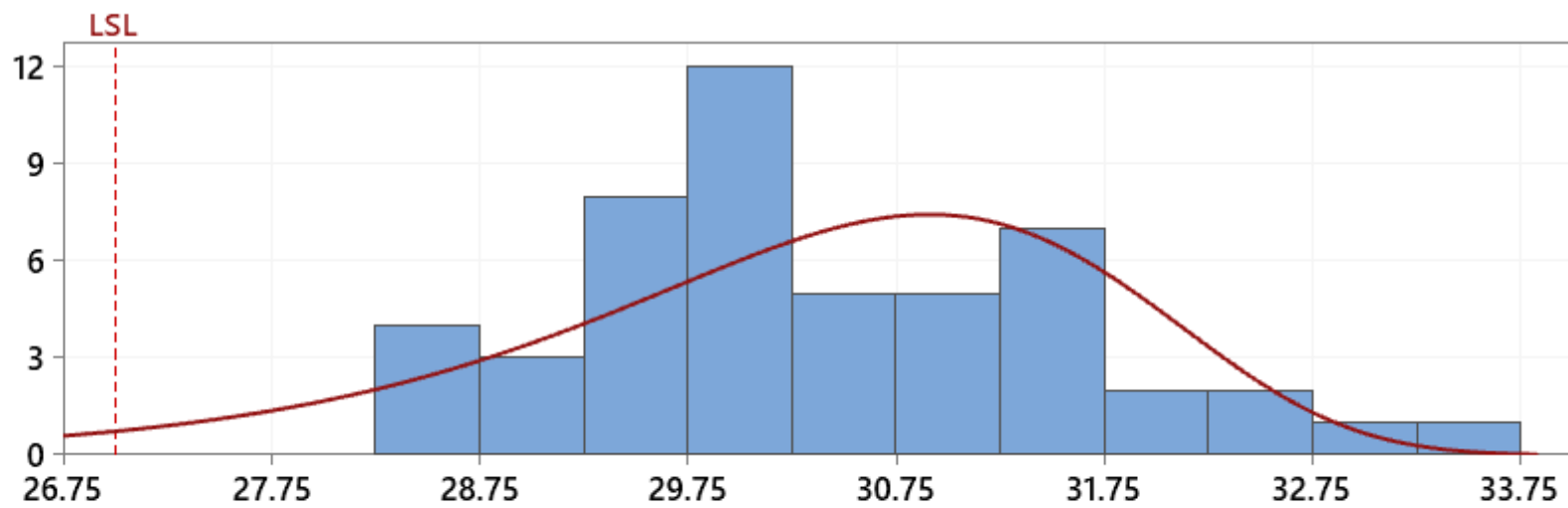
The actual process spread is represented by 6 sigma.

Process Performance Indices

The Process Performance Index is a dimensionless number that is used to represent the ability to meet specification limits on a characteristic of interest.

The Pp is Computed as Pp= USL-LSL/ 6* Standard deviation.

Similar to the Cpk the Ppk is Computed as Ppk = Min (Ppku,Ppkl)

Process performance Indices Ppk tend to be a bit larger than their corresponding capability indices since they are often based on smaller sample size.

Where Ppku is the upper process capability index and given by Ppku = USL-XBar/ 3 * Standard Deviation.

Ppkl is the lower Process capability and given by Ppkl = Xbar- LSL/ 3 * Standard deviation.

If the data is Non-Normal you can do a Non-Normal Capability Analysis using the option Stat→Quality Tools→Capability Analysis→Non Normal Capability Analysis.

Long Term and Short Term Capability

Cp and Cpk Represents long term capability while Pp and Ppk represent short term capability. The AIAG suggests using Ppk for less than a 30 day production (that is short term) and Cpk for everything thereafter is long Term.

Example of Normal Capability Sixpack

An engine manufacturer uses a forging process to make piston rings. The quality engineers want to assess the process capability. They collect 25 subgroups of five piston rings and measure the diameters. The specification limits for piston ring diameter are 74.0 mm ± 0.05 mm.

The engineers perform normal capability sixpack to check the assumptions for normal capability analysis and to evaluate how well the diameters of the piston rings meet the requirements.

1.   Open the sample data, **PistonRingDiameter.MTW**.

2.   Choose **Stat** > **Quality Tools** > **Capability Sixpack** > **Normal**.

3.   In **Single column**, enter *Diameter*.

4.   In **Subgroup size**, enter *5*.

5.   In **Lower spec**, enter *73.95*.

6.   In **Upper spec**, enter *74.05*.

7.   Click **Options**.

8.   In **Target (adds Cpm to table)**, enter *74*.

9.   Click **OK** in each dialog box.

Interpret the results

The Xbar and R charts indicate that the process is stable, with no points beyond the control limits. The Last 25 Subgroups plot indicates the data are randomly and symmetrically distributed around the process mean. The normal probability plot indicates that data are normally distributed. Therefore, the assumptions for normal capability analysis are satisfied and the capability of the process can be analyzed.

The histogram and capability indices indicate that the process is approximately centered on the target and the measurements are within the specification limits. The capability indices Cpk, Ppk, and Cpm are all greater than 1.33, which is a generally accepted minimum value for a capable process. Therefore, the engineers conclude that the forging process satisfies customer requirements for the diameters of the piston rings.
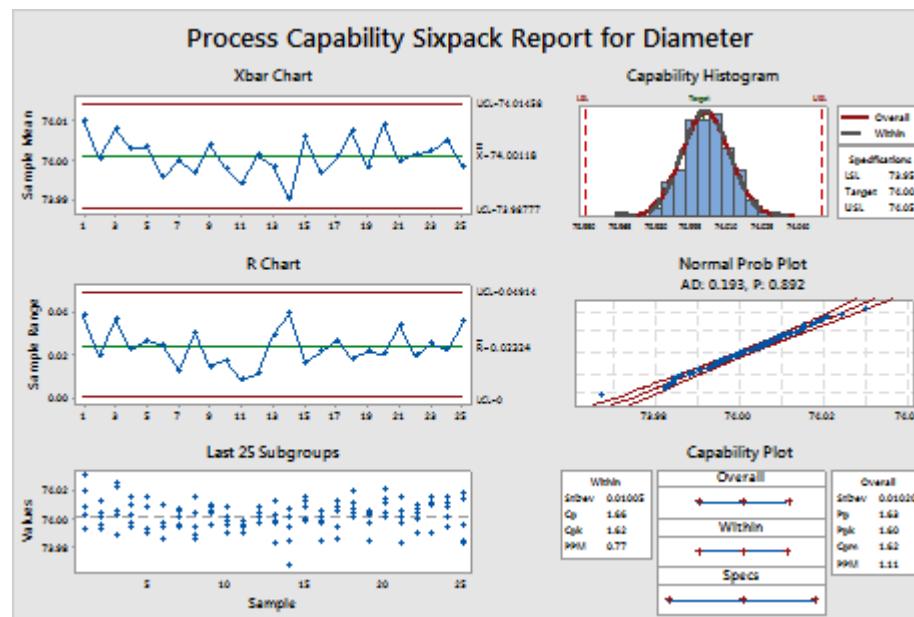
Why is Weibull the default distribution for nonnormal capability analysis?

The Weibull distribution is one of the most commonly used distributions to model nonnormal data. The Weibull distribution is described by the shape, scale, and threshold parameters. Depending on the values of these parameters, the Weibull distribution can take various shapes.
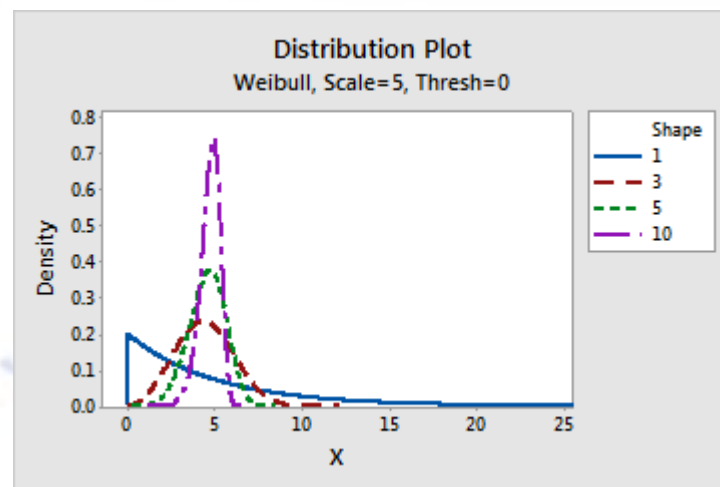
Effect of the shape parameter
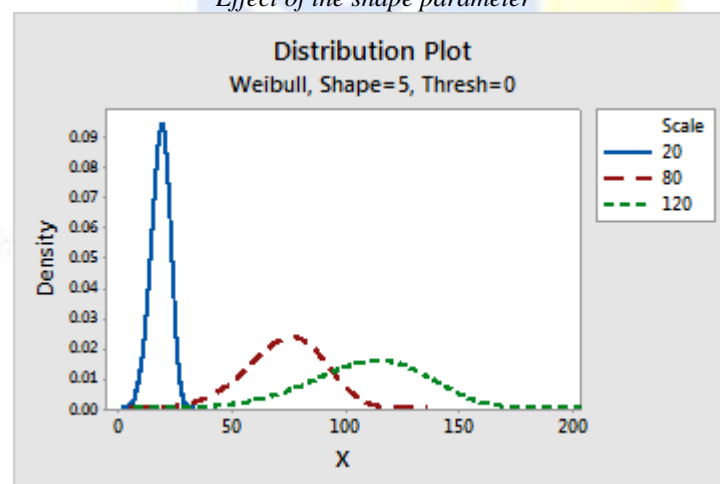
Effect of the scale parameter
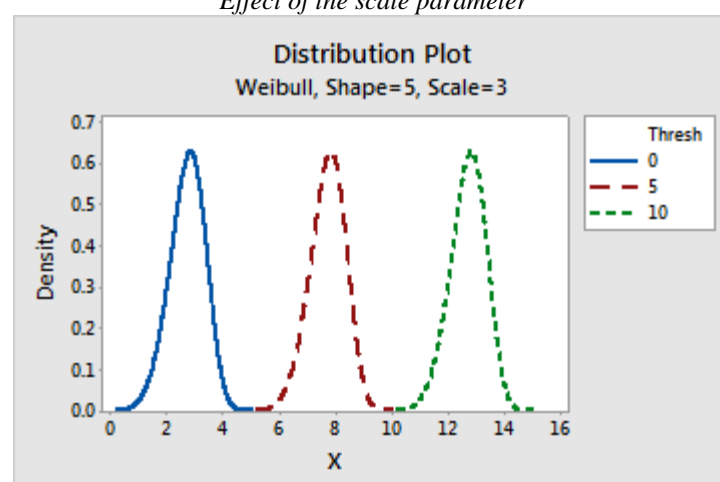
Effect of the threshold parameter

One of the main advantages of the Weibull distribution is that it can be similar to the characteristics of other types of distributions, making it very flexible in fitting different types of data. Examples of uses of the Weibull distribution in place of other distributions:

- The exponential distribution is a special case of Weibull distribution frequently used to study the scattering of radiation or wind speed.

- The Weibull distribution is an alternative to the normal distribution in the case of skewed data.

Other distributions for nonnormal capability analysis

Minitab also provides the following nonnormal distributions to model data for nonnormal capability analysis:

- Lognormal

- 3-parameter lognormal

- Exponential

- 2-parameter exponential

- Gamma

- 3-parameter gamma

- Logistic

- Loglogistic

- 3-parameter loglogistic

- Smallest extreme value

- Largest extreme value

To determine which distribution best fits your data, use your process knowledge and the results of a distribution fit test, such as Individual Distribution Identification available in Stat→ Quality Tools→ Individual Distribution identification.

How to Determine Sample Size, Determining Sample Size?
In order to prove that a process has been improved, you must measure the process capability before and after improvements are implemented. This allows you to quantify the process improvement (e.g., defect reduction or productivity increase) and translate the effects into an estimated financial result – something business leaders can understand and appreciate. If data is not readily available for the process, how many members of the population should be selected to ensure that the population is properly represented? If data has been collected, how do you determine if you have enough data?

Determining sample size is a very important issue because samples that are too large may waste time, resources and money, while samples that are too small may lead to inaccurate results.

In many cases, we can easily determine the minimum sample size needed to estimate a process parameter, such as the population mean μ.

When sample data is collected and the sample mean $\bar{x}$ is calculated, that sample mean is typically different from the population mean μ. This difference between the sample and population means can be thought of as an error.

Sample Size Calculation Example
Problem
A production manager at a call centre wants to know the average time an employee should spend on the phone with a customer. She wants to be within 2 minutes of the actual length of time and standard deviation of the average time spent is 3 minutes. What sample Size of calls should she consider if she wants to be 95% confident of her result?
Solution
We are solving for the sample size n.

A 95% degree confidence corresponds to $\alpha = 0.05$. Each of the shaded tails in the following figure has an area of $\alpha/2 = 0.025$. The region to the left of $z_{\alpha/2}$ and to the right of $z = 0$ is 0.5 – 0.025, or 0.475. In the table of the standard normal (z) distribution, an area of 0.475 corresponds to a z value of 1.96. The critical value is therefore $z_{\alpha/2} = 1.96$.
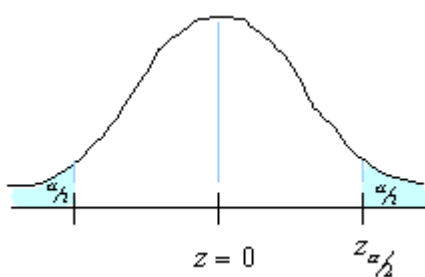
The margin of error $E = 2$ and the standard deviation $\sigma = 3$, $z_{\alpha/2} = 1.96$ Using the formula for sample size :

$$n = \left[\frac{z_{\alpha/2} \sigma}{E} \right]^2$$

n = ($z_{\alpha/2}$ * 3) ^2 / 2 ^2 = (1.96 * 3) ^2 /4 = 34.574 / 4 = 8.643

So we will need to sample at least 9 calls.

Example of Sample Size for Estimation

An analyst at an electronics company uses a sample size for estimation calculation before conducting a study to estimate the mean voltage of a new line of resistors used in circuit boards.

The analyst wants to know what sample size is required to obtain a margin of error of 5. Based on previous studies, the standard deviation is 22.5.

1. Choose **Stat** > **Power and Sample Size** > **Sample Size for Estimation**.
2. In **Parameter**, select **Mean (Normal)**.
3. Under **Planning Value**, enter *22.5* in **Standard deviation**.
4. In **Margins of error for confidence intervals**, enter *5*.
5. Click **OK**.

Interpret the results

To achieve a margin of error of 5 when estimating the mean voltage of resistors, the analyst needs to collect a sample size of 81.

Sample Size for Estimation

Method

Parameter   Mean

Distribution   Normal

Standard deviation   22.5 (estimate)

Confidence level   95%

Confidence interval Two-sided

Results

 Margin Sample

of Error   Size

  5   81

Probability is the chance or likelihood that something will happen. In statistics the words chance and likelihood are seldom used to describe the possibilities for the event to take place; instead the word probability is used along with some other basic concepts. An event is an outcome of an experiment. Determining the number of defects out of a sample of 100 is an experiment and there are many possible events the possible outcomes can be anywhere between 0 and 100.

Discrete probability distributions

A distribution is said to be discrete if it is built on discrete random variables. The discrete probability distributions are Binomial and Poisson

Binomial distribution is one of the simplest probability distributions. It assumes an experiment with n identical trials with each trial having only 2 possible outcomes considered as success or failure. Each trial is independent of the previous one.

Problem: An operations manager has 16 production lines that produce the exact same type of product. The Production lines are supposed to be operational at 6:00 AM every day. The Probability for a machine on a line to go down is 0.15. The operational manager wants to know how many lines will be operational at the start of the shift. He also wants to have the distribution for the probability of the lines not operating.

Solution:- Open Minitab -> Click on Calc then Click on Probability Distribution and then on Binomial and in column C1 enter values 1 to 16 when the binomial Distribution box appears in number of trials enter 16 and probability of success enter 0.15 and in input column enter C1 you get the probability as shown in the table below.

Binomial with n = 16 and p = 0.15

x	P(X ≤ x)
1	0.28390
2	0.56138
3	0.78989
4	0.92095
5	0.97646
6	0.99441
7	0.99894
8	0.99984
9	0.99998
10	1.00000
11	1.00000
12	1.00000
13	1.00000
14	1.00000
15	1.00000
16	1.00000

Poisson distribution: The binomial are used to calculate the probability for one outcome out of two. Not all situations exhibit only 2 alternatives. For instance, an engineer might want to know the number of defects in a engine these examples do not state a number of trials nor do they state the number of alternative outcomes they only describe the occurrence of an event within a time frame.

Problem: For Example, the employee attrition rate at a company follows a Poisson distribution with a mean of 4 a month; the HR Director wants to know the probability that between five and seven employees would leave the company next month.

We will use SigmaXL tool to do the Poisson Distribution: Open SigmaXL->Templates & calculators->Poisson Distribution calculator->Poisson and enter the values in the macro enable sheet and you will find the probability of five employees leaving is = 0.156.

Exponential Distribution: The exponential distribution is close to the poisson distribution but the poisson distribution is built on discrete random variables while the exponential distribution is continuous variables.

Solution: - Open Minitab -> Click on Calc then Click on Probability Distribution and then on Exponential and in column C1 enter values from the file Acid1.

Output as Shown Below:-

Results for: Acid1.MTW

Cumulative Distribution Function

Exponential with mean = 1

 x P(X ≤ x)

0.123	0.115736
0.109	0.103270
0.110	0.104166
0.109	0.103270
0.112	0.105956
0.109	0.103270
0.110	0.104166
0.110	0.104166
0.110	0.104166
0.112	0.105956
0.110	0.104166
0.101	0.096067
0.110	0.104166
0.110	0.104166
0.110	0.104166

The Deliverables of the Measure are given in the table below:

Project Stage	Deliverables
Measure	Detail Process Map with points at which to gather data
	Data collection forms
	Measurement tools, include gauge R&R studies
	Data on the Process
	Process capability and Six Sigma Calculation
	Cost of Quality
	Project Status Form

7.PARAMETRIC HYPOTHESIS TESTING (ANALYSE PHASE)

We often talk about fact-based decision making. In reality however there are a number of factors that influence or decision some of these are
Experience
Judgement
Assumption
A hypothesis is focused on a parameter of the population such as, the mean, standard deviation, variance, proportion, or median.

Now, let's understand why we need hypothesis. Hypothesis:

- Handles uncertainty
- Minimizes subjectivity
- Questions assumptions
- Prevents omission of important information, and
- Manage the risk of decision errors

Data base decision can help you overcome such influences and lead you in the right direction.
In hypothesis tests some commonly used terms are given below.
Data based Decisions can help you overcome influences and help you to lead in the right direction for example look at the points below: -
1] Who is a better supplier?
2] is the proposed process better? do we change the process
3] Are sales in some regions better than others?
4] Are we producing more after recruiting the new officer?
5] Are More customers buying our product after the release of the new advertisement?
In most of these and similar situations decisions are frequently based on judgement, the concern is how we can make our judgement accurate. What would be the impact be if we did a mistake or there were a error of judgement? To give an example an incorrect judgement about a new process could lead to investing in an expensive equipment that in reality is not is not significantly better than what we have. Making accurate decisions is therefore critical for any business, statistical testing of hypothesis is a useful data based approach to making qualified decisions.

Null Hypothesis written as Ho the hypothesis is the assumption about a population parameter such as mean standard deviation etc.

Alternate Hypothesis written as H1 or Ha is the opposite of null hypothesis.

Inequality sign indicates 2 tails while < or > indicates one tail.

There are two types of alternate hypotheses, and they are one tail and two tail. Let's discuss them.
A one tail test is a hypothesis test in which alternate hypothesis has only one end. It can be left-tailed test or right-tailed test. It's always directional in nature. It checks if the population parameter is greater than or less than reference value.
Two Tail A two tail test is a hypothesis test in which alternate hypothesis has two ends. It's non-directional in nature.
It determines whether the sample tested falls within or outside a certain range of value lying on either end tail.

Examples of Null Hypothesis and Alternate Hypothesis

1. A cement plant has found that the historical mean strength of cement is 25 units. The Company wants to assess whether the mean strength continues to be the same. In Null hypothesis we will assume that the mean strength (25 Units) has not changed. Therefore the null and alternate hypothesis will be written as :
Ho : $\mu = 25$
H1 : $\mu \neq 25$
The Number of tails is 2 as we want to assess whether the mean strength has changed
2. We want to evaluate whether a new incentive scheme has increased the mean daily production of the company. The historical mean is μo. In Null hypothesis we will assume that the mean production level has not changed. Therefor the null and alternate hypothesis would be written as
Ho : $\mu = \mu o$
H1 : $\mu > \mu o$
The number of tails =1 (right tail) as we want to assess whether the mean production has increased.
3. A company has appointed a new courier service. They wish to assess whether the package are delivered faster than before. In Null hypothesis we will assume that the mean delivery time μo has not changed; the null and alternate hypothesis will therefore be written as
Ho : $\mu = \mu o$

H1 : $\mu < \mu o$

The number of tails =1 (Left tail) as we want to assess whether the mean service time has reduced.

What is Confidence Interval?

The Practical Meaning of 95 Percent Confidence Interval can be states as"The Probability that the value of the population mean μ will lie between the two confidence interval bounds is 0.95".For example if take 1000 samples from a population we will have 1000 sample means and therefore 1000 confidence intervals ; we can expect that 95 percent or approximately 950 intervals will contain population mean μ.

In Statistics confidence intervals are of 3 types first is 95% Confidence Interval, second is 90% CI and Third is 99% CI ; by default it is always 95% CI but you can have 90 and 99% CI also. The statistical Term alpha is derived as α is = 1-0.95 or 1-0.99 or 1-0.90. We can calculate the Confidence Interval using formulas given in statistics.

For Example :- Suppose an Estimate is needed for the average coating thickness for a population of 1000 circuit boards received from a supplier. Rather than measure the coating thickness on all 1000 boards one might randomly pick up 36 boards for measurement. Suppose the average coating thickness of these 36 boards is 0.003 and the standard deviation of the 36 coating measurements is 0.0005. The standard deviation is assumed known from past experience. Determine the 95% confidence interval for the true mean.

From the Z table as the sample size is greater than 30 we use Z Table available in goggle search we know that $Z\alpha/2 = 1.96$ also we have

$\alpha = 0.05$, X Bar = 0.003 , $\sigma = 0.0005$, n=36

We will use the statistical formula to calculate Confidence Interval which is given below:-

XBar – $Z\alpha/2$ * σ/ sqrt of n $\leq \mu \leq$ X bar + $Z\alpha/2$ * σ/ Sqrt of n

Substituting the values in the formula we obtain

0.003-(1.96) * 0.0005/ Sqrt of 36 $\leq \mu \leq$ 0.003 + 1.96 * 0.0005/ Sqrt of 36

$0.00284 \leq \mu \leq 0.00316$ thus the 95% confidence interval for the mean is (0.00284,0.00316)

In a process, we may face Problem with Centering and/or Problem with Spread. Below diagram will allow us to understand these two problems in detail:
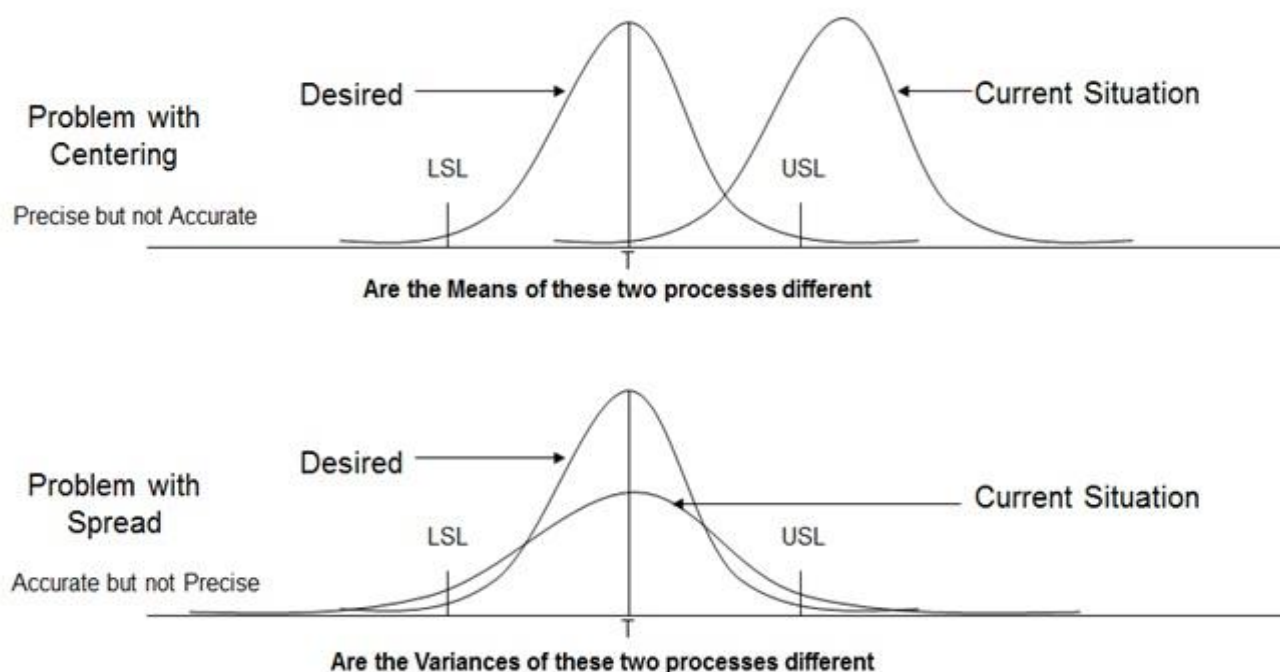
Practical Six Sigma Problems that require Hypothesis Testing

Hypothesis testing tells us whether there exists statistically significant difference between the data sets for us to consider that they represent different distributions.

What is the difference that can be detected using Hypothesis Testing?
For Continuous data, hypothesis testing can detect Difference in Average and Difference in Variance. For Discrete data, hypothesis testing can detect Difference in Proportion Defective.

Steps in Hypothesis Testing:

- **Step 1:** Determine appropriate Hypothesis test
- **Step 2:** State the Null Hypothesis Ho and Alternate Hypothesis Ha
- **Step 3:** Calculate Test Statistics / P-value against table value of test statistic
- **Step 4:** Interpret results – Accept or reject Ho

Mechanism:

- **Ho = Null Hypothesis** – There is No statistically significant difference between the two groups
- **Ha = Alternate Hypothesis** – There is statistically significant difference between the two groups

Hypothesis Testing Errors:
Type I Error – P (Reject Ho when Ho is true) = α
In type I Error, we reject the Null Hypothesis when it is true. It is also called as Alpha error or Producer's Risk.

Type II Error - P (Accept Ho when Ho is false) = β
Similarly, in type II Error, we accept Null Hypothesis when it is false. It is also called as Beta error or Consumer's Risk.

Six Sigma Hypothesis Testing Errors

P Value – Also known as Probability value, it is a statistical measure which indicates the probability of making an α error. The value ranges between 0 and 1. We normally work with 5% alpha risk, a p value lower than 0.05 means that we reject the Null hypothesis and accept alternate hypothesis.

Types of Hypothesis Testing:

We use the following grid to select the appropriate hypothesis test depending on the data types:

Select the appropriate Test		Output (Dependant Variable) Y	
		Continuous	Discrete
Input (Independent Variable) X's	Continuous	Simple Linear Regression Correlation	Logistic Regression
	Discrete	Normal Data T Test (1,2 Sample & Paired) ANOVA, F test , HOV Non-Normal Data Moods Median , HOV	Chi Square

Types of Six Sigma Hypothesis Testing

Situation	Statistical Test
Comparing a population mean against a given standard For example: Is the mean TAT of thread ≤15 minutes.	1-sample t-Test
Comparing means of two different populations For example: Is the mean of morning shift = mean of night shift.	2-sample t-Test
Comparing the means of more than two populations For example: Is the mean of staff A = mean of staff B = mean of staff C.	ANOVA
Comparing the variance of two or more than two populations For example: Is the variation of staff A = variation of staff B = variation of staff C.	Homogeneity Of Variance

Normal Continuous Y and Discrete X

Situation	Statistical Test
Comparing the variance of two or more than two populations For example: Is the variation of staff A = variation of staff B = variation of staff C.	Homogeneity Of Variance
Comparing the medians of two or more than two populations For example: Is the median of staff A = median of staff B = median of staff C.	Mood's Median Test

Non-Normal Continuous Y and Discrete X

Situation	Statistical Test
To see how output (Y) changes as the input (X) changes For example: If we need to find out how staff A's accuracy is related to his number of years spent in the process.	Simple Linear Regression

Continuous Y and Continuous X

Situation	Statistical Test
To see how output counts (Y) from two or more sub-groups (X) differ For example: If we want to find out whether defects from morning shift are significantly different from defects in the evening shift.	Chi-square Test of Independence

Discrete Y and Discrete X

Test	Null	Alternate
Normality	Data is Normal	Data is not Normal
Run Tests	No Special Causes	Special Causes Exist
t-test (1-sample)	μ = constant or T	$\mu \neq$ constant or T
t-test (2-sample, 2-tailed)	$\mu_1 = \mu_2$	$\mu_1 \neq \mu_2$
t-test (2-sample, 1-tailed)	$\mu_1 \leq \mu_2$	$\mu_1 > \mu_2$
Chi-square	$\chi^2 = 0$	$\chi^2 \neq 0$
HOV (3-sample)	$\sigma^2_1 = \sigma^2_2 = \sigma^2_3 = \ldots = \sigma^2_n$	$\sigma^2_1 \neq \sigma^2_2 \neq \sigma^2_3 \neq \ldots \neq \sigma^2_n$
ANOVA (3-sample)	$\mu_1 = \mu_2 = \mu_3 = \ldots = \mu_n$	Atleast one is different
Mood's Median (3-sample)	$Median_1 = Median_2 = \ldots = Median_n$	$Median_1 \neq Median_2 \neq \ldots \neq Median_n$

A hypothesis is a value judgment made about a circumstance, a statement made about a population .Based on experience an engineer can for instance assume that the amount of carbon monoxide emitted by a certain engine is twice the maximum allowed legally. However, his assertions can only be ascertained by conducting a test to compare the carbon monoxide generated by the engine with the legal requirements.

Number of Tails: The number of tails refers to the distribution used for testing the hypothesis. There are left and right tails for distribution. Depending on the objective of the test the left, right or both tails are considered in a hypothesis test and the number of tails decided. The Number can either 2 or 1 inequality sign $\neq$ indicates 2 tail and less than or greater than indicates one tail. ($<>$).

If the sample are less than 30, then the t-test is used

T= X bar -μ/ s/$\sqrt{n}$

Level of Risk: The level of risk addresses the kinds of errors that can be made while making an inference based on the test statistics obtained from the testing. Two types of errors can be made. The experimenter can falsely reject a hypothesis that is true. In that case we say that he made a type 1 error or α error. If he fails to reject a hypothesis that is actually false he makes a type II error or β error. In the case of the engineer testing the level of carbon dioxide is in fact twice as great as the prescribed level and he rejected the null hypothesis he would have made a type 1 error. If the carbon monoxide generated by the engine is less than the legally prescribed level and the experimenter fails to reject the null hypothesis, he would have made a type ii error he would have failed to reject a null hypothesis that happened to be false.

Decision Rule: Only two decisions are considered rejecting the hypothesis or failing to reject it. The decision rule determines the conditions under which the null hypothesis is rejected or failed to be rejected. The Decision to reject the null hypothesis is based on the alpha level. Before conducting the test, the experimenter must set the confidence level for the test. He can decide to test the hypothesis with a 95% confidence level. That means he would be 95% sure that the decision to reject or fail to reject the null hypothesis is correct. However, 95% confidence level means that 5% chance that an error will be made.

Example: A machine used to average a production rate of 245 units per hour before it went for repair. After it came back from repair over a period of 25h. It produced an average of 249 units with a standard deviation of 8.Determine if there is a statistically significant difference between the machines productivity before and after repair at a confidence level of 95%?

Solution: -

Since the sample is smaller than 30 we will use the t-test

The null hypothesis is the following

H0: The productivity before repair = Productivity after repair

The alternate hypothesis should be the opposite

HA: The productivity before repair $\neq$ the productivity after repair.

N=25, s=8, XBar=249, μ= 245

Since the Confidence level is set at 95%, α= 1-0.95 = 0.05, since the null hypothesis is stated as equality we have a 2 tailed curve with each tail covering the one half of alpha. With degree of freedom df = n-1 = 25-1 =24 the t critical can be obtained from the t table which is = 2.064.

If the calculated t-statistics falls within the interval [-2.064, + 2.064] we would fail to reject the null hypothesis; otherwise the null hypothesis would be rejected.

Let us find the calculated t-statistic:

T= Xbar - μ / s/$\sqrt{n}$ = 249-245/8 $\sqrt{25}$ = 2.5

The calculated t statistic is 2.5 since it falls outside the interval [-2.064, + 2.064] we will have to reject the null hypothesis and conclude that there is a statistically significant difference between the productivity of the machine prior to repair and after repair.

We can also Use the confidence interval method:

We can use the formula for confidence interval

Xbar –t α /2, n-1 s/$\sqrt{n} \leq \mu \leq$ Xbar + α /2, n-1 s/$\sqrt{n}$

There fore

249-2.064 8/ $\sqrt{25} \leq \mu \leq$ 249 + 2.064 8/ $\sqrt{25}$

245.698 $\leq \mu \leq$ 252.302

The null hypothesis is rejected because the mean μ (245) does not fall within the interval [245.698, 253.302]

Normalizing Data

Non Normal data Outliers **can cause your data to become skewed , in a non-normal data set the mean and the median have different values.**
When the data being analysed are not normal and the tools required for analysis require their normality then one option would be to normalize them. Normalizing the data means transforming them from non-normal to normal. This can be done using Box-Cox transformation or the Johnson transformation.

From the menu bar of Minitab click on stat then click on quality tools and from the drop down list select Johnson transformation the graph shows the probability plot before and after transformation now the p value becomes greater than the standard (0.05) the data are therefore concluded to be normally distributed. We have to select the non-normal data column and then mention also mention the column where to the converted normal data and that particular data we can use to do analysis where the data are required to be normal. From the three vertical line probability plot graph we can see that the P value has become greater than 0.05 and all the data points are within the three vertical red lines this is the probability plot graph of normal data.
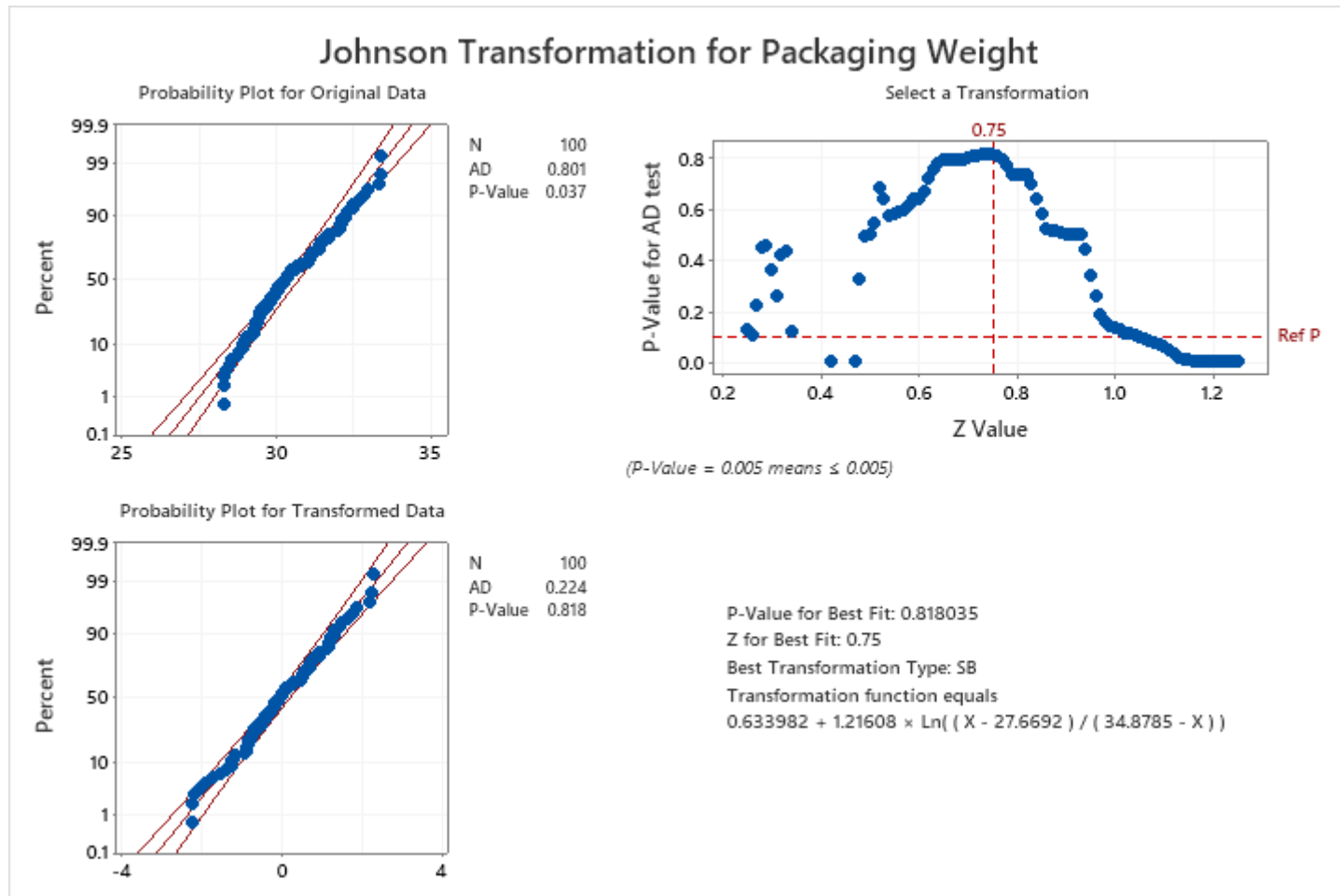
A Box-Cox transformation of your process data can help correct the following conditions:

- The process data are not normally distributed, especially if the data are not collected in subgroups.

- Subgroup variance is unstable because the variation in the data is proportional to the subgroup mean.

You can also perform a Box-Cox transformation when you create a control chart. For example, to transform the data when you create an Xbar-R chart, choose **Stat** > **Control Charts** > **Variables Charts for Subgroups** > **Xbar-R** > **Xbar-R Options** > **Box-Cox**.

Where to find this command

To perform a Box-Cox transformation, choose **Stat** > **Control Charts** > **Box-Cox Transformation**.

When to use an alternate analysis
If you have data values less than 0, use Johnson transformation.

Example: - A textile manufacturer developed a solar energy system to pre-heat feed water for a boiler that is part of the power system for the manufacturing process. A technician monitors the amount of energy that is used each hour to make sure that the pre-heat process is stable.

Before creating an I-MR chart of the data, the technician conducts a normality test on the data and finds that the data do not follow a normal distribution. The technician then conducts a Box-Cox analysis to determine whether a Box-Cox transformation is appropriate.

1. Open the sample data, **SolarEnergyProcess.MTW**.
2. Choose **Stat** > **Control Charts** > **Box-Cox Transformation**.
3. In **All observations for a chart are in one column**, enter *Energy*.
4. In **Subgroup sizes**, enter *1*.
5. Click **OK**.

Interpret the results

For the Box-Cox transformation, a λ value of 1 is equivalent to using the original data. Therefore, if the confidence interval for the optimal λ includes 1, then no transformation is necessary. In this example, the 95% confidence interval for λ (-2.87 to 0.66) does not include 1, so a transformation is appropriate. The estimated value for the optimal λ is -1.03. Because the rounded value of -1 is within the confidence interval, the technician should transform the data using $\lambda = -1$. A transformation that uses $\lambda = -1$ corresponds to the inverse transformation (transformed value = 1 / original value).
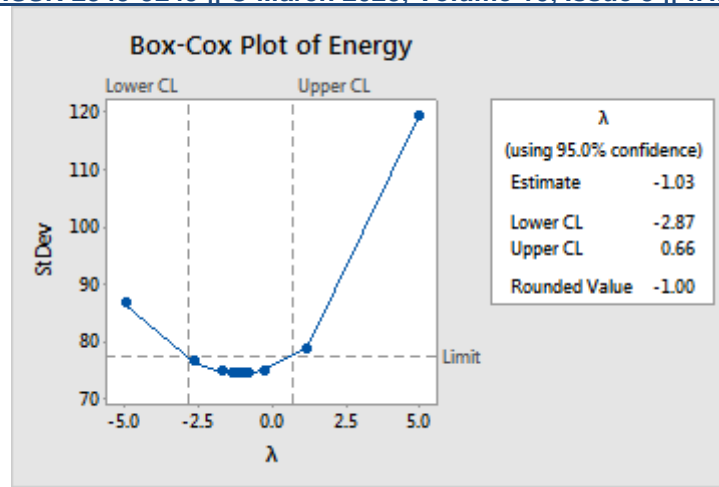
Pareto Chart

A Pareto diagram is a bar chart that graphically ranks defects from largest to smallest which can help prioritize quality problems.

Use Pareto Chart to identify the most frequent defects, the most common causes of defects, or the most frequent causes of customer complaints. Pareto charts can help to focus improvement efforts on areas where the largest gains can be made.

For example, a manager wants to investigate causes of customer dissatisfaction at a particular hotel. The manager investigates and records reasons for customer complaints.

Where to find this analysis to create a Pareto chart, choose **Stat** > **Quality Tools** > **Pareto Chart**
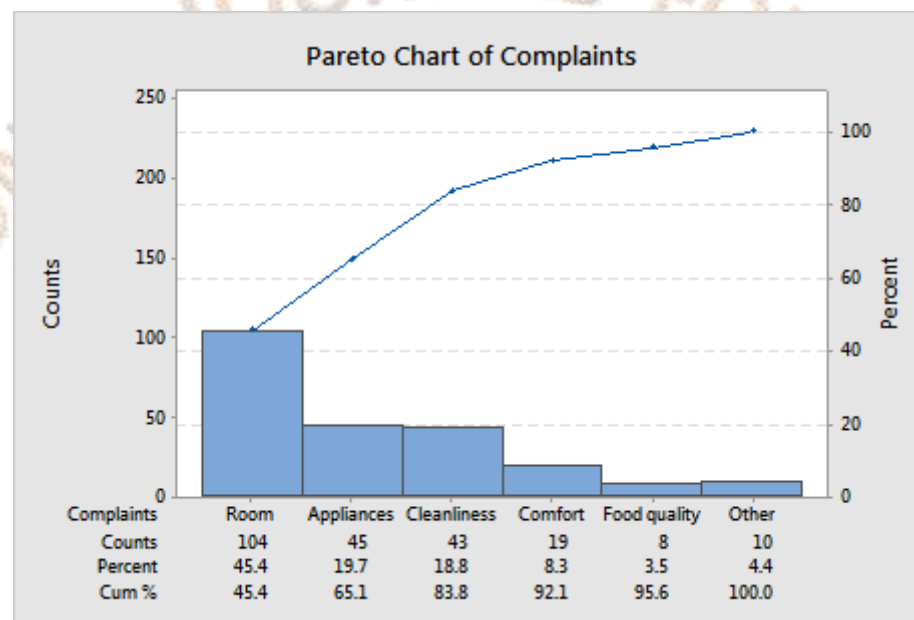
In the Pareto chart above the complaint count is on the Y axis and the various predictors are on the X axis from the graph it is evident that complaints in the room category is the highest as that bar is the tallest plus there are some other bars which show the intensity of the complaints.

1-Sample t Test (Mean v/s Target) this test is used to compare the mean of a process with a target value such as an ideal goal to determine whether they differ it is often used to determine whether a process is off centre

Example of 1 Sample T test: A bread Manufacturer claims that the carbohydrate content in his bread is not greater than 240 cal we will use the T Test to Compare the target against the data of carbohydrate content collected in his organization the data are as follows 230,240,230,230, 235,255,260,230,240,230,270,300 we will enter this data and check for target greater than 240 cal at 95% Confidence Interval.

1-Sample t Test for the Mean of Carbohydrate
Summary Report

Is the mean greater than 240?

| 0 | 0.05 | 0.1 | | > 0.5 |

Yes ... No

P = 0.152
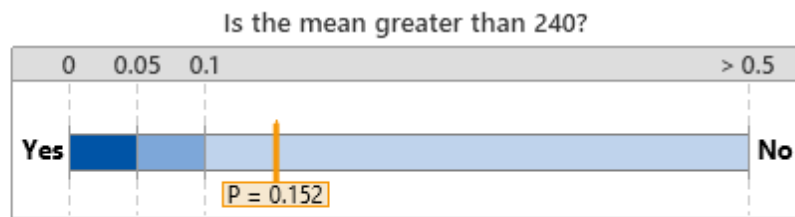
The mean of Carbohydrate is not significantly greater than the target (p > 0.05).

Statistics

Sample size	11
Mean	247.27
95% Lower bound	235.09
Standard deviation	22.289
Target	240

Distribution of Data
Where are the data relative to the target?

240
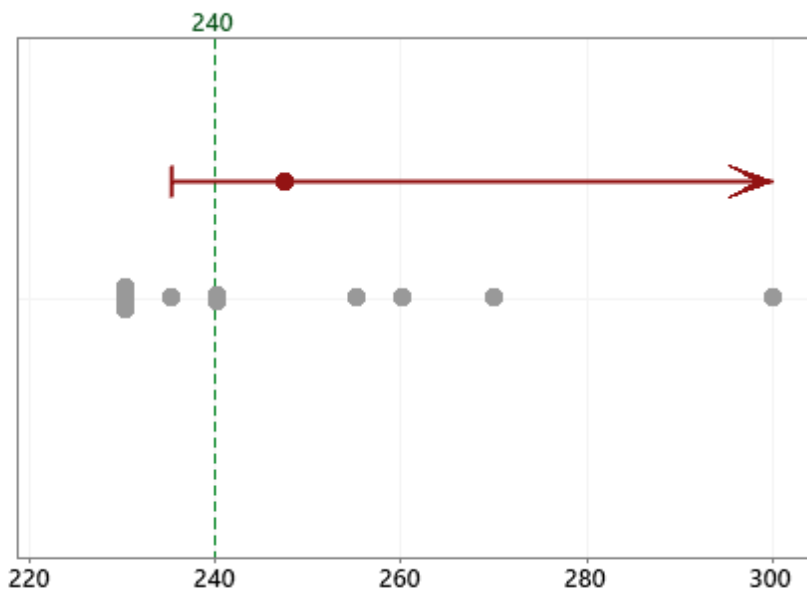
Comments

• Test: There is not enough evidence to conclude that the mean is greater than 240 at the 0.05 level of significance.
• CI: Quantifies the uncertainty associated with estimating the mean from sample data. You can be 95% confident that the true mean is greater than 235.09.
• Distribution of Data: Compare the location of the data to the target. Look for unusual data before interpreting the test results.

From the output of Minitab above we can say that the carbohydrate content in bread is not significantly greater than 240 so we have to accept what the bread manufacturer claims.

1-Sample t Test for the Mean of Carbohydrate
Report Card

Check	Status	Description
Unusual Data	✓	There are no unusual data points. Unusual data can have a strong influence on the results.
Normality	⚠	Because your sample size is less than 20, normality can be an issue. If the data are not normally distributed, the p-value may be inaccurate with small samples. Because normality cannot be reliably checked with small samples, you should use caution when interpreting the test results.
Sample Size	ⓘ	Your data does not provide sufficient evidence to conclude that the mean is greater than the target. This may result from having a sample size that is too small. Based on your sample size, standard deviation, and α, you would have a 90% chance of detecting a difference of 21.166. To determine how large your sample needs to be to detect a difference that has practical implications, repeat the analysis and enter a value for the difference.

1 Sample Z Test Example: -

A scientist for a company that manufactures processed food wants to assess the percentage of fat in the company's bottled sauce. The advertised percentage is 15%. The scientist measures the percentage of fat in 20 random samples. Previous measurements found that the population standard deviation is 2.6%.

Before collecting the data for a 1-sample Z-test, the scientist uses a power and sample size calculation to determine the sample size required to obtain a power of 0.9 and to detect a difference of 1.5% or greater.

1.   Choose **Stat** > **Power and Sample Size** > **1-Sample Z**.

2.   In **Differences**, enter *1.5*.

3.   In **Power values**, enter *0.9*.

4.   In **Standard deviation**, enter *2.6*.

5.   Click **OK**.

Interpret the results

To detect a difference of 1.5% with a power of 0.9, the scientist needs to collect a sample size of 32. The scientist determines that a sample size of 32 is reasonable, and proceeds with data collection.

Power and Sample Size

1-Sample Z Test

Testing mean = null (versus ≠ null)

Calculating power for mean = null + difference

α = 0.05 Assumed standard deviation = 2.6

Results

	Sample	Target	
Difference	Size	Power	Actual Power
1.5	32	0.9	0.903816
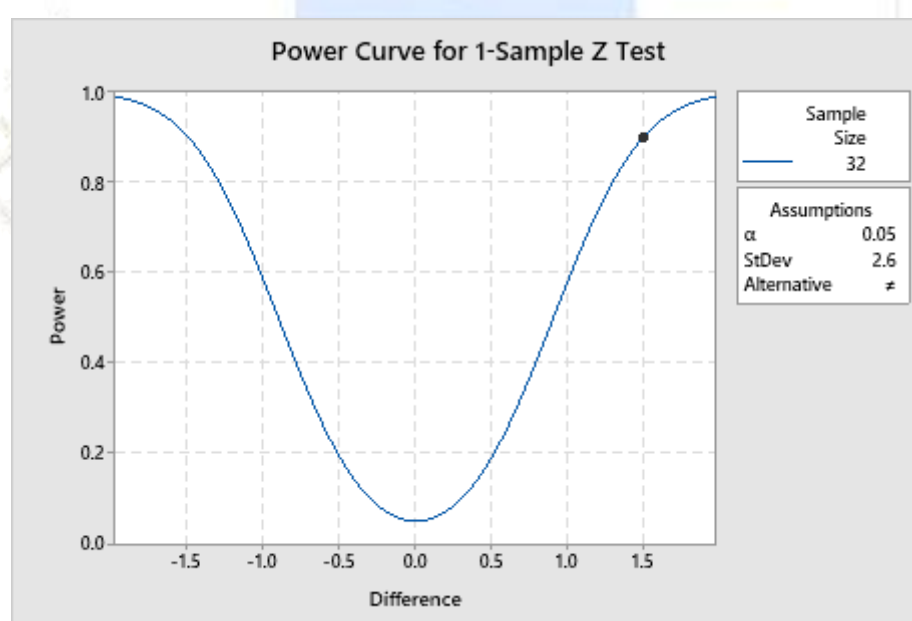
1 Sample Standard Deviation This test is used to compare the standard deviation of the process with a target value such as a benchmark whether they differ often used to evaluate how consistent a process is
Compare the standard deviation of a process with a target value, such as a benchmark, to determine whether they differ. Often used to evaluate how consistent a process is.
Example: -
A lumber distributor wants to analyze how consistently a sawmill produces beams of a particular length. The distributor measures a sample of beams to determine whether the standard deviation of the lengths is less than the maximum allowable value of 1 cm. From the output of Minitab given below the horizontal thermometer graph depicts that the standard deviation is not greater than the allowable value of 1 cm so there is not much variation from the target value set by the lumber.

1-Sample Standard Deviation Test for Saw Mill
Summary Report

Is the standard deviation greater than 1?

| 0 | 0.05 | 0.1 | | > 0.5 |

Yes ——————————————— No

P = 0.720
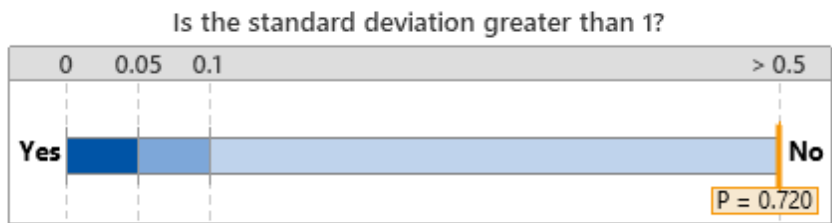
The standard deviation of Saw Mill is not significantly greater than the target (p > 0.05).

95% Lower Bound for the Standard Deviation
Is the entire interval above the target?

1

0.50   0.75   1.00   1.25   1.50

Distribution of Data

0   1   2   3   4
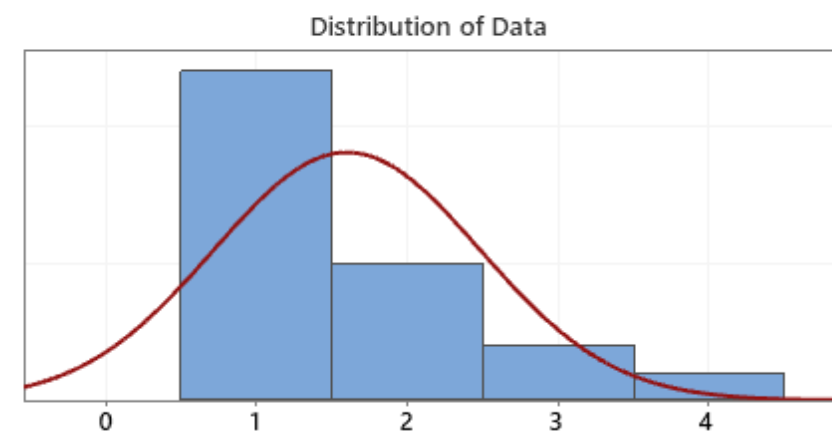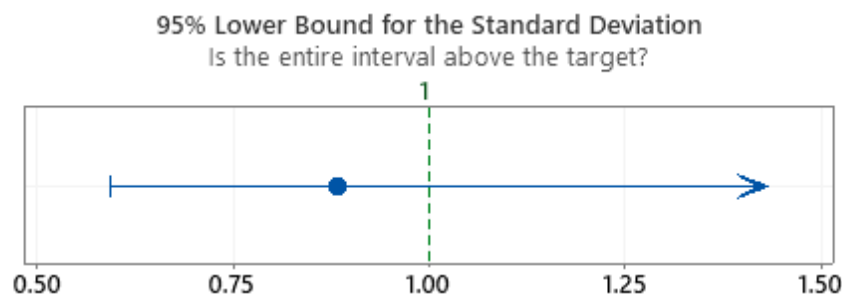
Statistics

Sample size	20
Mean	1.6
Standard deviation	0.88258
95% Lower bound	0.59260
Target	1

Comments

- Test: There is not enough evidence to conclude that the standard deviation is greater than 1 (p > 0.05).
- CI: Quantifies the uncertainty associated with estimating the standard deviation from sample data. You can be 95% confident that the true standard deviation is greater than 0.59260.
- Distribution of data: Examine the spread of the data. Look for unusual data before interpreting the results of the test.

---

2 Sample T (Comparing 2 Means) Two sets of different items are measured each under a different condition there the measurements of one sample are independent of the measurements of other sample.

Example of 2 sample T Test is is two populations two samples from this test we can find the average expenditure of the male customer if it is equal to the average expenditure of the female customer.

2-Sample t Test for the Mean of Male Expendi and Female Expen
Summary Report

Mean Test
Is Male Expendi greater than Female Expen?

| 0 | 0.05 | 0.1 | | > 0.5 |

Yes ——————————————— No

P = 0.916
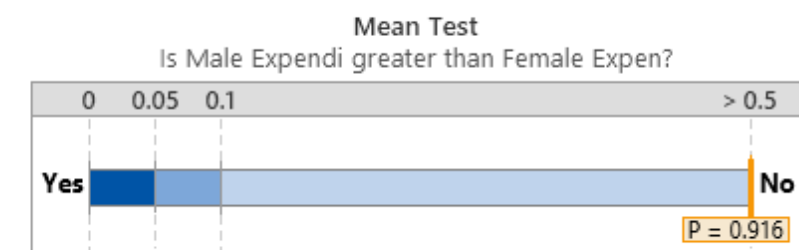
The mean of Male Expendi is not significantly greater than the mean of Female Expen (p > 0.05).

95% Lower Bound for the Difference
Is the entire interval above zero?

-1600   -1200   -800   -400   0
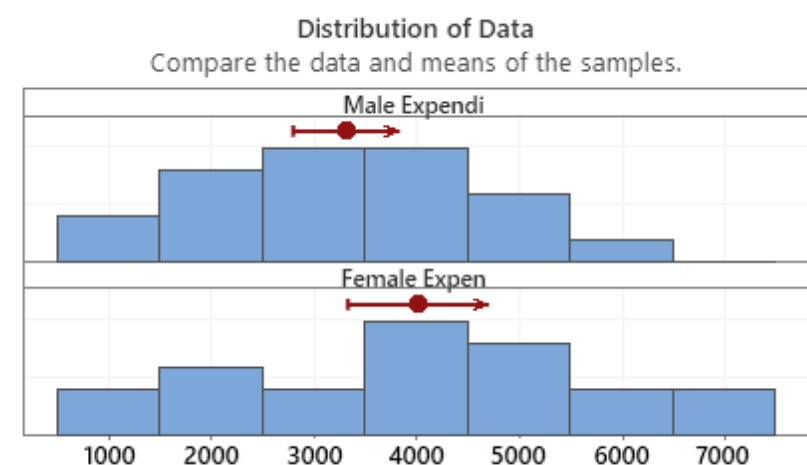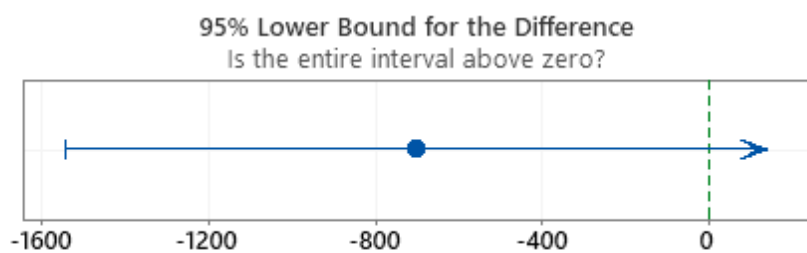
Distribution of Data
Compare the data and means of the samples.

Male Expendi

Female Expen

1000   2000   3000   4000   5000   6000   7000

Individual Samples

Statistics	Male Expendi	Female Expen
Sample size	20	20
Mean	3320	4020
95% Lower bound	2800	3334.8
Standard deviation	1346.2	1772.2

Difference Between Samples

Statistics	*Difference
Difference	-700
95% Lower bound	-1540.8

*Difference = Male Expendi - Female Expen

Comments

- Test: There is not enough evidence to conclude that the mean of Male Expendi is greater than Female Expen at the 0.05 level of significance.
- CI: Quantifies the uncertainty associated with estimating the difference in means from sample data. You can be 95% confident that the true difference is greater than -1540.8.
- Distribution of Data: Compare the location and means of samples. Look for unusual data before interpreting the results of the test.

From the thermometer horizontal graph above, it clearly says that the male expenditure is not greater than female expenditure because the orange vertical line is at no.

FLOW CHART OF HYPOTHESIS
TEST PROCESS IN ANALYSE
PHASE

START

DEFINE OBJECTIVE

FORMULATE NULL AND ALTERNATE HYPOTHESIS

DECIDE CONFIDENCE INTERVAL AND THEN CALCULATE TEST STATISTIC

Test statistic is calculated using formula in statistics e.g Z test & T test have a formula and critical value is value you get after checking the T table and Z table which are available in google search or on the last pages of any six sigma book

IS TEST STATISTIC BEYOND CRITICAL VALUE

NO ▶ INSUFFICIENT EVIDENCE TO REJECT H0

YES

REJECT H0 ACCEPT ALTERNATE HYPOTHESIS

Paired T The same set of items are measured under 2 different conditions therefore the 2 measurements of the same item are dependant or related to each other.

Paired T Test is used to compare population means when data is in pairs and not independent of each other examples are performance of participant's before and after training

Problem Paired T Test: Blood samples of five persons taken at the same time were sent to two laboratories to check blood sugar . value of sugar were found to be 122/136, 148/153 , 93/98,234/236 and 105/112 is there a significance difference between the labs at 95 per cent confidence?

$T = dbar/sd/\sqrt{n}$ where d is the average difference between the 2 samples , Sd is standard deviation of differences and n is the number of pairs. here in this example n is 5-1 = 4

Lab 1	Lab 2	Diff
122	136	14
148	153	5
93	98	5
234	236	2
105	112	7

So calculate the Diff Column Standard deviation which is = 4.51 and dbar = 6.60, so T calculated statistic= 3.276 and T critical obtained from the T table = 2.776; since T calculated 3.276 is beyond t critical 2.776 we can conclude that there is significant difference between the laboratories.

T-Table is Listed Below: -

t Table

cum. prob	*t* .50	*t* .75	*t* .80	*t* .85	*t* .90	*t* .95	*t* .975	*t* .99	*t* .995	*t* .999	*t* .9995
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%

Confidence Level

2-Sample Standard This test is used when comparing 2 standard deviations

Compare the standard deviations of two processes or two process conditions to determine whether the variation differs.

Example
A lumber distributor wants to compare the variation of beam lengths that are cut by two different sawmills. The distributor measures the length of the beams from each sawmill to determine whether the consistency of the beam lengths differs. From the thermometer graph it is evident that there is not much variation between the beam lengths cut by saw mill 1 and saw mill 2.

2-Sample Standard Deviation Test for Saw Mill 1 and Saw Mill 2
Summary Report

Do the standard deviations differ?

P = 0.194
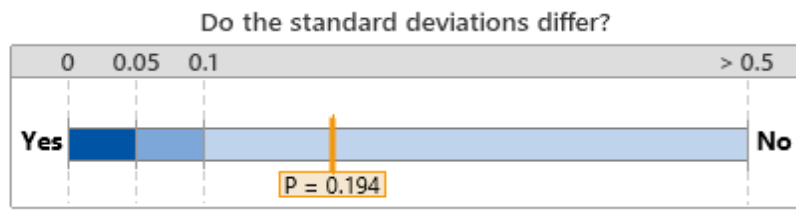
The standard deviation of Saw Mill 1 is not significantly different from Saw Mill 2 (p > 0.05).

Statistics	Saw Mill 1	Saw Mill 2
Sample size	20	21
Mean	1.55	1.9524
Standard deviation	0.68633	0.92066
Individual 95% CI	(0.4898, 1.066)	(0.7147, 1.308)
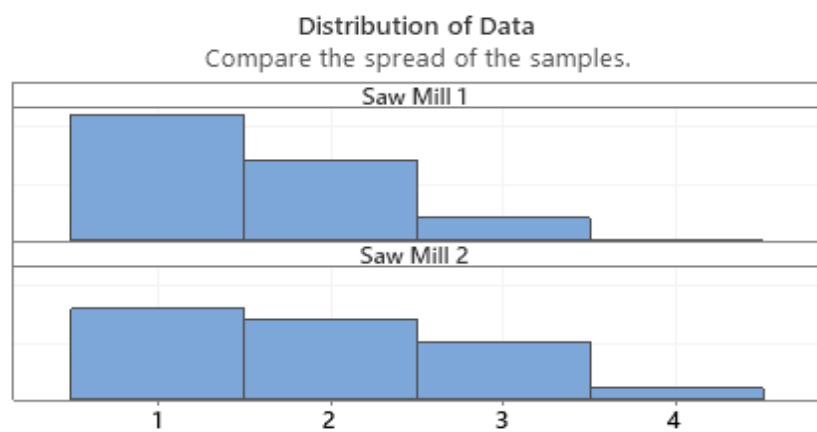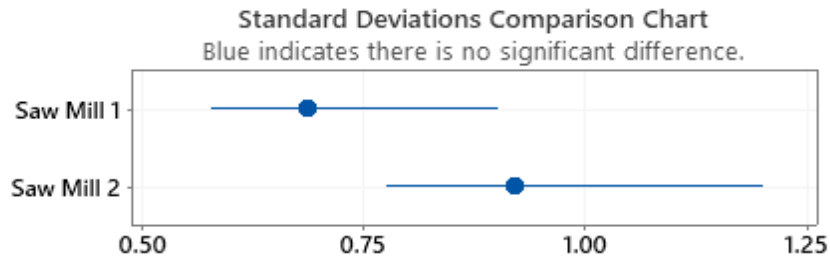
Standard Deviations Comparison Chart
Blue indicates there is no significant difference.

Comments

• Test: There is not enough evidence to conclude that the standard deviations differ at the 0.05 level of significance.
• Comparison Chart: Blue intervals indicate that the standard deviations do not differ significantly.
• Distribution of Data: Compare the spread of the samples. Look for unusual data before interpreting the results of the test.

Distribution of Data
Compare the spread of the samples.

Standard Deviation test This Test is used when comparing more than 2 standard deviations of samples to be compared.

Compare the standard deviations of more than two processes or more than two process conditions to determine whether the variation differs.

Example

A lumber distributor wants to compare the variation of beams that are cut by three different sawmills. The distributor measures the length of the beams to determine whether the consistency of the beam lengths differs among the sawmills; from the horizontal thermometer graph it is evident that there is not much difference between the beams cut from saw mill 1, saw mill 2, saw mill 3.

Standard Deviations Test for Saw Mill 1, Saw Mill 2, Saw Mill 3
Summary Report

Do the standard deviations differ?

P = 0.155
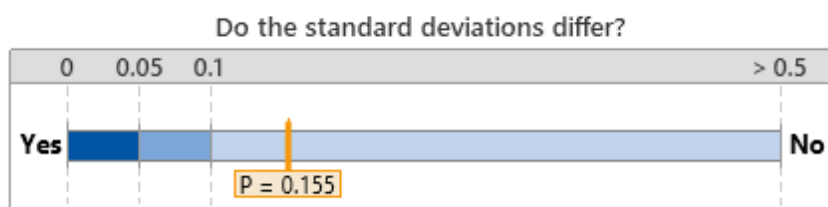
Differences among the standard deviations are not significant (p > 0.05).

Which standard deviations differ?

#	Sample	Differs from
1	Saw Mill 3	
2	Saw Mill 1	None Identified
3	Saw Mill 2	

Standard Deviations Comparison Chart
Blue indicates there are no significant differences.
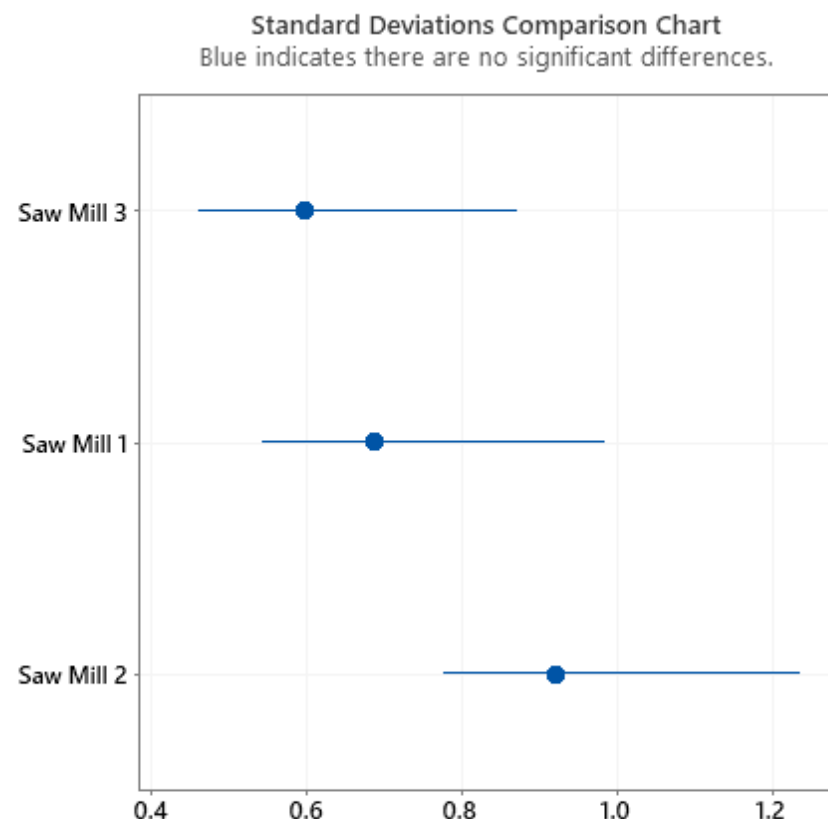
Comments

• Test: There is not enough evidence to conclude that there are differences among the standard deviations at the 0.05 level of significance.
• Comparison Chart: Blue intervals indicate that the standard deviations do not differ significantly.

By Default Six Sigma Shift

By offsetting normal distribution by a 1.5 standard deviation on either side, the adjustment takes into account what happens to every process over many cycles of manufacturing… Simply put, accommodating shift and drift is our 'fudge factor,' or a way to allow for unexpected errors or movement over time. Using 1.5 sigma as a standard deviation gives us a strong advantage in improving quality not only in industrial process and designs, but in commercial processes as well. It allows us to design products and services that are relatively impervious, or 'robust,' to natural, unavoidable sources of variation in processes, components, and materials."

Statistical Take Away: The reporting convention of Six Sigma requires the process capability to be reported in short-term sigma – without the presence of special cause variation. Long-term sigma is determined by subtracting 1.5 sigma from our short-term sigma calculation to account for the process shift that is known to occur over time.

Generally, z-tests are used when we have large sample sizes (n > 30), whereas t-tests are most helpful with a smaller sample size (n < 30). Both methods assume a normal distribution of the data, but the z-tests are most useful when the standard deviation is known.

A T test is usually done to compare the means of two treatments for instance if we want to compare to compare the performance of a machine before some adjustments are performed on it and the performance after the adjustments are performed , the mean of one sample of products taken prior to adjustments can be compared to the mean of another sample taken after adjustment. In that case a t-test can be useful.

The hypothesis testing performed based on t-test is conducted using the degree of freedom and the confidence level, but when two sample means are being compared there is always a room for making error. If alpha = 0.05 there would be 5% chance of rejecting a null hypothesis that happens to be true. If for instance three sample means A,B,C are being compared using the t-test with a confidence interval of 95% two factors are compared at a time .A is compared with B , then A with C and then b with C. Every time two factors are being compared there are 0.05 probablities for rejecting a true null hypothesis . Therefore when are three factors are compared using the t-test the type of making Type I error is inflated. In order to limit the chances of making a Type I Error inflation , we can use analysis of variance (ANOVA). ANOVA is a hypothesis test when more than two factor means are being compared.

The use of p-value method enables us not have pre-set the value of alpha , the null hypothesis is assumed to be true ; the p-value sets the smallest value of alpha for which the null hypothesis has to be rejected. For instance in the example above the p-value generated from Minitab was 0.020 and alpha = 0.05 there alpha is greater than the p-value and we have to reject the null hypothesis.

a) So if p value is less than alpha we have to reject the null hypothesis and accept the alternate hypothesis where alpha is pre-set at 0.05.

b) If p value is greater than alpha, we fail to reject the null hypothesis and reject the alternate hypothesis.

Two Errors in Hypothesis Testing: -

Type I Error: - Error occurs when you reject the null hypothesis although null hypothesis is true

α risk: Maximum probability of Committing a type I Error

Type II Error: - Error that you accept Null Hypothesis although Null Hypothesis is False

β risk: Probability of Committing a Type II Error.

Power of test : power of test is the probability of correctly rejecting Ho; the power of test is also called as $(1-\beta)$ thus if $\beta = 0.1$ the power is (1-0.1) or 0.9.

Z Table. When a set of data follows a normal distribution pattern, the mean and standard deviation can be *used* to calculate the percentage of data falling inside a given range.

Example: The diameter of steel ring is critical to quality the production process for manufacturing the steel rings has yielded a mean of 5cm with a standard deviation of 0.05 cm.The process mean of 5 cms meets engineered standards ; after oil was changed on the machine that produces the steel rings the new process mean has been 5.05 cm with the standard deviation unchanged. A sample of five steel rings are taken.

What is the probability that the supervisor would not be alerted that the process is going out of control

Ans:- This is an example of Type II error B risk. A false null hypothesis error that you accept the false null hypothesis although it false based on the power probability 1-beta = 1-0.777=0.223 in other words the probability that the supervisor would not be alerted that the process is going out of control when in fact it is is Beta= 0.777.

T-test and Z test are used in the analyze phase in Hypothesis tests; T Tests are for Sample Size less than 30 it is also called Students Distribution and Z test for Sample Size greater than 30.

If α=0.05 there would be 5% chance of rejecting a null hypothesis that happens to be true.

Example: The mean flow of a fuel injection component is a critical characteristic. The manufacturing process is known to produce parts with a mean flow of 100 kg/ minute with a standard deviation of 5 kg the machine undergoes preventive maintenance and is reset by the operator; after starting the machine again the first five component measure 97,99,101,96 and 100 should the operator continue production; assume the confidence of 95%.

$\mu_0 = 100$, $\sigma = 5$, n=5 , Xbar = (97+99+101+96+100)/5 = 98.6

Null hypothesis Ho= μ = 100

Alternate Hypothesis H1 = μ ≠ 100

Since we are concerned about the difference this is a test with 2 tails thus α = 0.05 should be distributed on both tails Z = X bar - μo/ σ divided by √n = 98.6-100/ 5 divided by √5 = -0.626

From Z table we get Z α/2 = Z 0.025 = -1.96 and +1.96 if we find the formula calculated value between -1.96 and + 1.96 we should conclude that the average has not changed; the calculated z value is -0.626 thus we cannot reject the null hypothesis so the mean which was 100 kg/minutes has not changed.

Example

The mean weekly sales of a company for a specific consumer product are Rs 20 Million with standard deviation of 2 million. The Company has launched a new advertisement with a superstar. Data of subsequent 6 weeks show average weekly sales of 24 million. Have the sales increased significantly with 95 per cent confidence?

Mean weekly sales $\mu_0 = 20$, $\sigma = 2$, αrisk =5%=0.05;

XBar = 24, n=6;

Null Hypothesis H0=μ=20 ; Alternate Hypothesis Ha: μ> 20(Right tailed Test);

Test Statistic Z= Xbar- μo/ σ/√ n=24-20/2/Sqrt 6=4.89;

Critical value of Z is Zα As α = 0.05 this value is Z0.05=1.64 this can be determined from z tables or excel functions

Z0.05=NORMSINV(0.95)

As the calculated Z statistic is 4.89 which is > 1.64 we must reject H0; thus we conclude that the sales have changed significantly

The use of Z Test in Practice is difficult as we often do not Know population standard deviation; in such cases we need to use students t-test.

Example

A software company has set a target of 75 days to complete a new software project of a particular type after initiating many actions , the team finds that the average of 16 completed projects in 72 days with standard deviation of 12 days . Is the evidence enough to recognize the team for achieving the target at 99 percent confidence interval?

From the problem we have μo=75, n=16, Ho:μ=75, H1:μ<75,Xbar=72, α=0.01 distributed on left tail.

T= Xbar- μo/s/√ n=-1

T find the critical value of T Distribution in T table or using the Excel Function TINV(2*0.01,15)=-2.6025.

Since T Statistic is -1 and T Critical is -2.6025 that is T Statistic is greater than T Critical so in that case cannot reject the Null Hypothesis.

Example

The monthly electricity bills for a company averages $500 the company decides to cut down on electricity consumption by encouraging employees to open their window shades instead of using lights. Twelve months later the electricity bills were as shown in the table below. Can we say that there has been an improvement in the electricity consumption with a confidence level of 99%?

Jan	Feb	March	April	May	June	july	August	Sept	oct	Nov	Dec
479	509	501	470	489	494	445	502	467	489	508	500

The Null hypothesis is

H0: The average electricity bill before changes = the average electricity bill after changes

And the alternate hypothesis

Ha: The average electricity bill before changes not equal to the average electricity bill after changes.

Where s=19.264, Xbar = 487.75, n=12

Because the confidence interval is 99% we have α = 1-0.99=0.01

We can determine the confidence interval using the formula

Xbar – tα/2,n-1 s/√n <equal to μ < equal to X bar + t α/2 , n-1 s/√n

Substituting the values in the formula we get 470.477 < equal to μ < equal to 505.023

The mean $500 falls well within the confidence interval; therefore, we cannot reject the null hypothesis and have to conclude that there has not been a statistically significant change in the level of electricity consumption because the employee opening the window shades instead of using their lights.

Comparing Variances F-Test: -

Example: A new Supplier has supplied samples of valves.Five Samples of these and six samples of Current Source were tested for 1000 hours to compare wear of the former with the current source. Wear on the five valves tested from new source was 0.054, 0.062, 0.068,0.058 and 0.04 mm. wear on the six valves from current source was 0.047,0.059,0.068,0.082,0.070 and 0.056. is the variation in new source comparable to the current source ? assume 95 percent confidence level.

Ho: σ1^2= σ2^2 and H1 = : σ1^2 not equal to σ2^2.

Standard deviation for Current from formula = F Current = 0.0123 and S new = 0.0105

F= S1^2/S2^2= 0.0123 ^2/0.0105^2= 1.3598.

Critical value from F table F 0.025,5,4=9.36

Now F cal = 1.3598 and F critical = 9.36 as F cal < F critical we cannot reject H0 so the variances are therefore not significantly equal.

Test of two proportions: -

A company has 2 manufacturing plants, both manufacture the same model of car. Plant 1 has produced 2500 cars , 75 of which required rework of transmissions. Plant 2 has manufactured 1800 cars and 63 of there were reworked is there a significant difference in quality? Assume 95% confidence level.

H0: P1= P2 H1= P1 Not equal to P2, X1=75, n1= 2500, X2=63, n2=1800

The formula for 2 proportion is Z= X1/n1-X2/n2 the Whole Divided by $\sqrt{p(1-p)(\frac{1}{n1}+\frac{1}{n2})}$

Where P= X1 + X2/n1+n2

P=75+63/2500+1800=138/4300=0.021

Z=73/2500-63/1800 the whole divided by $\sqrt{0.0321(1-0.0321)(\frac{1}{2500}+\frac{1}{1800})}$=-0.92

From the Z table we get the Z critical as Z= 1.96

If Z cal is < then Z critical or table we cannot reject the null hypothesis; in this case Z cal is = -0.92 and Z critical or table = 1.96 so Z cal is is less than Z critical so we cannot reject the null hypothesis and conclude that there is no significant differences in the 2 plants at 95 percent confidence level.

1-Sample Equivalence Test is used to evaluate whether the mean of a population is close enough to a target value or a reference value to be considered equivalent.

When you use a 1-sample equivalence test, you must specify a range of values that are "close enough" to be considered equivalent to the target. This equivalence interval, also called the *zone of equivalence,* is based on your knowledge of the product or process and should be determined before you perform the test. The analysis then determines whether you have enough evidence to claim that the difference between the population mean and the target value is within the equivalence interval.

For example, an analyst wants to test whether the strength of a new drug is equivalent to a target of 5 mg/ml. The analyst defines equivalence as a strength of 5 ± 0.1 mg/ml. If the confidence interval of the difference between the population mean and the target is contained completely within the equivalence interval (–0.1, 0.1), then the strength of the new drug is equivalent to the target.

Example in Minitab Equivalence test: -

A packaging engineer wants to test a new method to seal snack bags. The force that is required to open the bags should be within 10% of the target value of 4.2 N (Newton's). The engineer randomly samples 28 bags that are sealed using the new method and records the force that is required to open each bag.

The engineer performs a 1-sample equivalence test to determine whether the mean force that is required to open bags with the new seal is within 10% of the target of 4.2 N.

1.   Open the sample data, **SnackBagSeal.MTW**.

2.   Choose **Stat** > **Equivalence Tests** > **1-Sample**.

3.   From the drop-down list, select **Sample in a column**.

4.   In **Sample**, enter *Force*.

5.   In **Target**, enter *4.2*.

6.   From **What do you want to determine? (Alternative hypothesis)**, select **Lower limit < test mean - target < upper limit**.

7.   In **Lower limit**, enter *–0.1*.

8.   In **Upper limit**, enter *0.1*.

9.   Select **Multiply by target**.

10.   Click **OK**.

Interpret the results

The confidence interval is not completely within the equivalence interval. Therefore, the engineer cannot claim that the force that is required to open the bags with the new seal is equivalent to the target of 4.2 N.

One-Sample Equivalence Test: Force

Method

Target = 4.2

Lower equivalence limit = -0.1 × target = -0.42

Upper equivalence limit = 0.1 × target = 0.42

Descriptive Statistics

Variable	N	Mean	StDev	SE Mean
Force	28	4.4850	0.73188	0.13831

Difference: Mean(Force) - Target

Difference	SE	95% CI for Equivalence	Interval
0.28500	0.13831	(0, 0.520586)	(-0.42, 0.42)

CI is not within the equivalence interval. Cannot claim equivalence.

Test

Null hypothesis: Difference ≤ -0.42 or Difference ≥ 0.42

Alternative hypothesis: -0.42 < Difference < 0.42

α level: 0.05

Null Hypothesis	DF	T-Value	P-Value
Difference ≤ -0.42	27	5.0972	0.000

Difference ≥ 0.42   27   -0.97605   0.169

The greater of the two P-Values is 0.169. Cannot claim equivalence.

Equivalence Test: Mean(Force) - Target

Equivalence Test: Mean(Force) - Target
(LEL = Lower Equivalence Limit, UEL = Upper Equivalence Limit)

95% CI for Equivalence of Mean(Force) and Target of 4.2: (0, 0.52059)
CI is not within the equivalence interval of (-0.42, 0.42). Cannot claim equivalence.
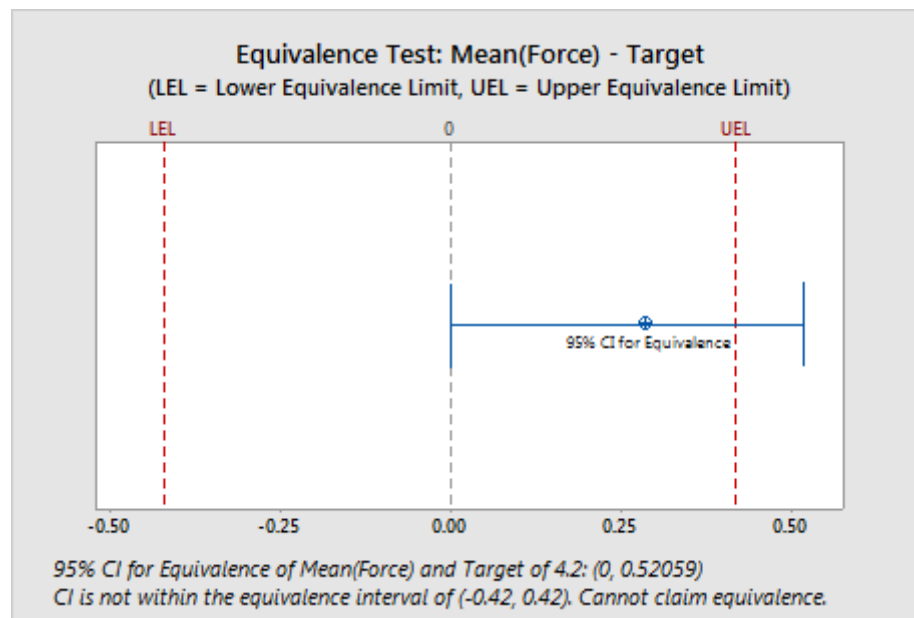
Anova is a Parametric Test

ANOVA TABLE MANUAL CALCULATION

Sources of Variation	Sum of Squares	Degree of Freedom	Mean Square	F-Statistic
Between Treatments	SST=∑ $nj(Xj\ bar - Xj\ double\ bar)^2$	Dftreatments=K-1	MST=SST/Dftreatment	F=MST/MSE
Within Treatments	$\sum_{j=1}^{k}\sum_{i=1}^{nj}(xij - xbarj)^2$	Df error= n-k	MSE=SSE/Df error	
Total	SST+SSE	Dftreatments+Dferror		

If for instance 3 sample means A, B, C are being compared using the t-test is cumbersome for this we can use analysis of variance ANOVA can be used instead of multiple t-tests.

ANOVA is a Hypothesis test used when more than 2 means are being compared.

If K Samples are being tested the null hypothesis will be in the form given below

H0: $\mu1 = \mu2 = ….\mu k$

And the alternate hypothesis will be

H1: At least one sample mean is different from the others

Annova are One-way, 2-way, 3 way etc. one way anova has one independent factor and 2 way anova has 2 Independent factors.

The Sum of Squares between samples (or Treatments) is noted as SST and is obtained from the formula SST= ∑ n j (Xbarj- XDouble Bar)^2.

Example: - An Operations Manager is Comparing the Productivity per Hour of Four Machines. He takes sample of units produced from each Machine and tabulates them in the table given below. Can we say that the production of the four machines are equal with a confidence level of 95%?

Table A:

Sample 1	Sample 2	Sample 3	Sample 4
23	25	25	23
24	22	25	23
25	22	25	23
24	23	24	23
24	24	24	24
25	22	23	24
26	23	26	25

Solution: - The Grand Mean X Double Bar is = 23.893

The null hypothesis will be

H0: mean of sample 1= mean of sample 2 = mean of sample 3 and the alternate hypothesis HA: At least one sample mean is different from others.

Table B: Sum of Square for treatments

	Sample 1	Sample 2	Sample 3	Sample 4
	23	25	25	23
	24	22	25	23
	25	22	25	23
	24	23	24	23
	24	24	24	24
	25	22	23	24
	26	23	26	25
xBar j =24.429	**23.00**	**24.571**	**23.571**	
(xbarj-xdouble bar)^2 =0.287	**0.797**	**0.460**	**0.103**	

∑ (Xbarj- XDouble Bar) ^2= **0.287+0.797+0.460+0.103 =1.648.**

SST= ∑ n (Xbarj- XDouble Bar)^2 = 7 * 1.648 = 11.536

Table C: Sum of Squares for Error

Sample 1	Sample 2	Sample 3	Sample 4
$(23-24.429)^2$ =2.041 By Applying the formula $(X_{ij}-X_{bar J})^2$	4.000	0.184	0.327
0.184	1.000	0.184	0.327
0.327	1.000	0.184	0.327
0.184	0.000	0.327	0.327
0.184	1.000	0.327	0.184
0.327	1.000	2.469	0.184
2.469	0.000	2.041	2.041
5.714	**8.000**	**5.714**	**3.714**

So SSE = 5.714 + 8.0000 + 5.714 + 3.714 =23.143

So TSS = SST + SSE = 11.536 + 23.143 = 34.679.

Degree of Freedom

Degree of freedom between treatments: Since there are four treatments (Samples),the degree of freedom=DF=k-1= 4-1 =3.

Degree of Freedom within treatments: Since there are 28 observations and 4 treatments the degree of freedom will be **=dferror=n-k = 28-4 = 24.**

Mean Squares MST = SST/ DFtreatment = 11.536 / 3 = 3.845.

MSE = SSE / DF error = 23.143 / 24 = 0.963.

Calculated F Statistic F = MST / MSE = 3.845 / 0.963 = 3.993.

The Computed Statistics can be summarize in the ANOVA table

Sources of Variation	Sum of Squares	Degree of Freedom	Mean Square	F-Statistic
Between Treatments	**11.536**	**3**	**3.845**	
Within Treatments	**23.143**	**24**	**0.963**	**3.993**
Total	**34.679**	**27**		

We can find the F-Statistics in the F-Table. The Critical F Statistic is based on the degree of freedom of the treatment, the degree of freedom for error based on the table.

Based on the table the Critical F-Statistic is equal to 3.01 which we get from the F-Anova table; while the calculated F-Statistic is = 3.993 the calculated F statistic is larger than the critical F-Statistic ; therefore we have to reject the null hypothesis an conclude that at least one sample mean is different from others.

F-Anova Table is Listed Below: -

Table of critical values for the F distribution (for use with ANOVA):

How to use this table?

There are two tables here. The first one gives critical values of F at the p = 0.05 level of significance. The second table gives critical values of F at the p = 0.01 level of significance.

1. Obtain your F-ratio. This has (x,y) degrees of freedom associated with it.

2. Go along x columns, and down y rows. The point of intersection is your critical F-ratio.

3. If your obtained value of F is equal to or larger than this critical F-value, then your result is significant at that level of probability.

An example: I obtain an F ratio of 3.96 with (2, 24) degrees of freedom.

I go along 2 columns and down 24 rows. The critical value of F is 3.40. My obtained F-ratio

is larger than this, and so I conclude that my obtained F-ratio is likely to occur by chance with a p<.05.

Critical values of F for the 0.05 significance level:

	1	2	3	4	5	6	7	8	9	10
1	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54	241.88
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.39	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
10	4.97	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98
11	4.84	3.98	3.59	3.36	3.20	3.10	3.01	2.95	2.90	2.85
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49
17	4.45	3.59	3.20	2.97	2.81	2.70	2.61	2.55	2.49	2.45
18	4.41	3.56	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35
21	4.33	3.47	3.07	2.84	2.69	2.57	2.49	2.42	2.37	2.32
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.38	2.32	2.28
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.26
25	4.24	3.39	2.99	2.76	2.60	2.49	2.41	2.34	2.28	2.24
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.17
31	4.16	3.31	2.91	2.68	2.52	2.41	2.32	2.26	2.20	2.15
32	4.15	3.30	2.90	2.67	2.51	2.40	2.31	2.24	2.19	2.14
33	4.14	3.29	2.89	2.66	2.50	2.39	2.30	2.24	2.18	2.13
34	4.13	3.28	2.88	2.65	2.49	2.38	2.29	2.23	2.17	2.12
35	4.12	3.27	2.87	2.64	2.49	2.37	2.29	2.22	2.16	2.11

Problem of 2-way Anova: Consider an experiment on aluminium castings .Customer requires hardness to be controlled. Hardness is an important to quality characteristic (CTQ) we therefore want to evaluate the effect of two factors on hardness (y).The 2 potential contributors are percentage of copper and magnesium. We have Controlled Copper percentage at 3.5 and magnesium at 1.2 and 1.8 percent data is available in the file hardness.xls

Solution: Open the XLS file Anova Hardness and the Minitab window opens click on stat->Anova-> and select 2 way a window pops up in response select hardness and row factor select copper and in column factor select magnesium at 95% confidence intervals you will get the output as shown below

Two-way ANOVA: Hardness versus Copper_1, Magnesium

Source   DF   SS   MS   F   P

Copper_1   1   1.125   1.125   1.29   0.320

Magnesium   1   21.125 21.125 24.14 0.008

Interaction 1   15.125 15.125 17.29 0.014

Error   4   3.500   0.875

Total   7   40.875

S = 0.9354   R-Sq = 91.44%   R-Sq(adj) = 85.02%

The p value of copper is > 0.05 which is not significant so copper alone does not contribute to the hardness; P value of Magnesium is significant at 0.008 so it contributes to the hardness and the interaction between copper and magnesium is also 0.014 which is statistically significant as it is less than 0.05 so magnesium and the interaction between magnesium and copper contribute to the hardness.

Example of General MANOVA

An automotive parts supplier assesses the usability and quality of the door locks that they provide. The locks are manufactured using two different methods at three plants. The production manager wants to determine whether the production method and the plant affect the final product. The production manager collects data on locks from each plant, produced by each method.

The manager collects data on the quality and usability of samples of locks. To assess how method and plant affect both response variables at the same time, the manager does a general MANOVA. The manager decides to use a significance level of 0.10 to decide which effects to examine in more detail.

1.   Open the sample data, **CarLockRatings.MTW**.

2.   Choose **Stat** > **ANOVA** > **General MANOVA**.

3.   In **Responses**, enter *'Usability Rating' 'Quality Rating'*.

4.   In **Model**, enter *Method Plant Method*Plant*.

5.   Click **OK**.

Interpret the results

The p-values for the production method are statistically significant at the 0.10 significance level. The p-values for the manufacturing plant are not significant at the 0.10 significance level for any of the tests. The p-values for the interaction between plant and method are statistically significant at the 0.10 significance level. Because the interaction is statistically significant, the effect of the method depends on the plant.

General Linear Model: Usability Ra, Quality Rati versus Method, Plant

MANOVA Tests for Method

Criterion	Test Statistic	F	DF Num	Denom	P
Wilks'	0.63099	16.082	2	55	0.000
Lawley-Hotelling	0.58482	16.082	2	55	0.000
Pillai's	0.36901	16.082	2	55	0.000
Roy's	0.58482				

s = 1   m = 0.0   n = 26.5

MANOVA Tests for Plant

Criterion	Test Statistic	F	DF Num	Denom	P
Wilks'	0.89178	1.621	4	110	0.174
Lawley-Hotelling	0.11972	1.616	4	108	0.175
Pillai's	0.10967	1.625	4	112	0.173
Roy's	0.10400				

s = 2   m = -0.5   n = 26.5

MANOVA Tests for Method*Plant

Criterion	Test Statistic	F	DF Num	Denom	P

Wilks'	0.85826	2.184	4	110	0.075
Lawley-Hotelling	0.16439	2.219	4	108	0.072
Pillai's	0.14239	2.146	4	112	0.080
Roy's	0.15966				

s = 2   m = -0.5   n = 26.5

8. Non parametric hypothesis testing: -

Non Parametric tests should be used when all the following conditions are true

- **Data are Non-Normal.**
- **Data cannot be readily transformed to Normality**
- **Sample size is small, say less than 30.**

In the previous examples we used means and standard deviation to determine if there were statistically significant differences between samples. What happens if the data cannot yield arithmetic means and standard deviations? What happens if the data are nominal or ordinal?

When we deal with categorical, nominal, or ordinal data non parametric statistics are used to conduct hypothesis testing. The Chi-square test and the Mann-Whitney U test, Kruskall Wallis, Moods Median are examples of nonparametric tests.

Chi-Square test:-

Chi Square goodness of fit test: -

Fouta electronics and Touba Inc are computer manufacturers that use the same third party call centre to handle their customer services. ToubaInc conducted a survey to evaluate how satisfied its customers were with the services that they receive from the call centre, the results of the survey are given in the table below.

Table A

Categories	Rating %
Excellent	10
Very good	45
Good	15
Fair	5
Poor	10
Very poor	15

After having the results of the survey, Fouta electronics decided to find out whether they apply to its customers, so it interviewed 80 randomly selected customers and obtained the results as shown in table below.

Categories	Rating(absolute value)
Excellent	8
Very good	37
Good	11
Fair	7
Poor	9
Very poor	8

To analyse the results the quality engineer at Fouta electronics conducts a hypothesis testing. However in this case, because he is faced with categorical data he cannot use a t-test since a t-test relies on the standard deviation and the mean which we cannot obtain from either table. We cannot deduct a mean satisfaction or a standard deviation satisfaction. Therefore another type of test will be needed to conduct the hypothesis testing. The test that applies to this situation is the Chi-square test, which is a non-parametric test.

Step 1: State the hypothesis

The null hypothesis will be

H0: The results of Toubainc Survey = the same as the results of Fouta electronics survey

And the alternate hypothesis will be

H1: The results of ToubaInc Survey ≠ the same as the results of Fouta electronics survey.

Step 2: Test Statistic to be used: The test statistic to conduct hypothesis testing is based on the calculated

$x^2 = \sum (f0-fe)^2 / fe$ where fe represents the expected frequencies and f0 represents the observed frequencies

Step 3: Calculating the X^2 test statistic: -

We will use the same table as given above if a sample of 80 customers were surveyed the data in the table

Table A

Categories	Rating %	Expected frequencies fe
Excellent	10	0.10 * 80 =8
Very good	45	0.45 * 80 = 36
Good	15	0.15 * 80 = 12
Fair	5	0.05 * 80 = 4
Poor	10	0.10 * 80 = 8
Very poor	15	0.15 * 80 = 12
Total	100	80

We can summarize the observed frequencies and the expected frequencies in the table given below:

Categories	Observed Frequencies fo	Expected Frequencies fe	(f0-fe)^2/fe
Excellent	8	8	0
Very good	37	36	0.028
Good	11	12	0.083
Fair	7	4	2.25
Poor	9	8	0.125
Very poor	8	12	1.33
Total	**80**	**80**	**3.816**

Therefore, we conclude $X^2 = \sum (f0-fe)^2/ fe = 3.816$.

Now that we have found the calculated X^2 we can find the critical X^2 from the table. The Critical X^2 is based on the degree of freedom and the confidence level since the number of categories is 6 the degree of freedom df is = 6-1=5, if the confidence level is set at 95%, α = 0.05; therefore, the critical x^2 is equal to 11.070 which we get from Chi-Square Table.

Since the critical X^2 0.05,5 = 11.070 is much greater than the calculated X^2 =3.816 we fail to reject the null hypothesis and we have to conclude that the surveys done by Touba Inc and Fouta Electronics gave statistically similar results.

In Minitab go to assistant click on hypothesis test and select chi-square goodness of fit test under more than 2 samples and take the sample data as umbrella from Help.

Chi Square Goodness of Fit Test

Use Chi-Square Goodness-of-Fit Test to determine whether the proportion of items in each category is significantly different from the proportions that you specify. You can test whether the proportions are equal across the categories (uniform), specify a different proportion for each category, or specify historical counts for each category.

For example, a researcher wants to determine whether the sample proportions of people who prefer certain colours of shoes match the values in the following table.

Proportion	Colour
0.2	White
0.3	Black
0.4	Blue
0.1	Any other colour

Where to find this analysis

To perform a chi-square goodness-of-fit test, choose **Stat** > **Tables** > **Chi-Square Goodness-of-Fit Test (One Variable)**.

Example: - A buyer for a t-shirt shop wants to compare the proportion of t-shirts of each size that are sold to the proportion that were ordered. The buyer counts the number of t-shirts of each size that are sold in a week.

The buyer performs a chi-square goodness-of-fit test to determine whether the proportions of t-shirt sizes sold are consistent with the proportion of t-shirt sizes ordered.

1.   Open the sample data, **TshirtSales.MTW**.

2.   Choose **Stat** > **Tables** > **Chi-Square Goodness-of-Fit Test (One Variable)**.

3.   In **Observed counts**, enter *Counts*.

4.   In **Category names (optional)**, enter *Size*.

5.   Under **Test**, select **Specific proportions**, and enter *Proportions*

6.   Click **OK**.

Interpret the results

In these results, the observed count for each t-shirt size is not very different from the expected count. The break-down by size is as follows:

- 25 small shirts were sold, while 22.5 were expected to be sold.

- 41 medium shirts were sold, while 45 were expected to be sold.

- 91 large shirts were sold, while 90 were expected to be sold.

- 68 extra-large shirts were sold, while 67.5 were expected to be sold.

The largest difference between observed and expected sales is in the medium category. Consequently, this category has the largest contribution to the chi-square statistic, 0.355.

The overall chi-square statistic is 0.648 and has a p-value of 0.885. Because the p-value is greater than the significance level of 0.05, the buyer fails to reject the null hypothesis. The buyer concludes that there is not a significant difference between the observed t-shirt sales and the expected t-shirt sales.

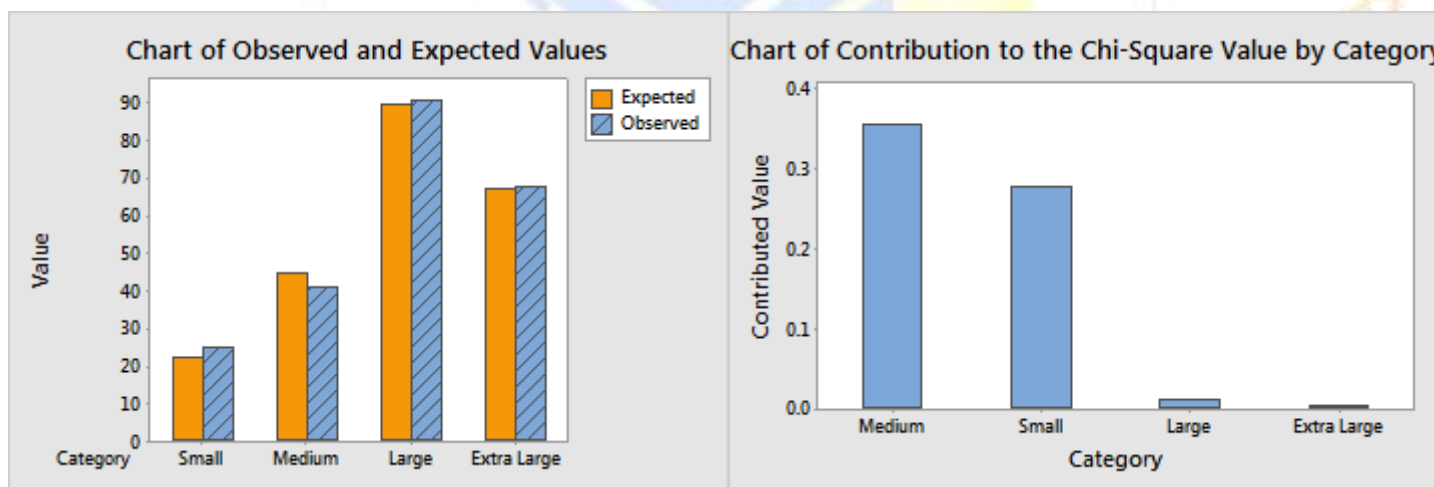**Chi-Square Goodness-of-Fit Test for Observed Counts in Variable: Counts**

Using category names in Size

Observed and Expected Counts

Category	Observed	Proportion	Expected	Test Contribution to Chi-Square
Small	25	0.1	22.5	0.277778
Medium	41	0.2	45.0	0.355556
Large	91	0.4	90.0	0.011111
Extra Large	68	0.3	67.5	0.003704

Chi-Square Test

N	DF	Chi-Sq	P-Value
225	3	0.648148	0.885

Chi Square Test for Association

Example in Minitab

At an umbrella manufacturing facility, umbrella handles are measured and then removed from the assembly line if they don't meet specifications. A daily report indicates how many rejected handles were produced by each of three presses at the facility during each of three shifts. A quality engineer wants to determine whether press and shift are associated.

The engineer performs a chi-square test for association to determine whether the press and the shift that produced the rejected handles are associated.

1. Open the sample data, **UmbrellaHandles.MTW**.
2. Choose **Stat** > **Tables** > **Chi-Square Test for Association**.
3. From the data drop-down list, select **Summarized data in a two-way table**.
4. In **Columns containing the table**, enter '*1st shift*' '*2nd shift*' '*3rd shift*'.
5. Under **Labels for the table (optional)**, in **Rows**, enter *Machine ID*.
6. Click **Statistics**.
7. Select **Each cell's contribution to chi-square**. Leave the default selections of **Chi-square test**, **Display counts in each cell**, **Display marginal counts**, and **Expected cell counts** selected.
8. Click **OK** in each dialog box.

Interpret the results

For this data, the Pearson chi-square statistic is 11.788 (p-value = 0.019) and the likelihood ratio chi-square statistic is 11.816 (p-value = 0.019). Both p-values are less than the significance level of 0.05. Thus, the engineer concludes that the variables are associated and that the performance of the presses varies depending on the shift.

The first shift produces the most rejected handles (160), and a large proportion of the bad handles come from press 2 (76). The number of bad handles produced on press 2 during shift 1 is much larger than would be expected if the variables were independent. The engineer uses this information to investigate the rejected handles from Press 2, made on the first shift.

Chi-Square Test for Association: Machine ID, Worksheet columns

Rows: Machine ID   Columns: Worksheet columns

	1st shift	2nd shift	3rd shift	All
1	48	47	48	143
	56.08	46.97	39.96	
	1.1637	0.0000	1.6195	
2	76	47	32	155
	60.78	50.91	43.31	
	3.8088	0.2998	2.9530	
3	36	40	34	110
	43.14	36.13	30.74	
	1.1809	0.4151	0.3468	
All	160	134	114	408

Cell Contents

    Count

    Expected count

    Contribution to Chi-square

Chi-Square Test

	Chi-Square	DF	P-Value
Pearson	11.788	4	0.019
Likelihood Ratio	11.816	4	0.019

Mood's Median Test

This test is used to determine whether there is sufficient evidence to conclude that samples are drawn from populations with different medians

Ho: The Population from which the samples are drawn have the same median

Ha: At least one of the populations has a different median

The procedure is best illustrated with an example.

Example: - Three machines produce plastic parts with a critical location dimension samples are collected from each machine with each sample size at least 10. The Dimension is measured on each part. Does Mood's median test permit rejection at the 90% significance level of the hypothesis that the median dimensions of the three machines are the same?

The Data:

Machine # 1: 6.48, 6.42, 6.47, 6.49, 6.47, 6.48, 6.46, 6.45, 6.46

N= 10

Machine # 2 : 6.42,6.46,6.41,6.47,6.45,6.46,6.42,6.46,6.46,6.48,6.47,6.43,6.48,6.47

N = 14

Machine # 3: 6.46,6.48,6.45,6.41,6.47,6.44,6.47,6.42,6.43,6.47,6.41

N = 11

Procedure:

1. Find the overall median of all 35 readings, overall median = 6.46
2. Construct a table with one column showing number of readings above the overall median and another showing number of medians below the overall category median or each category. Half of the readings that are equal to the median should be counted in the "above" column and half in the "below" column.

	Observed Values	
	Number above the overall Median	Number below the overall median
Machine #1	7	3
Machine #2	7	7
Machine #3	4.5	6.5

If the three Populations have the same median, each should have half their readings in the "above" column and half "below". Therefore the expected value for number of readings would be half the sample size in each case, so the expected values would be as shown in the table.

Expected Values		
	Number above overall median	Number below overall median
Machine # 1	5	5
Machine # 2	7	7
Machine # 3	5.5	5.5

The next step is to calculate (observed – expected) ^2 / expected. For each cell in the table

The sum of these values in these cells =1.96 this is x ^2 test statistic with degrees of freedom k-2 where k is the number of machines. Since the critical value for x ^2 1, 0.95 = 3.84 the data do not justify rejecting the null hypothesis.

(Observed-Expected)^2/ expected		
	Number above overall median	Number below overall median
Machine # 1	2^2/5 = 0.8	2^2/5 = 0.8
Machine # 2	0	0
Machine # 3	1/5.5=0.18	1/5.5 =0.18

To find the P-value for 1.96 using MS Excel, choose the statistical function CHIDIST and enter 1.96 for x ^ 2 and 1 for the degrees of freedom. You get the value 0.161513.
Mann-Whitney Test (Non-Parametric Test)

Mann-Whitney test is better explained thru an example.

Mann-Whitney test is used in Minitab by selecting the option Stat→ Non Parametric→Mann Whitney Test select sample1 row and sample 2 row and check whether their medians are equal at 95% Confidence interval; the null hypothesis is that the medians are equal and the alternate hypothesis is the medians are not equal check the output and see whether the medians are equal or not.

Example: An operations manager wants to compare the number of inventory discrepancies found in two operating shifts. The inventory discrepancies are not normally distributed. The manager takes a sample of discrepancies found over 7 days for the first shift and 5 days for the second shift tabulates the data as shown below

First Shift	Second Shift
15	17
24	23
19	10
9	11
12	18
13	
16	

We can make several observations from this table. First the sample sizes are small and we only have 2 samples so the first thing that comes to mind would be to use t-test, however the t-test assumes that the population from which the samples are taken should be normally distributed which is not the case therefore the t-test cannot be used, instead the Mann-Whitney U Test should be used. The Mann-Whitney U test assumes that samples are independent and from dissimilar populations

Step 1: Define the Null Hypothesis: Just as the case of T-Test the Mann-Whitney U Test is a hypothesis test the null and alternate hypothesis are

H0: The number of Discrepancies in the first shift is the same as the one in the second shift

H1: The number of Discrepancies in the first shift is different from the ones in the second shift

The result of the test will lead to the rejection of the null hypothesis or a failure to reject the null hypothesis.

Step 2: Analyse the data: The first step in the analysis of the data consists of naming the groups. In our case they are already named first and second shift. The Next Step consists of grouping the two columns in one and sorting the observations in ascending order ranked from 1 to n. Each observation is paired with the name of the original group to which it belonged

The table below illustrates the fact:

Observations	Group	Ranks
9	First Shift	1
10	Second Shift	2
11	Second Shift	3
12	First Shift	4
13	First Shift	5
15	First Shift	6
16	First Shift	7
17	Second Shift	8
18	Second Shift	9
19	First Shift	10
23	Second Shift	11
24	First Shift	12

We will call v1 the sum of the ranks of the observations of the first group called as first shift and v2 the sum of the ranks of the observations for group second shift

$$V1= 1+4+5+6+7+10+12 =45$$

$$V2 = 2+3+8+9+11 = 33$$

Step 3: Determining the values of U Statistic by the formula given below

$$U1 = n1*n2 + n1*(n1+1) / 2 - v1$$
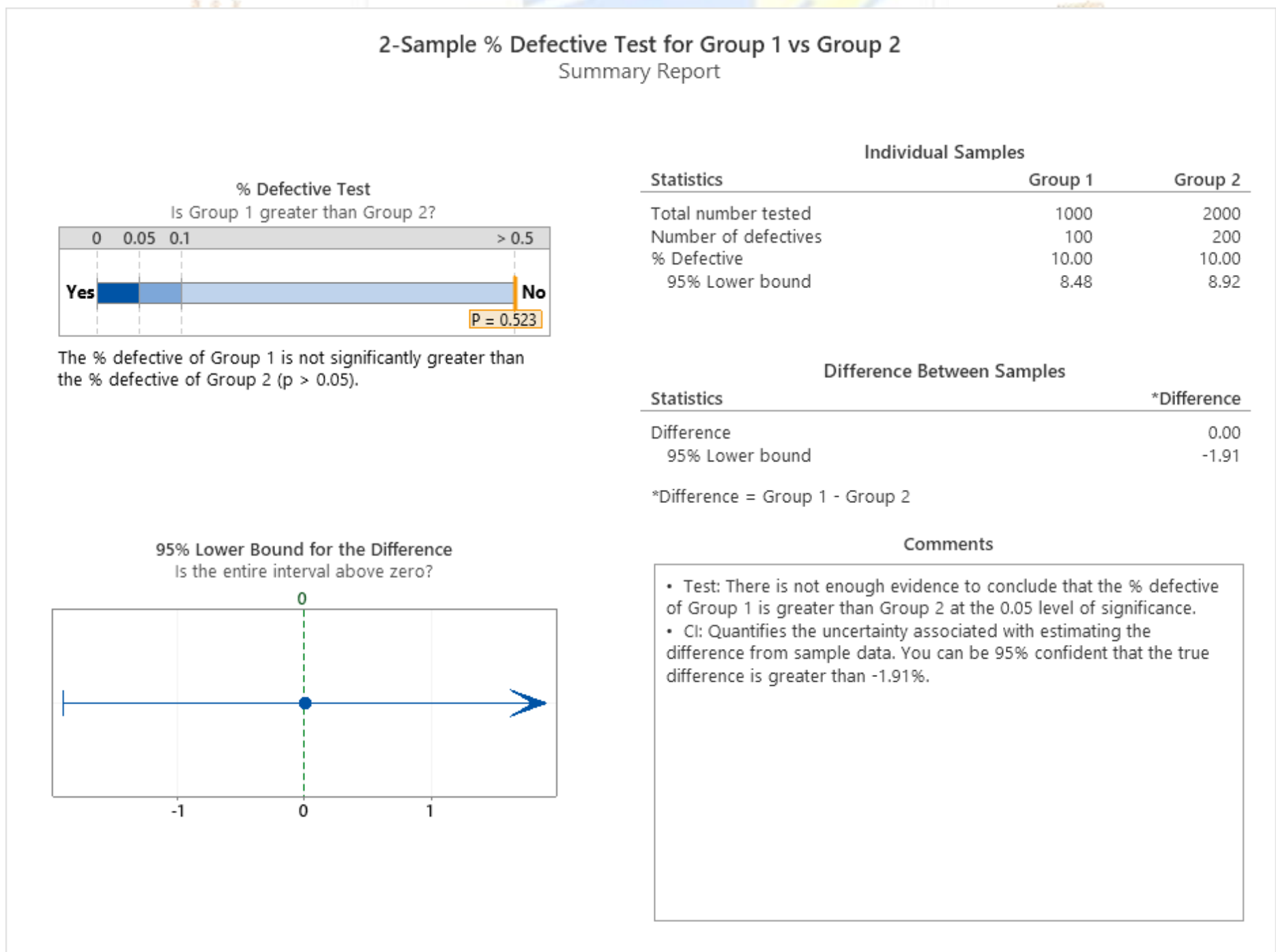
$$U2 = n1 * n2 + n2 (n2 + 1) / 2 - v2$$

If any or both of the sample size are greater than 10 , then U will be approximately normally distributed and we could use Z transformation but in our case both sample sizes are less than 10 there fore

$$U1 = 7*5 +7(7+1)/2 - 45 = 35 + 28 - 45 = 18$$

$$U2 = 7 * 5 + 5(5+1) / 2 - 33 = 35 + 15-33 = 17$$

Since the calculated test statistic should be the smallest of the two we will use U2 = 17 and n2=7 and n1=5 from the Mann Whitney table we find that p value is 5 therefore we fail to reject the null hypothesis and have to conclude that the number of discrepancies in the first shift are the same as the ones in the second shift.

2 Sample % Defective test: - In this test we have 2 Groups, Group 1 and Group 2 and from the Production floor we have to enter the total number tested and number of defectives. In this particular scenario we have entered total number of items tested for group 1 as 1000 and number of defectives found as 100 and in group 2 we have entered total number of items tested as 2000 and the number of defectives as 200.The output of Minitab given below in which the horizontal thermometer graph clearly depicts that the % of defectives of group 1 is not significantly greater than group 2. This test is used to find the difference in percentage in defectives among 2 groups of samples collected.

2-Sample % Defective Test for Group 1 vs Group 2
Summary Report

% Defective Test
Is Group 1 greater than Group 2?

P = 0.523

The % defective of Group 1 is not significantly greater than the % defective of Group 2 (p > 0.05).

Individual Samples

Statistics	Group 1	Group 2
Total number tested	1000	2000
Number of defectives	100	200
% Defective	10.00	10.00
95% Lower bound	8.48	8.92

Difference Between Samples

Statistics	*Difference
Difference	0.00
95% Lower bound	-1.91

*Difference = Group 1 - Group 2

95% Lower Bound for the Difference
Is the entire interval above zero?

Comments

• Test: There is not enough evidence to conclude that the % defective of Group 1 is greater than Group 2 at the 0.05 level of significance.
• CI: Quantifies the uncertainty associated with estimating the difference from sample data. You can be 95% confident that the true difference is greater than -1.91%.

Chi Square % Defective: -

More than two % defectives

Each item is classified into one of two categories, such as pass/fail or defective/non defective. You count the number of defective items in each sample and compare the percentage of defectives between the samples. In this test you can enter more number of rows for items tested and defectives unlike 2 sample % Defective.

Example

Engineers examine samples of bolts from four machines for severe cracks that make the bolts unusable. For each sample, the engineers record the number of bolts that are inspected and the number of bolts that are rejected. They want to determine whether the % defective differs for each machine.

Each item is classified into one of three or more outcome categories, such as poor, fair, good, and excellent. You count the number of items in each category and compare the percentage in each category between the samples. From the output of Minitab given below we can conclude that the percentage defectives are different for each machine from the horizontal thermometer graph.
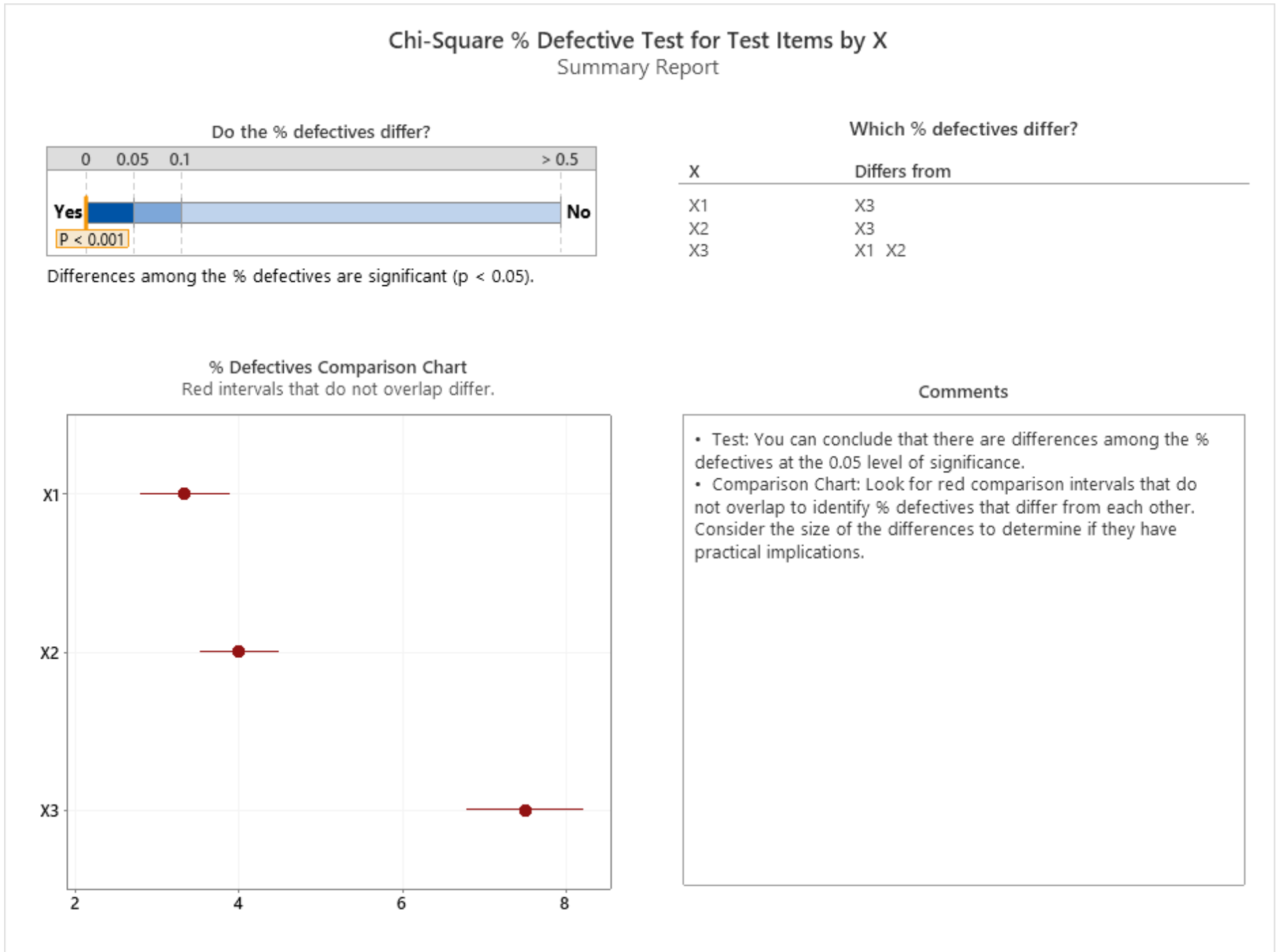
Kruskal-Wallis Test: -

A health administrator wants to compare the number of unoccupied beds for three hospitals in the same city. The administrator randomly selects 11 different days from the records of each hospital and enters the number of unoccupied beds for each day.

This data can be used to demonstrate **Kruskal-Wallis Test** and other analyses that compare population medians.

Worksheet column	Description
Beds	The number of unoccupied beds in the hospital for the day (response)
Hospital	The hospital identification number (factor)

Test

		H-Value	P-Value
Null hypothesis	H₀: All medians are equal		
Alternative hypothesis	H₁: At least one median is different		

Method	DF	H-Value	P-Value
Not adjusted for ties	2	7.05	0.029
Adjusted for ties	2	7.05	0.029

From the output it is seen that the P value is 0.029 which is less than 0.05 so we have to accept the alternate hypothesis and conclude that the unoccupied beds in the hospitals are significantly different.

1 Sample Wilcoxon: In this test we compare against a target median.

A chemist for a pharmaceutical company wants to determine whether the median reaction time for a newly developed antacid is less than 12 minutes. The chemist measures the reaction time for 16 samples of the antacid.

You can use this data to demonstrate **1-Sample Wilcoxon**. We have to enter 12 in the target median as input.

Worksheet column	Description
Time	The reaction time for each sample.

Test

		N for Test	Wilcoxon Statistic	P-Value
Null hypothesis	H₀: η = 12			
Alternative hypothesis	H₁: η ≠ 12			

Sample	N for Test	Wilcoxon Statistic	P-Value
Time	16	53.00	0.453

From the output it is seen that the P value is 0.453 which is greater than 0.05 so we have to accept the null hypothesis and conclude that the median is equal to 12 and not less than 12. Example of Friedman Test

Friedman's Test is a Non Parametric Test

Example :- A marketing analyst wants to compare the relative effectiveness of three types of advertising: direct mail, newspaper, and magazine. The analyst performs a randomized block experiment. For 12 clients, the marketing firm used all three types of advertising over a 1-year period and recorded the year's percentage response to each type of advertising.

To determine whether the median treatment effect differs for the type of advertising, the analyst uses the Friedman test.

1.   Open the sample data, **AdvertisingEffectiveness.MTW**.

2.   Choose **Stat** > **Nonparametric** > **Friedman**.

3.   In **Response**, enter *Response*.

4.   In **Treatment**, enter *Ad type*.

5.   In **Blocks**, enter *Company*.

6.   Click **OK**.

Interpret the results

Because the p-value for the advertising data is less than the significance level of 0.05, the analyst rejects the null hypothesis and concludes that at least one of three types of advertising has a different effect. Also, the median responses for direct mail (6.100) and magazine (8.150) are close to the overall median (9.183), but the median response for newspaper advertising (13.300) is substantially higher. These results indicate that newspaper advertising might be more effective than the other types of advertising.

Friedman Test: Response vs Ad type, Company

Method

Treatment = Ad type

Block = Company

Descriptive Statistics

Ad type	N	Median	Sum of Ranks
direct-mail	12	6.1000	16.0
magazine	12	8.1500	24.0
newspaper	12	13.3000	32.0
Overall	36	9.1833	

Test

Null hypothesis   H₀: All treatment effects are zero

Alternative hypothesis H₁: Not all treatment effects are zero

DF	Chi-Square	P-Value
2	10.67	0.005

Multi-Vari analysis is used when you have multiple discreet Xs (like work shift, employee, location) and Y is continuous (like part length or cycle time).

An engineer wants to assess the effect of sintering time on the compressive strength of three different metals. The engineer measures the compressive strength of five specimens of each metal type at each sintering time: 100 minutes, 150 minutes, and 200 minutes.

The engineer creates a multi-vari chart to look for possible trends and interactions in the data.

1.   Open the sample data, **SinteringTime.MTW**.

2.   Choose **Stat** > **Quality Tools** > **Multi-Vari Chart**.

3.   In **Response**, enter *Strength*.

4.   In **Factor 1**, enter *SinterTime*.

5.   In **Factor 2**, enter *MetalType*.

6.   Click **OK**.

Interpret the results

The multi-vari chart indicates a possible interaction between the type of metal and the length of sintering time. The greatest compressive strength for Metal Type 1 is obtained by sintering for 100 minutes, for Metal Type 2 by sintering for 150 minutes, and for Metal Type 3 by sintering for 200 minutes.
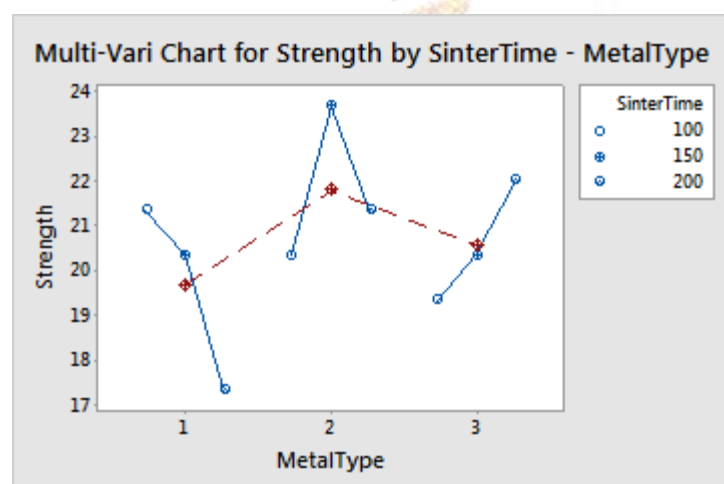
The data show that the strength varies differently across sintering times for different metal types, indicating an interaction.
To quantify this interaction and to determine whether it is statistically significant, the engineer could further analyse this data with an ANOVA (analysis of variance) or a general linear model.

The Variation is given by Sum of Squares / Degree of Freedom

Each MS (mean Square) value represents variance due to the source mentioned in the row we can conclude that magnesium an interaction between magnesium and copper have significant effect on the hardness of aluminium castings.

In ANOVA if the calculations are done manually using formulas we apply the F-Statistic table and find the end result.

MULTIVARIATE ANALYSIS IS USED IN ANALYSE PHASE –

Overview for Principal Components Analysis

Use Principal Components Analysis to identify a smaller number of uncorrelated variables, called "principal components", from a large set of data. With this analysis, you create new variables (principal components) that are linear combinations of the observed variables. The goal of principal components analysis is to explain the maximum amount of variance with the fewest number of principal components.

For example, an analyst uses a principal components analysis to analyze customer responses to several characteristics of a new shampoo. The analyst wants to determine whether they can form a smaller number of uncorrelated variables that are easier to interpret and analyze than the observed variables that they measured.

Principal components analysis is commonly used as one step in a series of analyses. For example, you can use principal components before you perform a regression analysis, in order to avoid multi-collinearity or to reduce the number of predictors relative to the number of observations.

Example: - Using Census Data Collected in the table below perform a principal components analysis using Minitab. Determine the factors which contribute the greatest to the variability.

Principal Components, Factor Analysis, Discriminant Analysis, Multiple Analysis of Variance are used to investigate the sources of variation and are done in the analyze phase.

Principal Components have wide applicability in the social sciences and market research.

Population	School	Employ	Health	Home
5.935	14.2	2.265	2.27	2.91
1.523	13.1	0.587	0.75	2.62
2.599	12.7	1.237	1.11	1.72
4.009	15.2	1.649	0.81	3.02
4.687	14.7	2.312	2.50	2.22
8.044	15.6	3.641	4.51	2.36
2.766	13.3	1.244	1.03	1.97
6.538	17.0	2.618	2.39	1.85
6.451	12.9	3.147	5.52	2.01
3.314	12.2	1.606	2.18	1.82
3.777	13	2.119	2.83	1.80
1.530	13.8	0.798	0.84	4.25
2.768	13.6	1.336	1.75	2.64
6.585	14.9	2.763	1.91	3.17

Choose Stat→ Multivariate→Principal Components→ Select all five fields for variables and select correlation for type of Matrix.

Principal Component Analysis: Population, School, ... y, Health, Home
Eigen analysis of the Correlation Matrix

Eigenvalue	3.0287	1.2911	0.5725	0.0955	0.0123
Proportion	0.606	0.258	0.114	0.019	0.002
Cumulative	0.606	0.864	0.978	0.998	1.000

Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5
Population	0.558	0.131	-0.008	-0.550	0.607
School	0.313	0.629	0.549	0.453	-0.007
Employ	0.568	0.004	-0.117	-0.269	-0.769
Health	0.487	-0.310	-0.455	0.648	0.200
Home	-0.174	0.701	-0.691	-0.015	-0.014

The Eigen value row in the top table provides the variance of each component ; for instance population has variance of 3.028 and we also find the Eigen values to be low for health which is 0.0954 and home 0.0121 so from this we can interpret that the first 2 factors population and school account for 86.4% of the variability.

The Screen Plot Below shows with Eigen value on the Y-Axis and Principal Components on the X axis from here we can say that the factors which contribute most to the variability are Population, school & Employment.

Scree Plot of Population, ..., Home
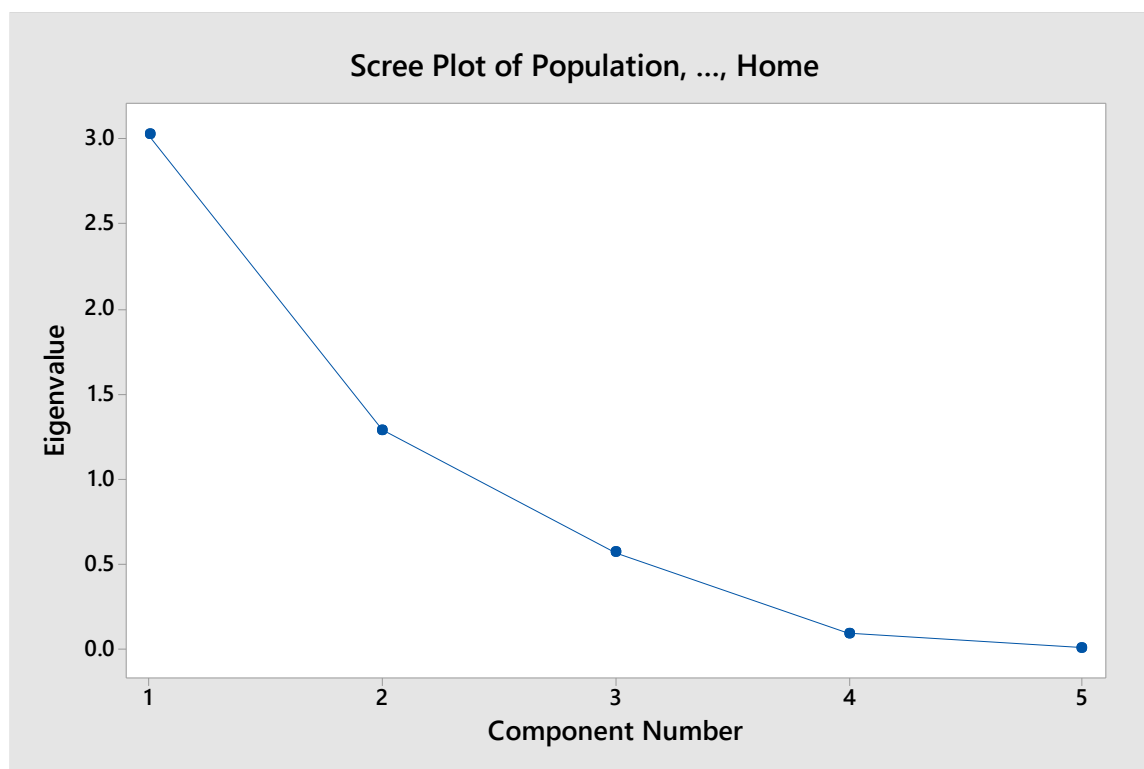
Eigen Values: A High Eigen Value indicates that the respective factor contributes to a high variation.

Factor analysis

Use Factor Analysis to assess the structure of your data by evaluating the correlations between variables. Factor analysis summarizes data into a few dimensions by condensing a large number of variables into a smaller set of latent factors that you do not directly measure or observe, but which may be easier to interpret. Using this analysis, you can model each original variable as a linear function of these underlying factors. Factor analysis is commonly used in the social sciences, market research, and other industries that use large data sets.

For example, a credit card company uses factor analysis to ensure that a customer satisfaction survey address three factors before sending the survey to a large number of customers. If the survey does not adequately measure the three factors, then the company should reevaluate the questions and retest the survey before sending it to customers.

9. REGRESSION

The Simple regression analysis is that it involves only 2 variables the independent and the dependant variable so in the equation y=f(x) y is the dependant variable and x is the independent variable.

Linear Regression: - In Linear regression the value of y increases proportionately to the independent variable x. Where it is necessary to calculate the value of y at a given x value the following important factors are to be borne in mind.

1. The intercept or the point at which the slope starts when the value of x is zero.
2. What exactly is the slope which represents the value of y with any changes in x?
3. Whether there would be any deviation in the value of y from the expected value of x?

We can explain the intercept in a simple equation y = a + bx. Where b is called the regression coefficient of the slope.

Everyone is taught in school the equation of a straight line:

$Y = a + bX$

Where a is the Y-intercept and b is the slope of the line. Using this equation and given any value of X, anyone can compute the corresponding Y.

Figure 1: Charting the Formula for a Straight Line
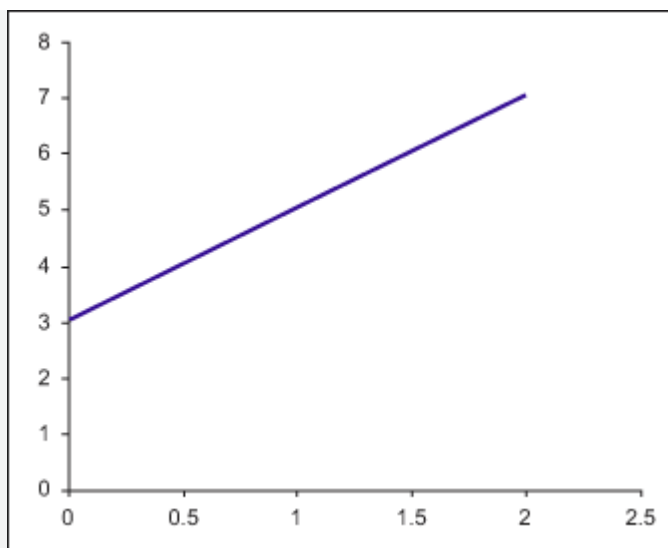
In Figure 1, $Y = 3 + 2X$. It is easy to see visually that a is 3. For the slope b, any two points on the line need to be chosen, say X1 = 1, Y1 = 5 and X1 = 2, Y1 = 7 and apply the following formula:
:

$$b = \frac{Y2 - Y1}{X2 - X1} = \frac{7 - 5}{2 - 1} = \frac{2}{1} = 2$$
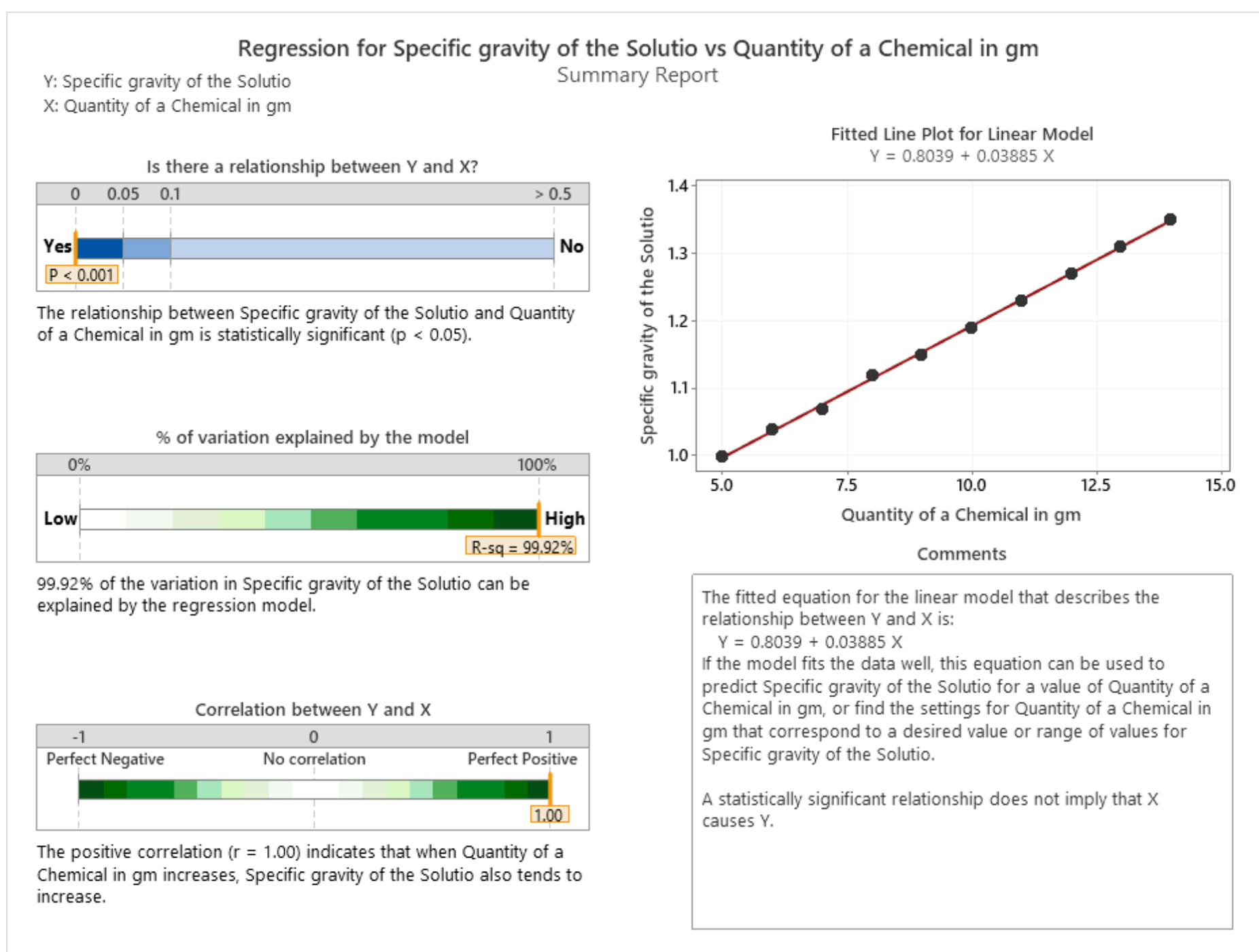
The relationship between y (Specific gravity of the Solution) and the quantity of the chemical was established and shows that the presence of chemical increases the specific gravity of the solution increases proportionately.

A fitted value is a statistical model's prediction of the mean response value when you input the values of the predictors, factor levels, or components into the model. Suppose you have the following regression equation: y = 3X + 5. If you enter a value of 5 for the predictor, the fitted value is 20. Fitted values are also called predicted values.

In the example below the response which is specific gravity is continuous and has to be selected in the response column of Minitab and in the X column select Quantity of Chemical in Gram.

Example: - A Six Sigma Project team in a chemical manufacturing company was analysing the customer complaints regarding the variation in specific gravity of the chemical being supplied. The team was interested to know whether there was any relationship between one specific chemical and the specific gravity of the solution they collected data of specific gravity at varying amounts of Chemical as given in the table below

| Quantity of a Chemical in gm	Specific gravity of the Solution
5	1
6	1.04
7	1.07
8	1.12
9	1.15
10	1.19
11	1.23
12	1.27
13	1.31
14	1.35

From the thermometer horizontal graph, it is very clear that as the quantity of chemical increases the specific gravity of the solution increases, this is an example of Simple Regression where only one factor X is there, when there are multiple factors we have to use multiple regression option of Minitab.

The HR director believes that the wages are the only significant factor that explains the high attrition rate in an organization. In order to minimize the cost of employee retention, she wants to create a model that will help them know what attrition rate to expect for each level of wages.

Before creating the model, they want to ascertain the intuition by actually verifying that there really is a correlation between attrition rate and wages.

HR director gathered data from 20 companies. Data will be used for drawing analysis.
We will Enter this data in Minitab and draw a scatter plot to find the relation between attrition and wages.

Companies	Attrition Rate	Wages
A	15	15.7
B	14	14.9
D	15	15.8
E	15	15.3
F	14	14.5
G	17	12
H	19	10
I	20	10.9
J	25	9
K	14	15
L	13	16.5
M	15	15.5
N	12	17
O	9	23
P	7	24
Q	14	16
R	5	25
S	17	15.4
T	3	27
U	15	15

Scatterplot of Attrition Rate vs Wages
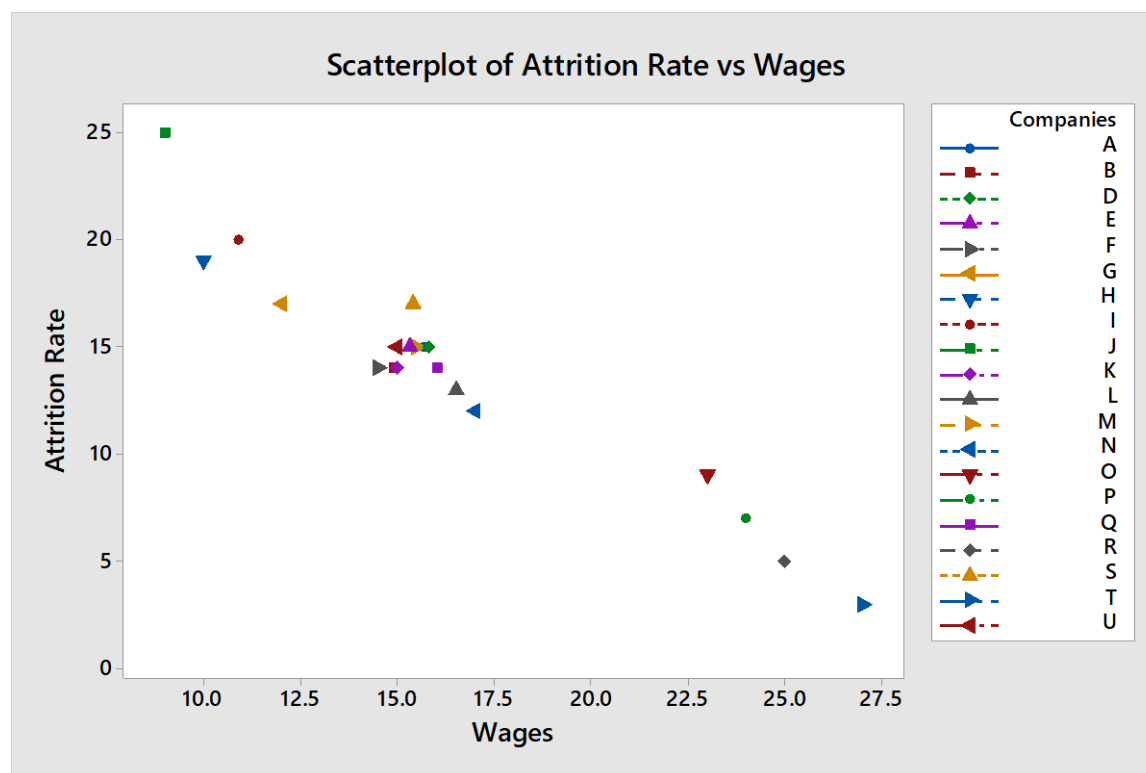
From the scatter plot above it is very clear that there is a relation between wages and attrition if the wages are more the attrition rate is less

Coefficient of Correlation The statistic used to determine the measure of relatedness between factors is the coefficient of correlation generally noted as R it is a number between -1 and + 1. When the coefficient of correlation is equal to -1 there is a perfect negative correlation between the factors; in other words, an increase in the magnitude of the independent factor will necessarily lead to a decrease in the dependent factor in the exact same proportion and a decrease in the independent factor will lead to an increase in the dependent factor in the exact same proportion.

If the coefficient of correlation is equal to 0 there is absolutely no relationship between the 2 factors and when it is equal to + 1 there is a positive correlation between the factors and increase in the independent factor leads to an increase in the dependent factor in the same proportions.

Coefficient of Determination: While the coefficient of correlation measures the strength of the relation between the 2 factors, the coefficient of determination shows what proportion in the variations of the dependent factor(y) is due to the variations in the in the independent factor(x). The coefficient of determination noted r^2 is the square of coefficient of relation

Multiple regression analysis: When more than one independent factor is used to explain the dependent factor a multiple regression analysis is used. The principle followed when conducting a multiple regression analysis is the same as when conducting a simple regression with the difference that more input factors (x's) are used.

After a regression line has been computed for a group of data, a point which lies far from the line (and thus has a large residual value) is known as an *outlier*. Such points may represent erroneous data, or may indicate a poorly fitting regression line. If a point lies far from the other data in the horizontal direction, it is known as an *influential observation*. The reason for this distinction is that these points have may have a significant impact on the slope of the regression line. Notice, in the above example, the effect of removing the observation in the upper right corner of the plot:
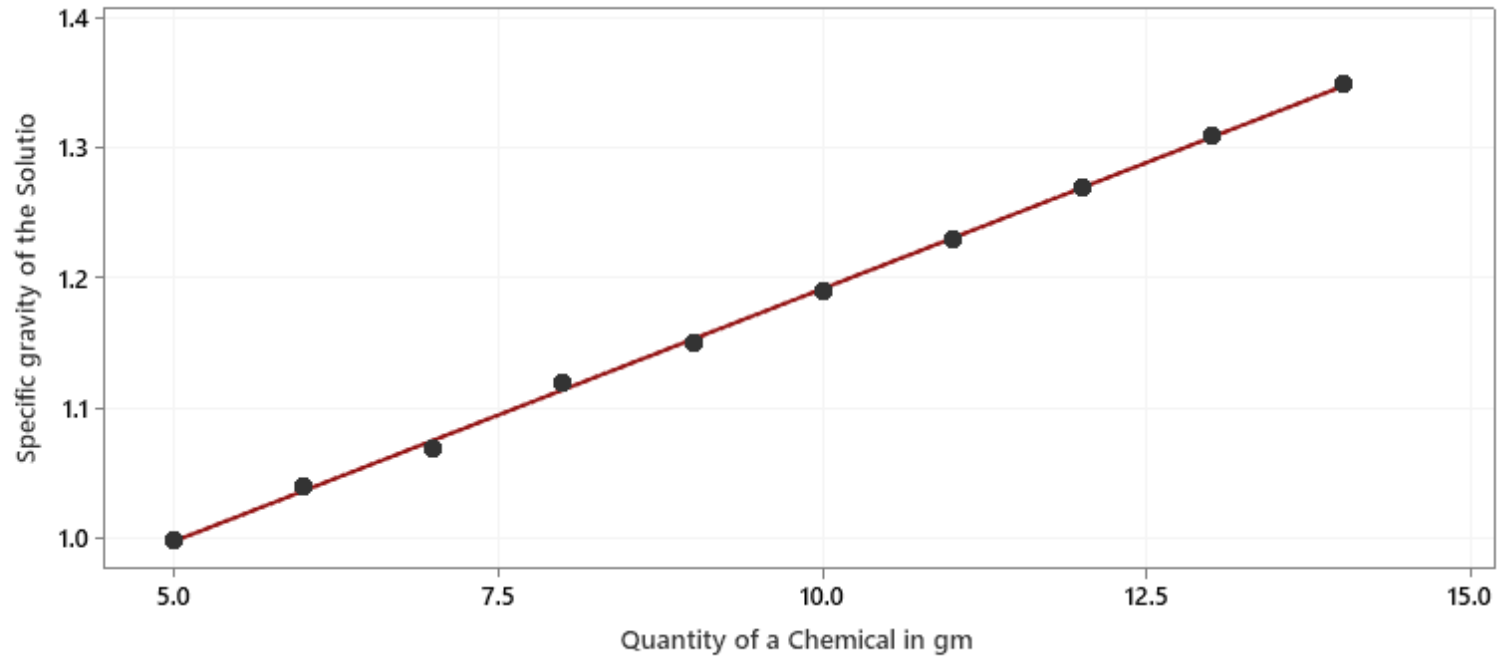
Regression for Specific gravity of the Solutio vs Quantity of a Chemical in gm
Model Selection Report

Y: Specific gravity of the Solutio
X: Quantity of a Chemical in gm

Fitted Line Plot for Linear Model
Y = 0.8039 + 0.03885 X

Statistics	Selected Model Linear	Alternative Model Quadratic
R-squared (adjusted)	99.91%	99.92%
P-value, model	<0.005*	<0.005*
P-value, linear term	<0.005*	<0.005*
P-value, quadratic term	—	0.243
Residual standard deviation	0.004	0.003

Statistically significant (p < 0.05)

Multiple Linear Regression Analysis: -

A materials scientist studies the heat that is generated in cement mixtures. The scientist varies the four ingredients in the mixtures to assess the impact on overall heat generation.

Because this data has 4 continuous predictor variables, you can use it to demonstrate **Fit Regression Model** and **Best Subsets Regression**.

| Worksheet column	Description	Variable type
Heat Evolved	The amount of heat that evolves in a cement mixture	Response
X1	The amount of tricalcium aluminate in the cement mixture	Predictor
X2	The amount of tricalcium silicate in the cement mixture	Predictor
X3	The amount of tetracalcium aluminoferrite in the cement mixture	Predictor
X4	The amount of dicalcium silicate in the cement mixture	Predictor

Multiple Regression for Heat Evolved
Summary Report

Is there a relationship between Y and the X variables?

| 0 | 0.1 | > 0.5 |

Yes | | No
P < 0.001

The relationship between Y and the X variables in the model is statistically significant (p < 0.10).

% of variation explained by the model

0% | | 100%

Low | | High
R-sq = 98.52%
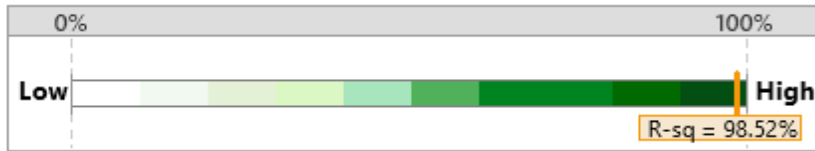
98.52% of the variation in Y can be explained by the regression model.

Comments

The following terms are in the fitted equation that models the relationship between Y and the X variables:
X1: X1
X2: X2
X2^2

If the model fits the data well, this equation can be used to predict Heat Evolved for specific values of the X variables, or find the settings for the X variables that correspond to a desired value or range of values for Heat Evolved.

Heat Evolved vs X Variables

X1 | X2 | X3
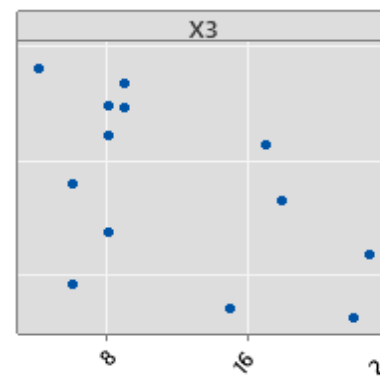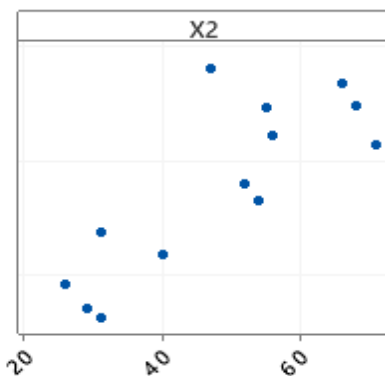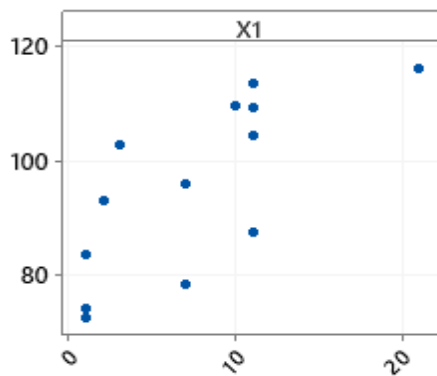
A gray background represents an X variable not in the model.

In Minitab in the response option you have to enter heat evolved and multiple X's in the factors or predictors column of Minitab. We find from the output above that the present of the chemicals tricalcium aluminate, tricalcium silicate increase the heat evolved in the cement mixture whereas the scatter graph represented by data scattered in the form of dots which has grey background that is the factor X3 ; X3 is the chemical of tetracalcium aluminoferrite doesn't contribute to the heating of the cement Mixture. Any scatter graph of factors in grey background doesn't contribute to the variation in the response variable.

You can see from the horizontal bar graph that the factor X2 is the longest bar so its presence is contributing more heat in the cement mixture than any other factor and the factor X3 is a in grey which means that it doesn't contribute to the heating in the cement mixture.

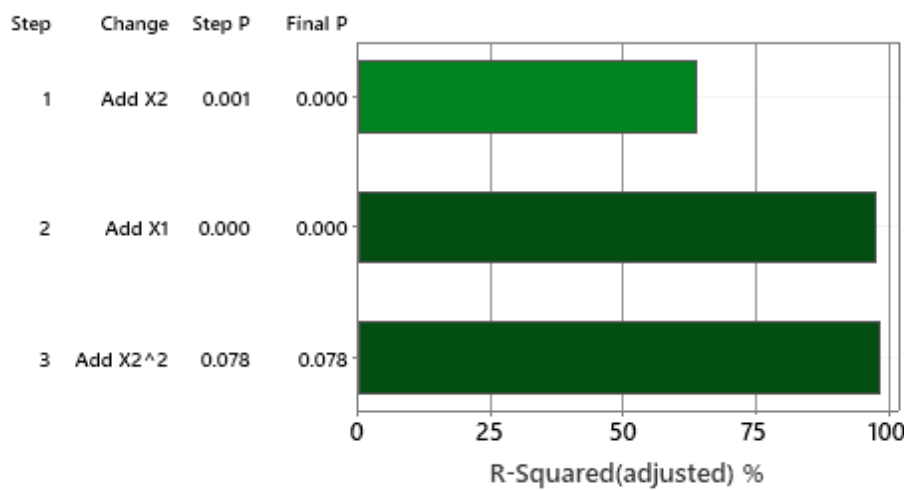## Multiple Regression for Heat Evolved
Model Building Report

X1: X1   X2: X2   X3: X3

Final Model Equation
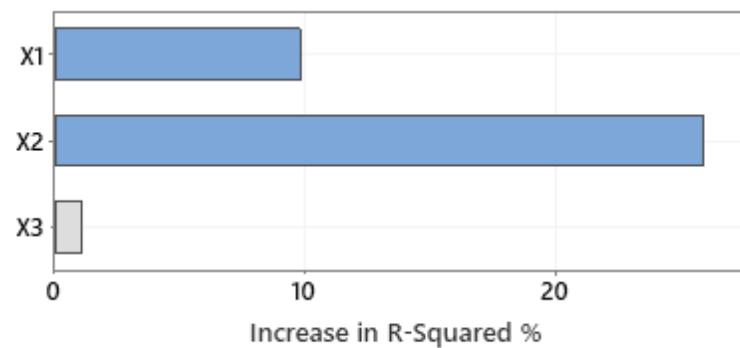$$\text{Heat Evolve} = 39.13 + 1.406\, X1 + 1.301\, X2 - 0.00662\, X2\wedge 2$$

Model Building Sequence
Displays the order in which terms were added or removed.

Step	Change	Step P	Final P
1	Add X2	0.001	0.000
2	Add X1	0.000	0.000
3	Add X2^2	0.078	0.078

R-Squared(adjusted) %

Incremental Impact of X Variables
Long bars represent Xs that contribute the most new information to the model.

X1
X2
X3

Increase in R-Squared %

Each X Regressed on All Other Terms
Gray bars represent Xs that do not help explain additional variation in Y.

X1
X2
X3

R-Squared %
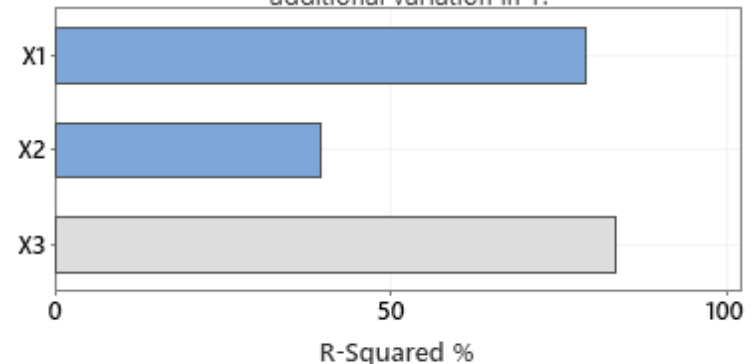
A gray bar represents an X variable not in the model.

Multiple regression can be used in banks to find out the factors which contribute most to the loan amount to be given to the customers like age, occupation, education, salary, credit rating etc.

Linear Regression is when all the variables are continuous and non-linear regression is when the Y(KPOV) is discrete and the X's are Continuous, you can use the Binary Logistic Regression option in Minitab under stat→Regression→Binary Logistic Regression, when the response variable is discrete.

Use Fit Binary Logistic Model to describe the relationship between a set of predictors and a binary response. A binary response has two outcomes; such as pass or fail. You can include interaction and polynomial terms, perform stepwise regression, fit different link functions, and validate the model with a test sample.

For example, marketers at a cereal company investigate the effectiveness of an ad campaign for a new cereal. The marketers can use binary logistic regression to determine whether people who saw the ad are more likely to buy the cereal.

After you perform the analysis, Minitab stores the model so that you can do the following:

- Predict the probability of an event for new or existing observations.
- Plot the relationships among the variables.
- Find values that optimize multiple responses.

Residual Analysis. Residuals are estimates of experimental **error** obtained by subtracting the observed response from the predicted response. ... Residuals can be thought of as elements of variation unexplained by the fitted model.

R-squared is a statistical measure of how close the data are to the fitted regression line. It is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression. ... 100% **indicates** that the model explains all the variability of the response data around its **mean**.

Variance inflation factor is a measure of the amount of **multicollinearity** in a set of multiple regression variables. ... **Variance inflation factor** measures how much the behavior (variance) of an independent variable is influenced, or inflated, by its interaction/correlation with the other independent variables.

Multicollinearity generally occurs when there are high correlations between two or more predictor variables. ... **Examples** of correlated predictor variables (also called multicollinear predictors) are: a person's height and weight, age and sales price of a car, or years of education and annual income.

Multicollinearity in regression is viewed as more of disadvantage, as it practically inflates unnecessarily the standard errors of coefficients in regression. Having studied Variance Inflation Factor (VIF) we know that a VIF of 5 and above is not good for regression model because it might render other significant variables redundant.

The **adjusted R-squared** is a modified version of **R-squared** that has been **adjusted** for the number of predictors in the model. The **adjusted R-squared** increases only if the new term improves the model more than would be expected by chance. It decreases when a predictor improves the model by less than expected by chance.

FMEA is one of the special tools used during analyse/improve phase to verify whether the experiment being planned will have its effect and what are the chances of failure. Failure mode effect analysis is a tool for facilitating the process of predicting failures, planning preventive measures, estimating the cost of failure, and planning redundant systems or system responses to failures. The primary objective is to identify ways in which the process input variables x can fail and determine what effect that has on process outputs.

Types of FMEA: -

Design FMEA and the process FMEA are the two most commonly used tools by Six Sigma teams. A design FMEA is called DFMEA, analyses the design for potential failures that could arise as a result of weakness in the design of the product rather than due to its processes or manufacture. If both FMEAs are used the design FMEA is usually done first before production begins. The Process FMEA called as PFMEA is used to identify the failures caused by weakness in processes such as transaction, assembly or production processes. During the process FMEA it is presumed that the product meets the intent of the design.

FMEA: What Is It?

FMEA is a tool that can help systematically organize, assess and prioritize failures based on their severity. Once failures are compiled and ranked, an FMEA can also help with developing a plan of action for addressing failures if they do occur and preventing them if possible.

There are a variety of FMEAs available; all of them focus on risk assessment, identification, quantification and mitigation of failures and issues. The two types organizations use the most are:

- **DFMEA:** Design Failure Modes and Effects Analysis, which looks at the issues with the product, including concept and design.
- **PFMEA:** Process Failure Modes and Effects Analysis, which focuses on the risks in the process rather than the product itself.

FMEA steps.

- FMEA is carried out on a new process, product or redesigned process, output.
- For each process step, list requirements for each process step.
- For each requirement, list the failure mode for each requirement.
- For each failure mode, list the effects of failure for each failure mode.
- For each effect of failure, estimate the severity.
- For each failure mode, list the causes.
- For each cause of failure, estimate the likelihood of occurrence.
- For each process control, estimate the detection.
- For each cause of failure, list the current process controls.
- For each process control, estimate the detection.
- For each cause of failure, calculate the Risk Priority Number by multiplying the scores associated with severity, occurrence, and detection.
- For high priority causes of failure and or failure modes, develop recommended actions.
- For each recommended action, assign responsibility and completion dates.
- For each recommended action, implement the action and note its effect.

For each implemented action, re-estimate the severity, occurrence, and detection rankings and recalculate the RPN.

Using COA and FMEA to Maintain High Quality Food Standards

Food manufacturers often have protocol in place to ensure that the ingredients they receive arrive with a Certificate of Analysis (COA). The supplier provides this certificate to the food manufacturer buying the ingredient to indicate it has passed their tests for quality and purity (including that an acceptably low level of pathogens were detected). Food manufacturers can just trust the COA from their suppliers and hope everything is exactly to their standards, or use an FMEA to validate the COA and have full confidence in their products.

Production processes can also expose food or beverages to pathogens or other food safety issues. This is where a PFMEA is the perfect tool to really study that process and find where the failure is occurring, but where you do begin?

Completing a Failure Mode and Effects Analysis

Minitab Workspace makes it easy to complete any FMEA, whether it's design or process focused. Once finished, it's a breeze to export and share any FMEAs you've created with the rest of your team and organization to keep everyone on the same page, get feedback and execute any changes needed.

A typical FMEA usually involves these steps:

- Identify potential failure types, or "modes," for each step of your process or design concept.
- List the effects that result when with those failures occur.
- Identify potential causes for each failure mode.
- Record existing controls that are in place to keep these failures from happening.
- Rate the Severity of the effect, the likelihood of Occurrence, and the odds of Detecting the failure mode before it causes harm.
- Multiply the values for severity, occurrence, and detection to get a risk priority number (RPN).
- Improve items with a high RPN, record the actions you've taken, then revise the RPN.

10. Predictive Analysis (CART Regression & CART Classification)
Overview:

Use CART® Regression to create a decision tree for a continuous response with many categorical or continuous predictors. CART® Regression illustrates important patterns and relationships between a continuous response and important predictors within highly complicated data, without using parametric methods.

CART® Regression provides insights for a wide range of applications, including manufacturing quality control, drug discovery, fraud detection, credit scoring, and churn prediction. Use the results to identify important variables, to identify groups in the data with desirable characteristics, and to predict response values for new observations. For example, a bank manager wants to identify potential customers that have higher response rates to specific initiatives.

CART® Regression is the only decision-tree methodology that uses the original code from world-renowned professors from Stanford University and University of California at Berkeley. While decision trees with various algorithms are popular tools, the CART® methodology of producing decision trees distinguishes itself through its features and performance. The CART® methodology remains proprietary and includes enhancements from decades of experience with practical applications.

A healthcare provider operates a facility that provides substance abuse treatment services. One of the services at the facility is an outpatient detoxification program where a regular course of treatment can last from 1 to 30 days. A team responsible for projecting staffing and supplies wants to study whether they can make better predictions about the length of time a patient uses services based on information that they can collect about the patient when the patient enters the program. These variables include demographic information and variables about the patient's substance abuse.

First, the team considers a traditional regression analysis in Minitab. Because of the missing value pattern in their data, the analysis omits over 70% of the data. The omission of such a large percentage of data implies that a lot of information is lost. The analytical results from the cases without any missing data can be very different from the results using the entire data set. Because CART® Regression automatically handles missing values in predictor variables, the team decides to use CART® Regression to further evaluate their data.

1. Open the sample data set **LengthOfService.MTW**.

2. Choose **Stat** > **Predictive Analytics** > **CART® Regression**.

3. In **Response**, enter *Length of Service*.

4. In **Continuous predictors**, enter *Age at Admission-Years of Education*.

5. In **Categorical predictors**, enter *Other Stimulant Use-DSM Diagnosis*.

6. Click **Validation**.

7. In **Validation method**, select **K-fold cross-validation**.

8. Select **Assign rows of each fold by ID column**.

9. In **ID column**, enter *Fold*.

10. Click **OK** in each dialog box.

Interpret the results

By default, Minitab displays the smallest tree that has an R^2 value within 1 standard error of the tree with the maximum R^2 value. Because the healthcare team uses k-fold validation, the criterion is the maximum k-fold R^2 value. This tree has 21 terminal nodes.

Before the researchers examine the tree, they examine the plot that shows the R^2 value from the cross-validation and the number of terminal nodes. This plot shows a pattern where the R^2 statistic increases rapidly for the first few nodes, then flattens out. Because this chart shows that the R^2 values are relatively stable between trees with about 20 nodes to trees with about 70 nodes, the researchers want to look at the performance of some of the even smaller trees that are similar to the tree in the results.
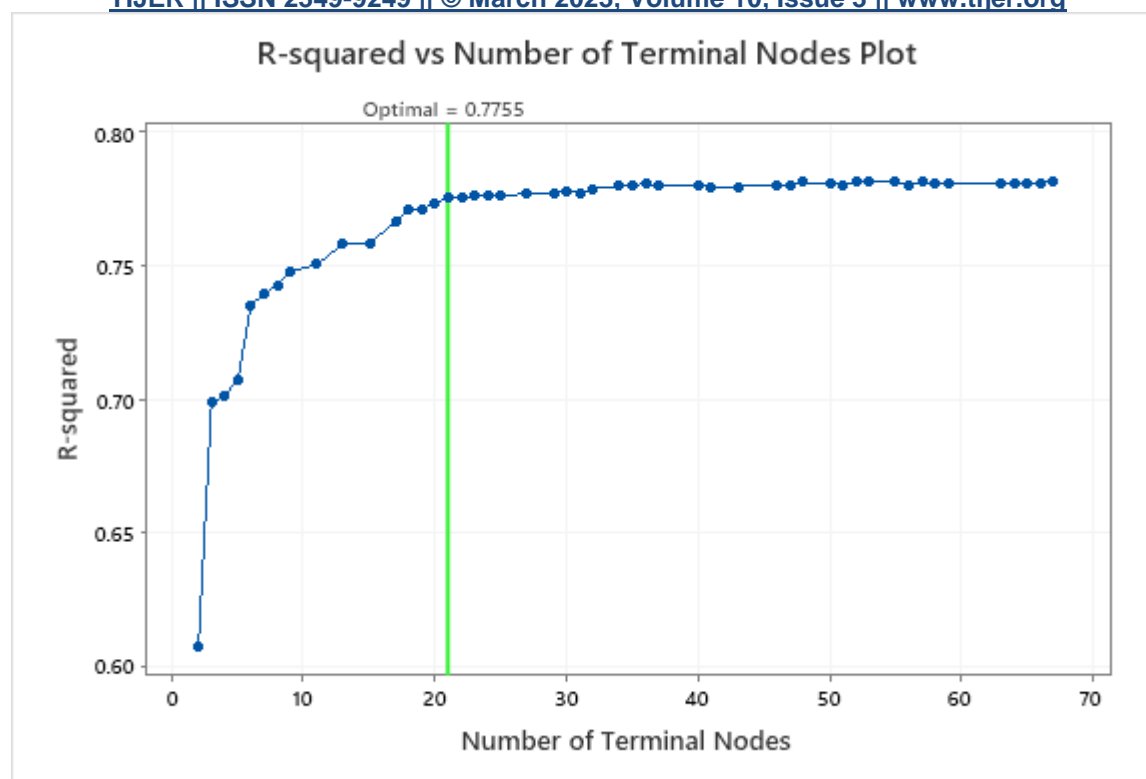
R-squared vs Number of Terminal Nodes Plot

Select an alternative tree

1.   In the output, click **Select an Alternative Tree**

2.   In the plot, select the 17-node tree.

3.   Click **Create Tree**.

Interpret the results

The researchers look at the plot of the R^2 statistic from the cross-validation and the number of terminal nodes. Because the tree with 17 nodes has an R^2 statistic close to the largest values on the plot, the results for the rest of the output are for the tree with 17 nodes.

R-squared vs Number of Terminal Nodes Plot
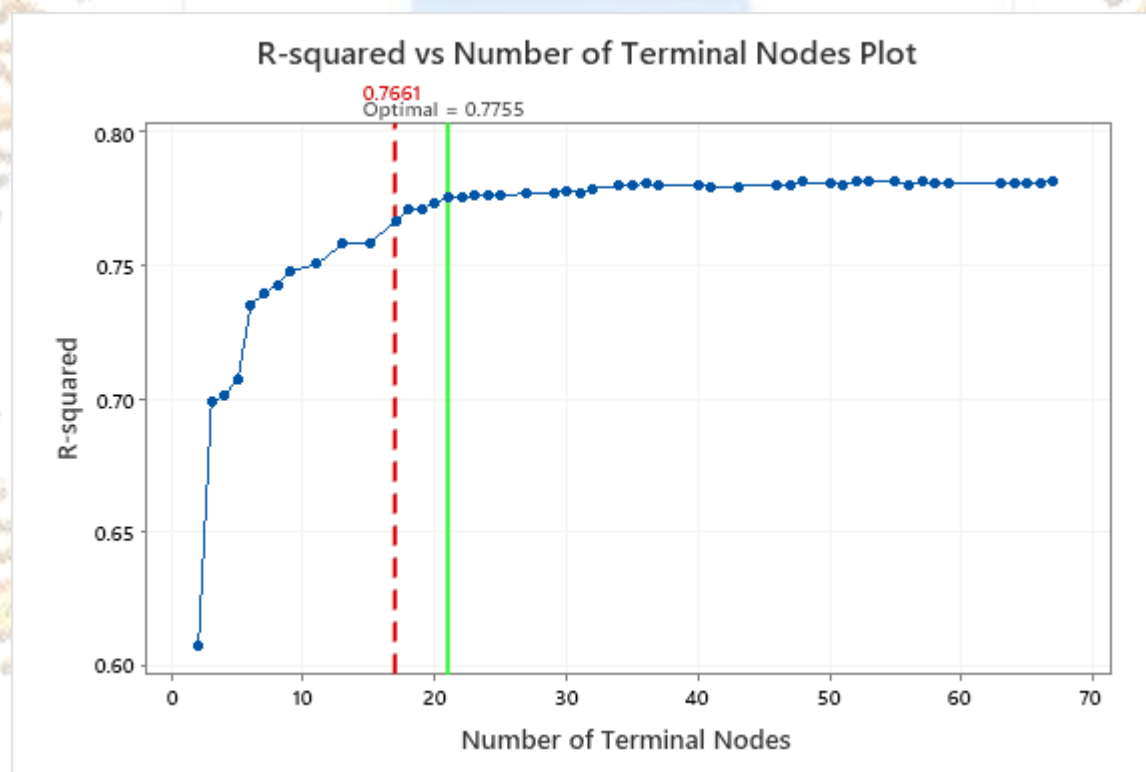
The researchers look first at the model summary to evaluate the performance of the smaller tree. The values for the training and test statistics are close together, so the tree does not seem overfit. The R^2 statistic is nearly as high as the 21-node tree, so the researchers decide to use the tree with 17 nodes to explore the relationships between the predictor variables and the response values.

17 Node CART® Regression: Length of Service versus Age at Admission, Age of First Drug Use, Arrests in Previous 30 Days, Days Waiting for Service, Previous Treatment Episodes, Years of Education, Other Stimulant Use, Planned Medication Therapy, Psychiatric Condition, Pregnant, Gender, Veteran, Alcohol Use, Cocaine Use, Marijuana Use, Heroin Use, Other Opioid Use, PCP Use, Methadone Use, Other Hallucinogen Use, Methamphetamine Use, Other Amphetamine Use, Benzodiazepine Use, Other Tranquilizer Use, Barbituate Use, Other Sedative Use, Inhalant Use, Non-Prescription Drug Use, Other Drug Use, Intravenous Drug Use, Living Arrangements, Frequency of Substance Abuse, Health Insurance, Marital Status, Ethnicity, Income Source, Primary Ingestion Route of Sub, Self-Help Attendance, Source of Payment, Race, Employment Status, Referral Source, Primary Substance of Abuse, DSM Diagnosis

Method

Node splitting   Least squared error

Optimal tree   Within 2.5 standard error of maximum R-squared

Model validation Cross-validation with rows defined by Fold

Rows used   4453

Response Information

Mean	StDev	Minimum	Q1	Median	Q3	Maximum
17.5960	9.29097	1	10	18	26	30

Model Summary

Total predictors	44
Important predictors	33
Number of terminal nodes	17
Minimum terminal node size	49

Statistics	Training	Test
R-squared	0.7799	0.7661
Root mean squared error (RMSE)	4.3585	4.4932
Mean squared error (MSE)	18.9967	20.1887
Mean absolute deviation (MAD)	3.4070	3.5226
Mean absolute percent error (MAPE)	0.6535	0.6674

The chart of the relative importance of the variables shows that the most important predictor variable is *Alcohol Use*. If the contribution of the top predictor variable, *Alcohol Use*, is 100%, then you can compare the other variables to *Alcohol Use* to determine their importance. Thus, you can focus on the most important predictors. The following list describes the next most important variables in this tree:

- *Primary Substance of Abuse* and *Planned Medication Therapy* are about 92% as important as *Alcohol Use*.

- *Heroin Use* is about 55% as important as *Alcohol Use*.

- *Primary Ingestion Route of Sub* and *Referral Source* are about 48% as important as *Alcohol Use*.

Although these results include 33 variables with positive importance, the relative rankings provide information about how many variables to control or monitor for a certain application. Steep drops in the relative importance values from one variable to the next variable can guide decisions about which variables to control or monitor. For example, in these data, the three most important variables have importance values that are relatively close together before a drop of almost 40% in relative importance to the next variable. Similarly, three variables have similar importance values near 50%. You can remove variables from different groups and redo the analysis to evaluate how variables in various groups affect the prediction accuracy values in the model summary table.

Variable importance measures model improvement when splits are made on a predictor.
Relative importance is defined as % improvement with respect to the top predictor.
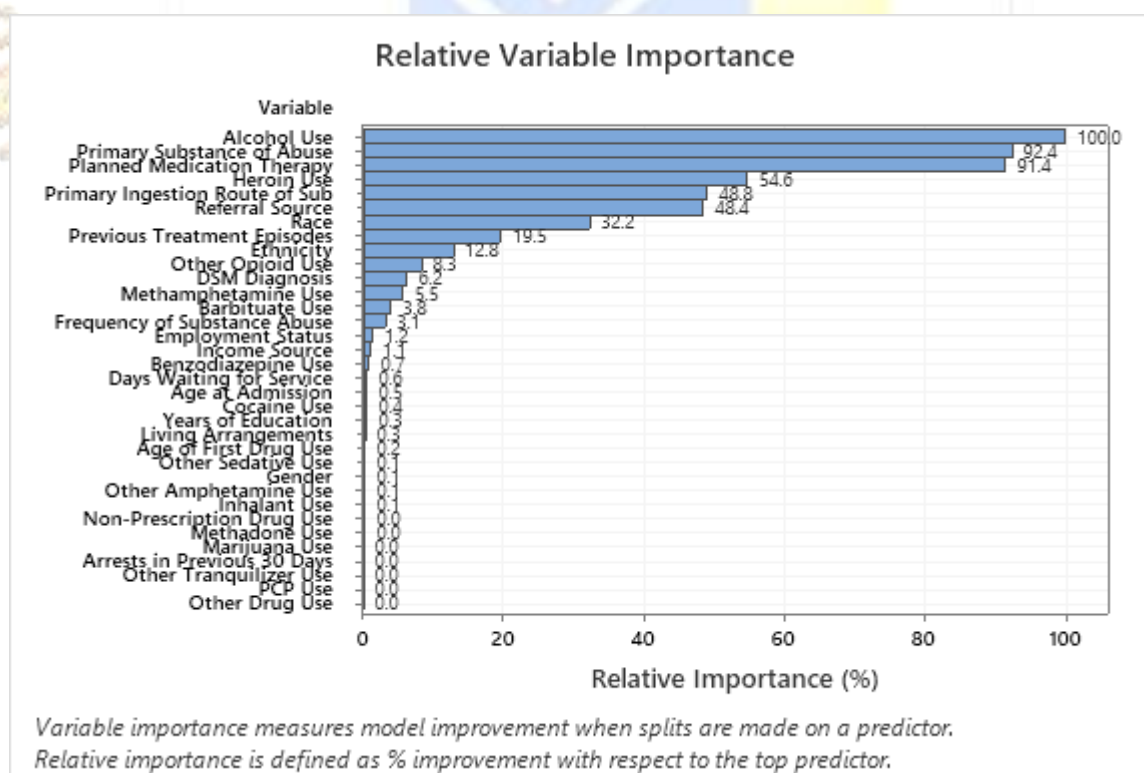
For an analysis with k-fold cross-validation, the tree diagram shows all 4453 cases from the full data set. You can toggle views of the tree between the detailed and node split view. The table of fits and error statistics and the criteria for classifying subjects give additional information about the terminal nodes.

The first node is split using the variable that records whether the patient had medication therapy.

- Node 2 includes the cases where *Planned Medication Therapy* = 1. This node has 1881 cases. The mean for the node is less than the overall mean. The standard deviation for Node 2 is about 5.4, which is less than the overall standard deviation because a split yields more pure nodes.

- Node 8 includes the cases where *Planned Medication Therapy* = 2. This node has 2572 cases. The mean for the node is more than the overall mean. The standard deviation for Node 8 is about 6.1, which is also less than the overall standard deviation.

Then, Node 2 splits by *Frequency of Substance Abuse* and Node 8 splits by the *Alcohol Use*. Terminal Node 17 has the cases for *Planned Medication Therapy* = 2, *Alcohol Use* = 1, and *Referral Source* = 3, 5, 6, 100, 300, 400, 600, 700, or 800. The researchers note that Terminal Node 17 has the highest mean, the smallest standard deviation, and the most cases.

Alternative Tree Diagram
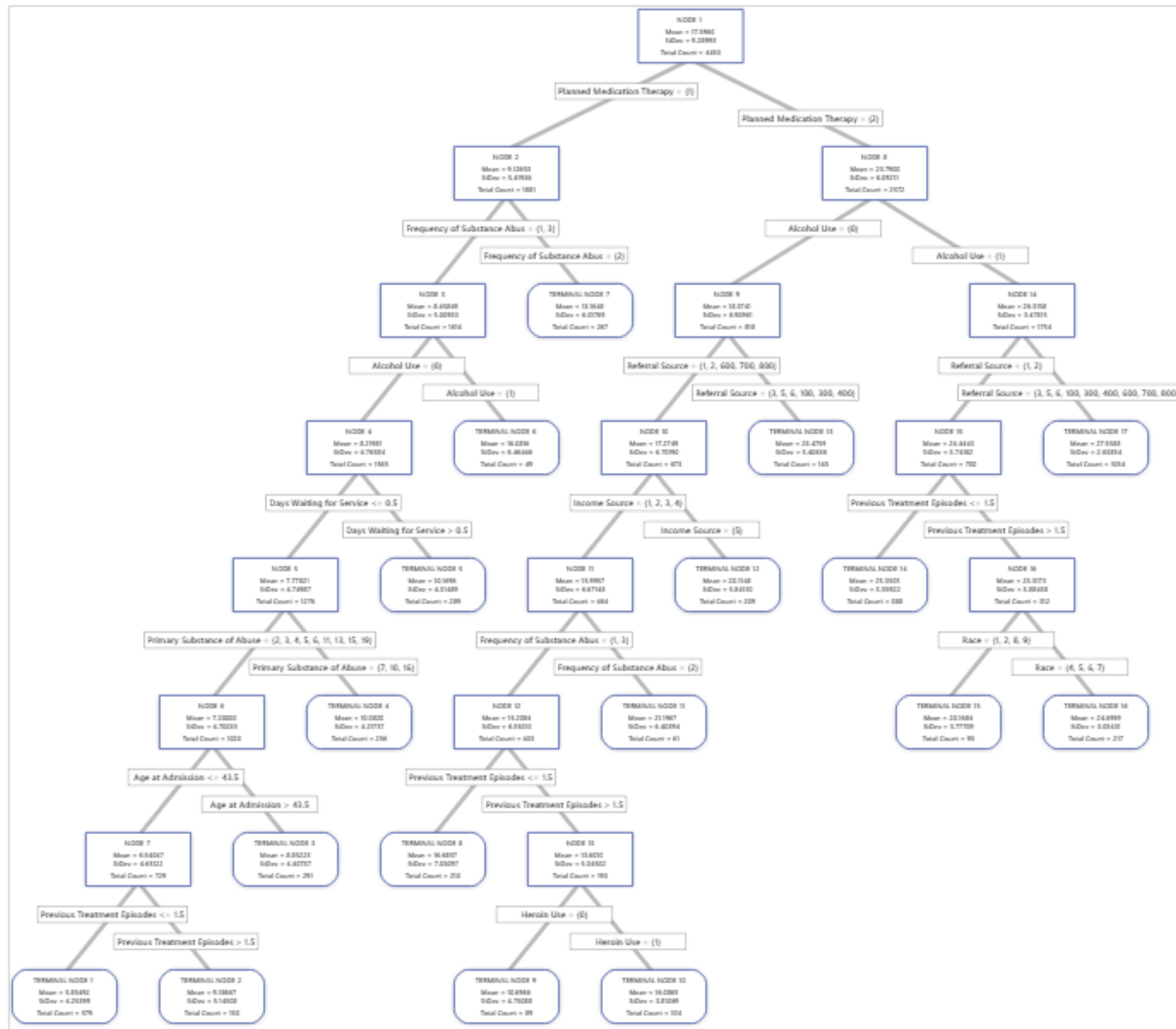
The results include a scatterplot of the fitted response values and the actual response values. The points for the training data set and the test data set show similar patterns. This similarity suggests that the performance of the tree on new data is close to the performance of the tree on the training data.
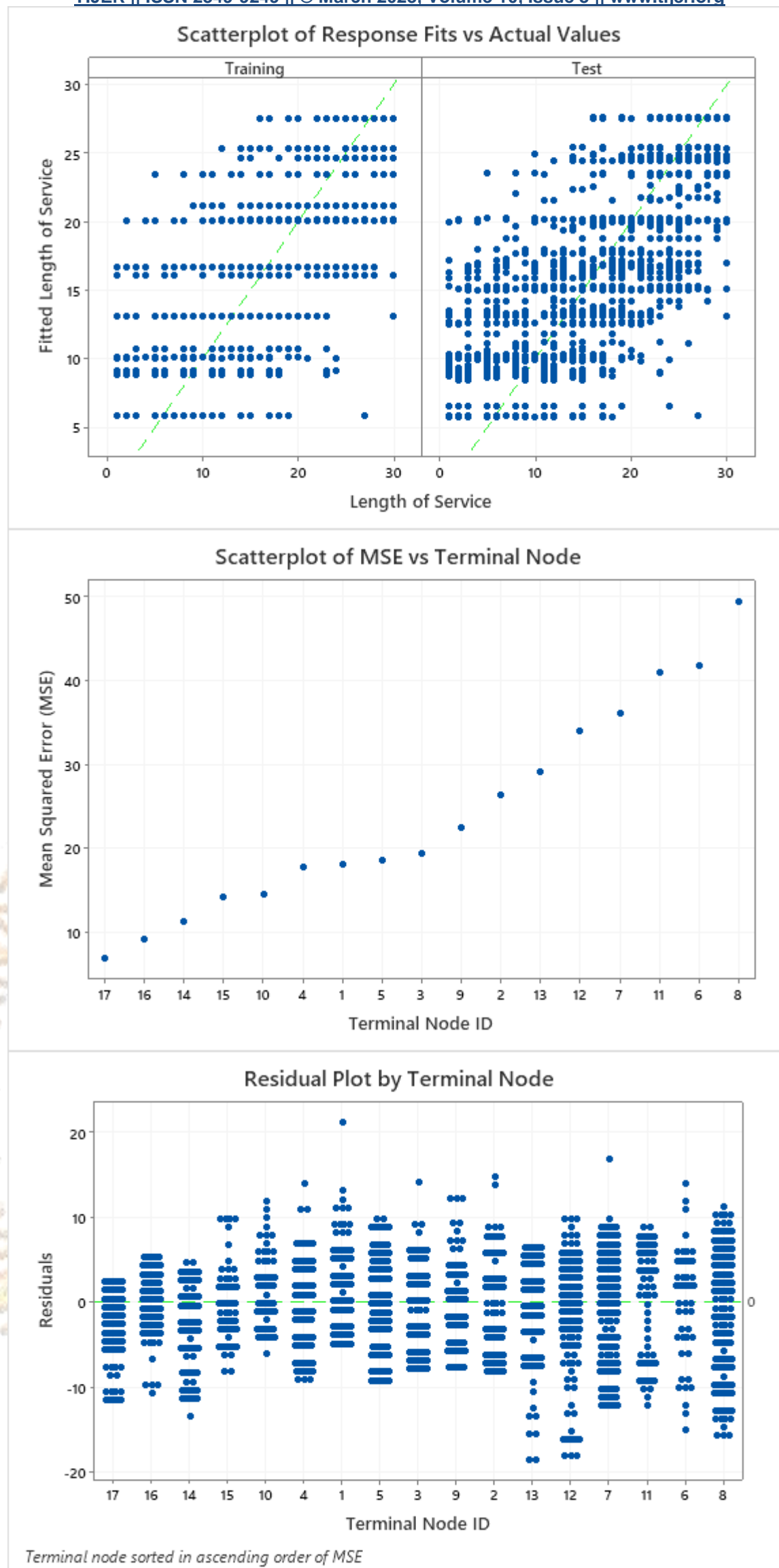
The plot of the MSE by terminal node shows that terminal node 8 is the least precise of the terminal nodes. You can have relatively more confidence in the accuracy of the fits for the nodes with lower MSE values. Patients in terminal node 8 have the following characteristics:

- *Planned Medication Therapy* = {2}

- *Alcohol Use* = {0}

- *Referral Source* = {1, 2, 600, 700, 800}

- *Income Source* = {1, 2, 3, 4}

- *Frequency of Substance Abuse* = {1, 3}

- *Previous Treatment Episodes* <= 1.5

The cases in terminal node 8 have the most opportunity to improve the tree if a way exists to reduce or explain the variation.

The plot of the residuals by terminal node shows that the fit is too large for a small cluster of the patients in Terminal Node 8. The analysts consider an investigation into why some of these patients use services for less time than a typical patient in their group. For example, if these patients are in a different geographic location from the other patients in the terminal node, then different government and insurance regulations could affect how long they use services.

The plot of the residuals by terminal node shows other cases where analysts can choose to investigate clusters or outliers. For example, in these data, there is one residual that appears much larger than the others in Terminal Node 1 and in Terminal Node 7. The analysts decide to investigate the reason that these patients used services for longer than other patients in their terminal node.

Scatterplot of Response Fits vs Actual Values

Scatterplot of MSE vs Terminal Node

Residual Plot by Terminal Node

Terminal node sorted in ascending order of MSE

CART Classification

Use CART® Classification to create a decision tree for a binomial or multinomial categorical response with many categorical or continuous predictors. The CART® Classification illustrates important patterns and relationships between a categorical response and important predictors within highly complicated data, without using parametric methods.

CART® Classification provides insights for a wide range of applications, including manufacturing quality control, drug discovery, fraud detection, credit scoring, and churn prediction. Use the results to identify important variables, to identify groups in the data with desirable characteristics, and to predict response values for new observations. For example, a market researcher can use CART® Classification to identify customers that have higher response rates to specific initiatives and to predict those response rates.

CART® Classification is the only decision-tree methodology that uses the original code from world-renowned professors from Stanford University and University of California at Berkeley. While decision trees with various algorithms are popular tools, the CART® methodology of producing decision trees distinguishes itself through its features and performance. The CART® methodology remains proprietary and includes enhancements from decades of experience with practical applications.

A team of researchers collects and publishes detailed information about factors that affect heart disease. Variables include age, sex, cholesterol levels, maximum heart rate, and more. This example is based on a public data set that gives detailed information about heart disease. The original data are from archive.ics.uci.edu.

The researchers want to create a classification tree that identifies important predictors to indicate whether a patient has heart disease.

1.   Open the sample data, **HeartDiseaseBinary.mtw**.

2.   Choose **Stat** > **Predictive Analytics** > **CART® Classification**.

3.   From the drop-down list, select **Binary response**.

4.   In **Response**, enter *Heart Disease*.

5.   In **Response event**, enter *Yes* to indicate that heart disease has been identified in the patient.

6.   In **Continuous predictors**, enter *Age*, *Rest Blood Pressure*, *Cholesterol*, *Max Heart Rate*, and *Old Peak*.

7.   In **Categorical predictors**, enter *Sex*, *Chest Pain Type*, *Fasting Blood Sugar*, *Rest ECG*, *Exercise Angina*, *Slope*, *Major Vessels*, and *Thal*.

8.   Click **OK**.

Interpret the results

By default, Minitab displays the smallest tree with a misclassification cost within 1 standard error of the tree that minimizes the misclassification cost. This tree has 4 terminal nodes.

Before the researchers examine the tree, they look at the plot that shows the misclassification cost from the cross-validation and the number of terminal nodes. In this plot, the pattern where the misclassification cost decreases continues after the 4-node tree. In a case like this, the analysts choose to explore some of the other simple trees that have lower misclassification costs.
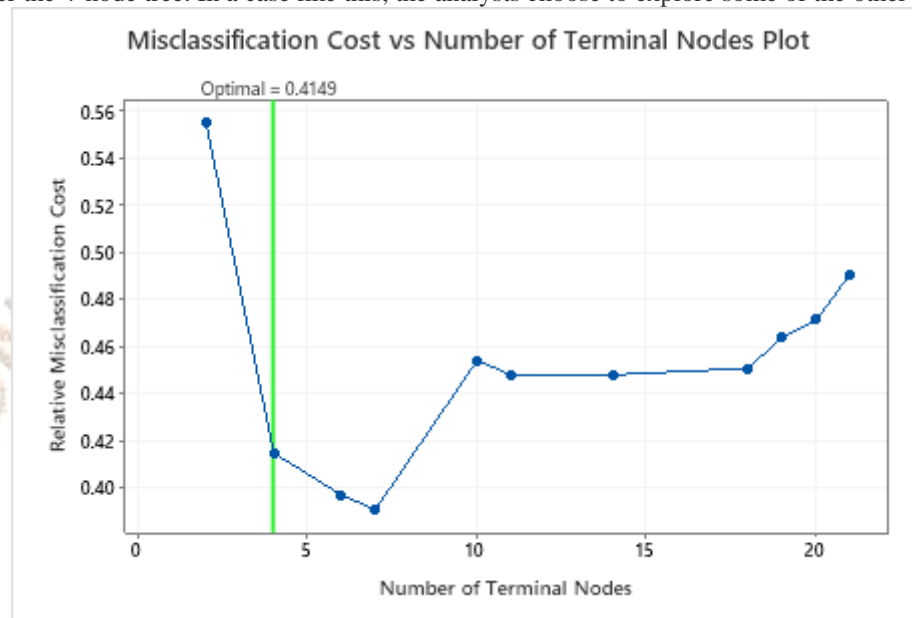
Select an alternative tree

1.   In the output, click **Select an Alternative Tree**

2.   In the plot, select the 7-node tree that has the least misclassification cost and the best ROC value.

3.   Click **Create Tree**.

Interpret the results

In the tree diagram, items that are blue are for the event level. Items that are red are for the nonevent level. In this output, the event level is "Yes" and indicates that someone has heart disease. The nonevent level is "No" and indicates that someone does not have heart disease.

At the root node, there are 139 counts of the Yes event and 164 counts of the No event. The root node is split using the variable, THAL. When THAL = Normal, go to the left node (Node 2). When THAL = Fixed or Reversible, go to the right node (Node 5).

•   Node 2: There are 167 cases when THAL was Normal. Of the 167 cases, 38 or 22.8% are Yes and 129 or 77.2% are No.

•   Node 5: There are 136 cases when THAL was Fixed or Reversible. Of the 136 cases, 101 or 74.3% are Yes and 35 or 25.7% are No.

The next splitter for both the left child node and the right child node is Chest Pain Type, where pain is rated as 1, 2, 3, or 4.

Explore other nodes to see which variables are most interesting. The nodes that are mostly blue indicate a strong proportion of the event level. The nodes that are mostly red indicate a strong proportion of the nonevent level.
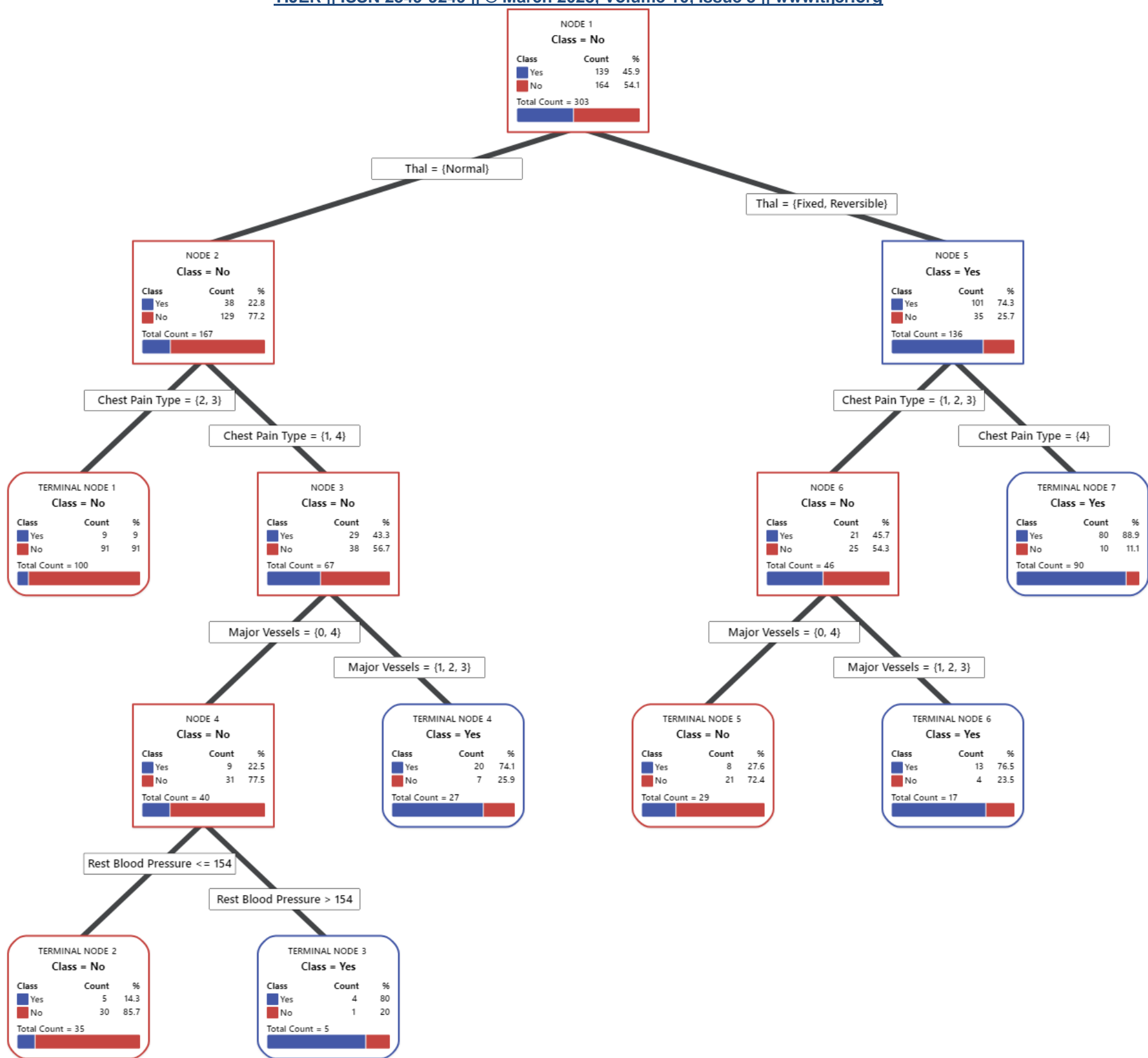
The tree diagram uses the entire data set or the training data set. You can toggle views of the tree between the detailed view and the node split view.
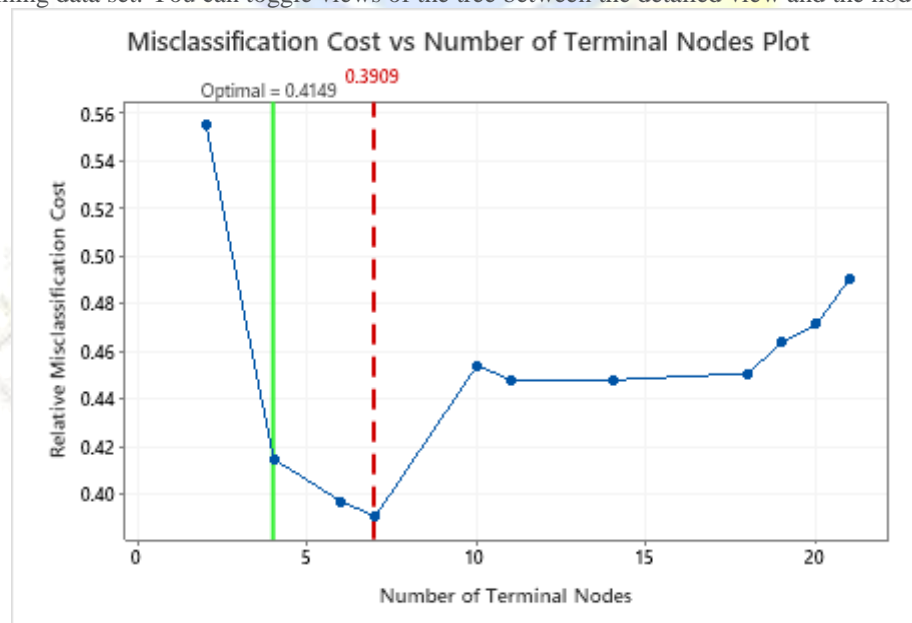
This tree has a misclassification cost of about 0.391.
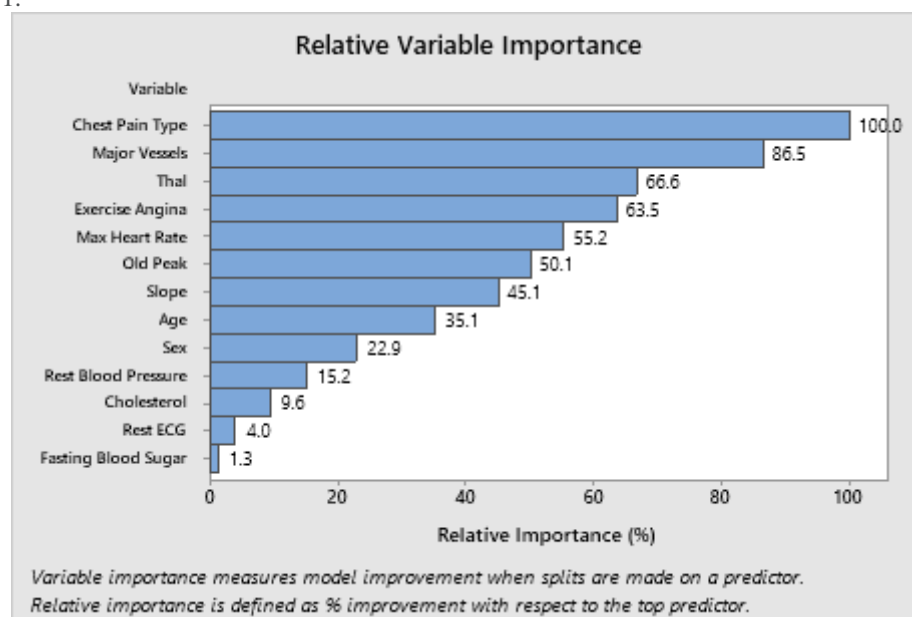
The most important predictor variable is Chest Pain Type. If the contribution of the top predictor variable, Chest Pain Type, is 100%, then the next important variable, Major Vessels, has a contribution of 86.5%. This means Major Vessels is 86.5% as important as Chest Pain Type in this classification tree.

Receiver Operating Characteristic (ROC) Curve

Area Under Curve: Training = 0.8861, Test = 0.8200
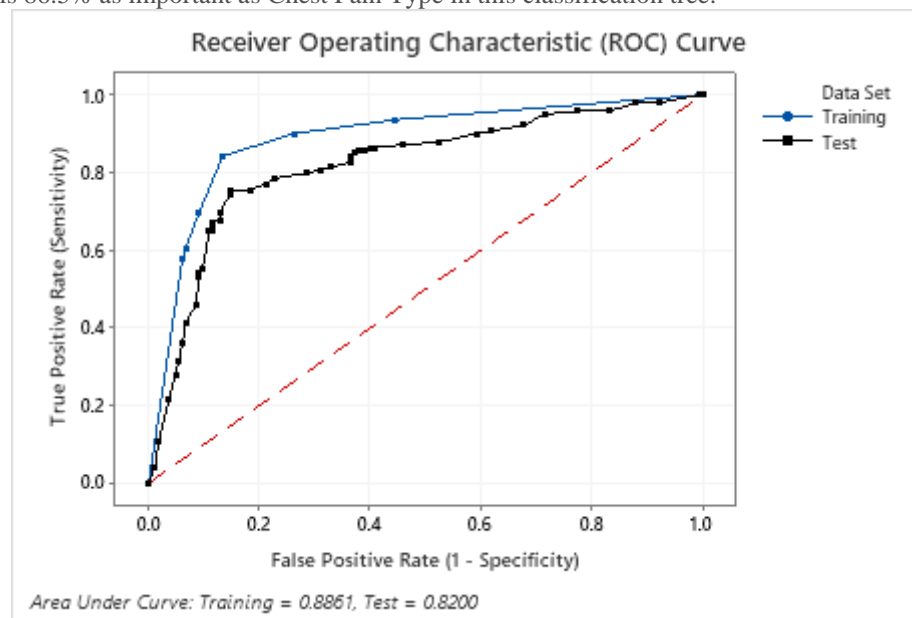
The area under the ROC curve for the test data is 0.8200, which indicates reasonable classification performance, in most applications.

7 Node Classification Tree: Heart Disease versus Age, Rest Blood Pressure, Cholesterol, Max Heart Rate, Old Peak, Sex, Fasting Blood Sugar, Exercise Angina, Rest ECG, Slope, Thal, Chest Pain Type, Major Vessels

Optimal Tree: 7 terminal nodes, 6 internal nodes

Max Tree: 21 terminal nodes, 20 internal nodes

* NOTE * 20 is larger than the 7 additional pruned trees identified. Storing

     information for 7 trees only.

Method

Prior probabilities Same for all classes

Node splitting   Gini

Optimal tree   Minimum misclassification cost

Model validation   10-fold cross-validation

Rows used   303

Binary Response Information

Variable	Class	Count	%
Heart Disease	Yes (Event)	139	45.9
	No	164	54.1
	All	303	100.0

Model Summary

Total predictors	13
Important predictors	13
Number of terminal nodes	7
Minimum terminal node size	5

Statistics	Training	Test
Deviance R-Squared	0.4243	0.2614
Average -LogLikelihood	0.3971	0.5094
Area under ROC curve	0.8861	0.8200

95% CI   (0.5590, 1) (0.7702, 0.8697)

Lift   1.9376   1.8165

Misclassification cost   0.2924   0.3909

Confusion Matrix

              Predicted Class

              (Training)   Predicted Class (Test)

Actual Class	Count	Yes	No	%Correct	Yes	No	%Correct
Yes (Event)	139	117	22	84.2	105	34	75.5
No	164	22	142	86.6	24	140	85.4
All	303	139	164	85.5	129	174	80.9

Statistics	Training (%)	Test (%)
True positive rate (sensitivity or power)	84.2	75.5
False positive rate (type I error)	13.4	14.6
False negative rate (type II error)	15.8	24.5
True negative rate (specificity)	86.6	85.4

Misclassification

Input

Misclassification   Predicted

Cost   Class

Actual Class	Yes	No
Yes	1.00	
No		1.00

              Training   Test

Actual Class	Count	Misclassed	% Error	Cost	Misclassed	% Error	Cost
Yes (Event)	139	22	15.8	0.1583	34	24.5	0.2446
No	164	22	13.4	0.1341	24	14.6	0.1463
All	303	44	14.5	0.1462	58	19.1	0.1955

11.RELIABILITY ANALYSIS:

In Minitab go to Stat→ Reliability/Survival → Distribution Analysis→Parametric Distribution Analysis or Non parametric Distribution Analysis

What is censored data?

In reliability analysis, failure data frequently contain individual times to failure. For example, you might collect times to failure for units operating at a particular temperature. You might also collect samples of times to failure under different temperatures, or under different combinations of stress variables.

Sometimes you record exact times to failure. Other times, the exact times to failure of some test units are unknown. In this case, the data are called censored. Failure data are often censored in some way. Therefore, you may have any of the following types of observations:

- Exact times to failure
- Right-censored data
- Interval-censored data
- Left-censored data

Exact failure time data

The exact time that each item failed is known. For example, an engineer tests electric fans and records the exact time to failure of each fan.

Right-censored data

Failures are seen only if they occur before a particular time. A unit surviving longer than that time is considered a right-censored observation. Right-censored data are sometimes time-censored or failure-censored. Time censoring means that you perform the study for a specified period of time. All units still operating at the end of the study are time-censored. Time censoring is also known as Type I censoring on the right. Failure censoring means that you conduct the study until you observe a specified number of failures. Failure censoring is also known as Type II censoring on the right.

For example, suppose that an engineer tests five fan belts. Three fan belts fail in 67 hours, 76 hours, and 104 hours. The remaining two fan belts are still operating when the engineer stops the test at 110 hours. These last two fan belts are right-censored at 110 hours.

Right-censored data can be:

Singly-censored

All the test units operate for the same amount of time. Units surviving at the end of the study are considered censored data. Failed units are considered exact failures. Singly-censored data are more common in controlled studies.

Suppose you collect failure data until 12 units fail:

Item	Unit	Failure Time
1	Failed	18.5
2	Failed	20.5
3	Failed	22.0
4	Failed	23.5
5	Failed	24.3
6	Failed	25.0
7	Failed	25.6
8	Failed	26.3
9	Failed	27.0
10	Failed	29.0
11	Failed	32.0
12	Failed	33.0
13	Censored	33.0
14	Censored	33.0
15	Censored	33.0

Minitab interprets this data set as single censoring because the failure times of the censored items (units 13 - 15) are the same as the failure time of the 12th unit.

11.IMPROVE PHASE

We have reached the fourth phase of DMAIC that is Improve. Improve phase focuses on identifying and implementing solutions to fix the root causes identified in the Analyse phase. The Improve phase consists of generating solutions, selecting solutions, describing solutions with lean approach, refining or making solutions risk proof, testing solutions, and justifying solutions.

Four Key Phases of the Innovation Cycle

(1) Define and Scope Innovation Opportunity
(2) Uncover or Discover New Ideas
(3) Develop Design Concepts to Experiment
(4) Demonstrate the Innovation Through Prototype

The first phase defines and scopes innovation opportunity from a customer's perspective. It is about documenting the business case for an innovation opportunity. This activity is also known as feasibility study.

The second phase relates to discovering new ideas. The target here has to be focused on exploring as many ideas as possible to solve the problem under consideration. According to the innovation-specific problem under consideration, the problem-solving techniques, such as Theory of Inventive Problem-Solving, that is TRIZ, can be considered for developing innovative solutions.

The third phase focuses on developing design concepts to experiment. This phase aims at building on the core set of ideas identified in the previous phase. The ideas here are transformed into functional concepts for developing the solution design.

The fourth phase is all about demonstrating the innovation through prototype. At this juncture, the prototype design is converted into a working prototype.

The first event of Improve involves generating solutions. Now, let's learn about TRIZ or Theory of Inventive Problem Solving approach which develops innovative solutions for problems. TRIZ is a Russian acronym for Theory of Inventive Problem Solving which was developed by Genrich S. Altshuller, a scientist and engineer, in the 1940s, to develop new "inventive" ideas by considering possible solutions from other disciplines and minimizing trial-and-error. Altshuller screened thousands of patents looking for inventive problems and how they were solved. Only 40,000 had inventive solutions; the rest were straightforward improvements. He categorized these patents by identifying the problem-solving process that had been used repeatedly. He discovered that the problems had been solved using one of the forty Inventive Principles.

TRIZ is a structured approach or an algorithm used to generate plausible concepts rapidly that solve technical problems. It provides the first understanding of the trends and patterns of evolution for technical systems. It captures patterns of creativity without addressing the creativity process itself.

TRIZ applies inventive principles to problem to develop innovative solutions. The inventive principles are rules for system transformations. Each principle is intended to eliminate a single contradiction or several contradictions. Also, these principles can be used simply to simulate, or initiate, the thought process to create the ideal solution to a problem. They can be used for inspiration in conceptual design, directly utilized in the case-based design, or used in various forms of analogical reasoning.

In the process of reviewing thousands of patents, Genrikh Altshuller distinguished between incremental and breakthrough inventions. The breakthrough inventions were used to develop 40 inventive principles. These principles of TRIZ solve contradictions or problems without compromising quality.

In many projects when data is analysed using the six sigma tools there are good chances that a solution will emerge in the analyse phase itself. This Solution may pertain to anything from say finding a new supplier, change of a process parameter, modification in a layout or to provide a new software application, a new poka-yoke gadget; however, if the solution is known implementing the process to get the desired result requires a great deal of effort. Take for instance the change in the measuring equipment; it may take a few weeks or even a month or two to procure or develop a new system. Similarly, if we want to switch to a new supplier, it may involve negotiation, capacity creation etc. in Some Projects we may not be lucky enough to arrive at the final solution at this stage. In this case we need to use some more tools such as the design of experiments (DOE).

The customer satisfaction index (CSI) is used to measure how pleased customers are about the services that they receive from the bank. The Quality engineer at the bank wants to know what factors have been causing the index to decrease recently to an unprecedented level. He isolated four factors as being potentially significant.

- Customers being kept on hold over the phone for too long.
- Long lines at the bank.
- Too much paper work.
- High Interest rates on short term loans

The quality engineer knows that some of these factors or their interactions have been detrimental to the CSI but he does not know which ones are. The experiment that can help him determine the significant factors is expensive and time consuming it involves changes in the interest rates offered by the bank, changes in the volume of paperwork, the opening of special fast lines at the cashiers and the hiring of new customer service personnel to speed up calls.

To limit the cost involved in the experiment, the engineer chooses to use DOE.

The Cpk index measures how capable a process is at meeting or exceeding customers' expectations; lately he computed Cpk has proved to be unacceptably low. The operations manager has isolated the four factors could contribute to poor performance.

- Raw material from different suppliers
- Machine operator
- Temperature in storage after processing
- Temperature in the trailers that transport the finished product to customers.

He wants to test these factors to determine which one of them or what combination is contributing to the lowering of the Cpk.He wants to isolate the significant factors to take corrective action. He chooses DOE to limit the cost involved in the testing.

Treatments :- For Example a level of temp at 65 degrees and level of time at 45 mts describes a treatment as it is related to the output of the yield.
Block :- A block is usually used when uncontrollable factors cannot be avoided during the DOE.
An Illustration of DOE:-

To Understand DOE let us begin with a simple example of Cooking rice. Consider the time taken to cook rice called response Y, is to be minimised. Time Y may depend on many factors such as the method of heating , the type of utensil used , the altitude of the location, the atmospheric temperature and humidity, the amount of water used , quality of rice grains etc. These are called factors and are usually denoted by X1,X2,.......Xn. some of these factors can be controlled during the experiment whereas others such as atmospheric temperature, altitude etc our beyond our control; therefore these factors are called as uncontrollable factors. X's are denoted as KPIV's and Y's are denoted as KPOV's . X's are classified as controllable and uncontrollable and are coded as C and U respectively. Uncontrollable factors are sometimes called as noise factors or common cause of variation.

	KPIV's (X's)	C/U	Process	KPOV's (Y's)	
X1	Cooking Method	C	Rice Cooking	Cooking time	Y1
X2	Heating Method	C			
X3	Amount of Water	C			
X4	Atmospheric Temperature	U			
X5	Atomospheric Humidity	U			
X6	Altitude	U			

We select open utensil as low level and pressure cooker as high level ; thus there are 2 factors and each factor has 2 level ; Experiments are denoted as L^F where L is the number of Levels and F is the number of Factors; therefore the experiment is 2 ^2 experiment totally the possible number of Combinations of factors and levels is four when all possible combinations are run the experiment is called as full factorial experiment.

DOE (Design of Experiments)

Design of experiments (DOE) is a key tool in the Six Sigma methodology. DOEs help improve processes in a quantum fashion, and is an approach for effectively and efficiently exploring the cause and effect relationship between numerous process variables (*X*s) and the output or process performance variable (*Y*).
DOE helps in the following ways:

• **The DOE helps in identifying the vital few sources of variation.**

• **DOEs quantify the effects of the important *X*s including their interactions.**

• **Performing DOE produces an equation that quantifies the relationship between the process *X*s and the process output *Y*, thus enabling the transition to the *Y=f(x)* philosophy of Six Sigma.**

There are many types of DOEs which can be applied to a particular problem based on various planning factors and the outcome desired at the end of the analysis. This article will try and explain the analysis strategy that a Black Belt can undertake for Resolution III and IV Design of Experiments.

Though a full factorial design is the most desirable design wherein one could gather information on all the main effects, two way interactions, three way interactions and other higher order interactions are very unpractical to run due to the prohibitive size of the experiments. For a design of seven factors at two levels one would have to complete 128 runs.

Fractional factorial designs are good alternatives to a full factorial design, especially in the initial screening stage of a project. The same seven factors could be tested in either 8 runs or 16 runs or 32 runs with the loss of certain information.

Let us consider the example of an experimenter who is trying to optimize the production of organic foods. After screening to determine the factors that are significant for his experiment he narrows the main factors that affect the production of fruits to "light" and "water". He wants to optimize the time that it takes to produce the fruits. He defines optimum as the minimum time necessary to yield comestible fruits.

To conduct his experiment he runs several tests combining the two factors (water and light) at different levels. To minimize the cost of experiments he decides to use only 2 levels of the factors: high and low. In this case we will have two factors and two levels therefore the number of runs will be $2^2=4$. After conducting observations he obtains the results tabulated in the table below.

Factors	Response
Water –High Light High	10 days
Water high – Light low	20 days
Water low – Light high	15 days
Water low – Light low	25 days

The coded form of the table above is given below:

Water	Light	Response in Days
+	+	10
+	-	20
-	+	15
-	-	25

The reading we make of the tables is that when the level of light is high and the level of water is high, it takes the fruits 10 days of time to become comestible and when the level of water is low and the level of light is low it takes 25 days for the fruit to become comestible. So the factors water and light has a significant effect on the response variable which is days in this experiment. You can also illustrate this experiment using Minitab 17.

Design of Experiments using Factorial Method

How to Plan a Six Sigma 2^k Factorial Experiment?

Like in most other endeavours, time spent planning for Six Sigma is rewarded with better results in a shorter period of time. Planning 2^k factorial experiments follows a simple pattern: choosing the factors you want to experiment with, establishing the high and low levels for those factors, and creating the coded design matrix.

Select the experiment factors

The first thing to do is identify the input variables, the *X*s that you'll include in your experimental investigation. The factors you include should be potential contributors to the output *Y* you're investigating and should be ones that are critical. How many factors you want in your experiment guides you in choosing the right experimental design. 2^k factorial experiments work best when you have between two and five *X*s.

If you have over five *X*s in your experiment, full 2^k factorial experiments become relatively inefficient and can be replaced with pared down versions called *fractional factorials,* or with other screening designs. One good strategy is to include all potential *X*s in a first screening experiment — even the ones you're sceptical about.

You then use the analysis of the experiment results to tell you objectively, without any guessing, which variables to keep pursuing and which ones to set aside. Remember, in Six Sigma, you let the data do the talking.

Plackett-Burman experiment designs are an advanced method you may hear about for efficiently screening dozens of potential *X*s. Although they don't reveal all the detailed knowledge provided by a 2^k factorial design, Plackett-Burman experiments quickly identify which experimental variables are *active* in your system or process. You then follow these screening studies up with more detailed characterization experiments.

Set the factor levels

2^k factorial experiments all have one thing in common: They use only two levels for each input factor. For each *X* in your experiment, you select a high and a low value that bound the scope of your investigation.

For example, suppose you're working to improve an ice cream carton filling process. Each filled half-gallon carton needs to weigh between 1,235 and 1,290 grams. Your Six Sigma work up to this point has identified ice cream flavour, the time setting on the filling machine, and the pressure setting on the filling machine as possible critical *X*s to the *Y* output of weight.

For each of these three factors, you need to select a high and a low value for your experiment. With only two values for each factor, you want to select high and low values that bracket the expected operating range for each variable. For the ice cream flavour variable, for example, you may select vanilla and strawberry to book-end the range of possible ice cream consistencies.

Variable	Symbol	Low Setting	High Setting
Ice cream flavour	X_1	Vanilla	Strawberry
Fill time (seconds)	X_2	0.5	1.1
Pressure (psi)	X_3	120	140

2^k experiments are intended to provide knowledge only *within* the bounds of your chosen variable settings. Be careful not to put too much credence on information inferred outside these original boundaries.

Explore experimental codes and the design matrix

With the experiment variables selected and their low and high levels set, you're ready to outline the plan for the runs of your experiment. For 2^k factorial experiments, you have 2^k number of unique runs, where k is the number of variables included in your experiment.

For the ice cream carton filler example, then, you have $2^3 = 2 \times 2 \times 2 = 8$ runs in the experiment because you have three input variables. For an experiment with two variables, you have $2^2 = 2 \times 2 = 4$ runs, and so on.

Each of these 2^k experimental runs corresponds to a unique combination of the variable settings. In a full 2^k factorial experiment, you conduct a run or cycle of your experiment at each of these unique combinations of factor settings. In a two-factor, two-level experiment, the four unique setting combinations are with

- Both factors at their low setting

- The first factor at its high setting and the second factor at its low setting

- The first factor at its low setting and the second factor at its high setting

- Both factors at their high setting

These groupings are the only ways that these two factors can combine. For a three-factor experiment, eight such unique variable setting combinations exist.

A quick way to create a complete table of an experiment's run combinations is to create a table called the *coded design matrix*. Make a column for each of the experiment variables and a row for each of the 2^k runs. Using –1s as code for the low variable settings and +1s as code for the high settings, fill in the left-most variable column cells with alternating –1s and +1s.

Repeat the process with the next column to the right, this time with alternating *pairs* of –1s and +1s. Fill in the next column to the right with alternating *quadruplets* of –1s and +1s, and so on, repeating this process from left to right until, in the right-most column, you have the first half of the runs marked as –1s and the bottom half listed as +1s.

Run	X_1	X_2	X_3
1	–1	–1	–1
2	+1	–1	–1
3	–1	+1	–1
4	+1	+1	–1
5	–1	–1	+1
6	+1	–1	+1
7	–1	+1	+1
8	+1	+1	+1

Remember that these three factors are coded values; when you see a –1 under the X_1 column, it really represents a discrete value, such as "vanilla" in the ice cream experiment; a +1 really represents the other value, like "strawberry."

Example DOE :- A materials engineer at a plastic manufacturing company wants to increase the tensile strength of a plastic product. The engineer identifies several factors to evaluate as possible contributors to tensile strength, including processing temperature, additive, agitation rate, and processing time. Because the temperature of the processing oven is difficult to change, the engineer designs a split-plot full factorial experiment so that the temperature is held constant while the other factors vary for each temperature setting.

You can use this data to demonstrate **Analyze Factorial Design** for a split-plot design.

Worksheet column	Description
StdOrder	The order of the runs in standard order (also called Yates order).
RunOrder	The order of the runs in random order.
PtType	The point type. This design has only corner points (1).

Worksheet column	Description
Blocks	The blocks. In this design, all the design points are contained in a single block.
WP	The whole plot indicator: 1, 2, 3, or 4.
Temp[HTC]	The temperature: -1 or 1 (hard-to-change factor).
Add	The additive percent: -1 or 1 (factor).
Rate	The agitation rate: -1 or 1 (factor).
Time	The processing time: -1 or 1 (factor).
Strength	The strength of the plastic (response).

Example of Design of Experiments in Minitab :- Go to Stat→DOE→Factorial→Create Factorial and after click on the option Analyse Factorial Design. In the response column enter strength. The Factors or X's are Temp, Additive, Rate, Time. Design of experiments finds out which factors and its combinations are the ones which improve the tensile strength of plastic. From the Pareto graph given below we can find that AC (Combination of Temp and Rate) improve the tensile strength of plastic, so also D(Time) and AD (Temp & Time) as the horizontal blue bar crosses the dotted red line; all the other factors and their combinations do not at all increase the tensile strength of plastic so they are of no use.

Design of Experiments has vast use in the pharmaceutical industry as we can find out which chemical and their combinations helps the tablet or capsule dissolve in the blood faster or which combination of chemicals can reduce the acidity in the stomach faster.
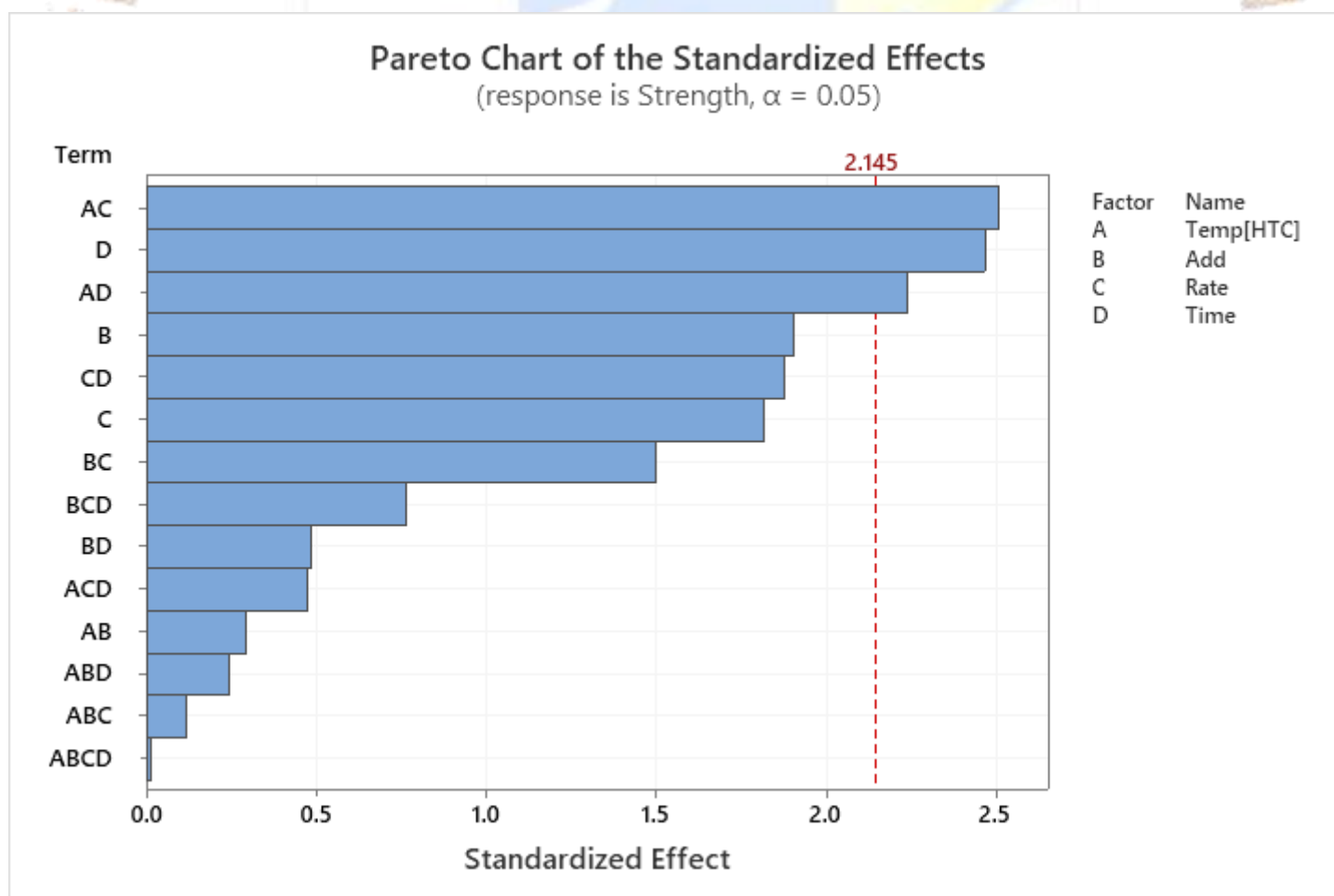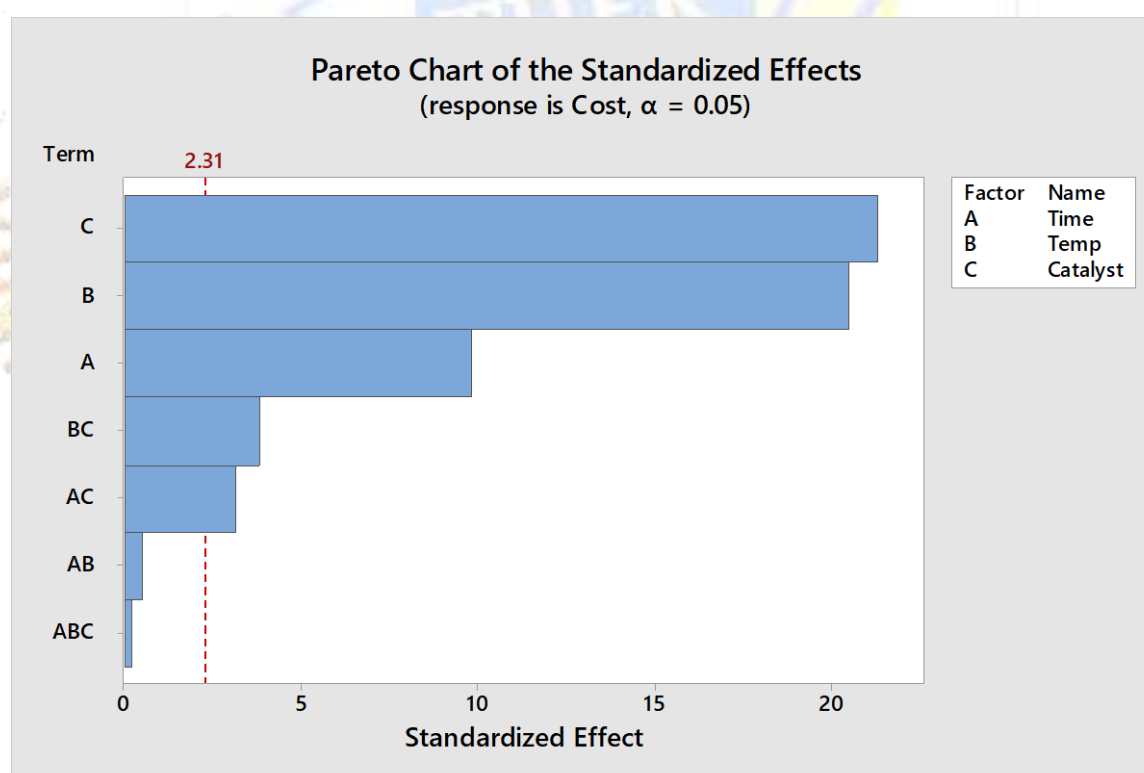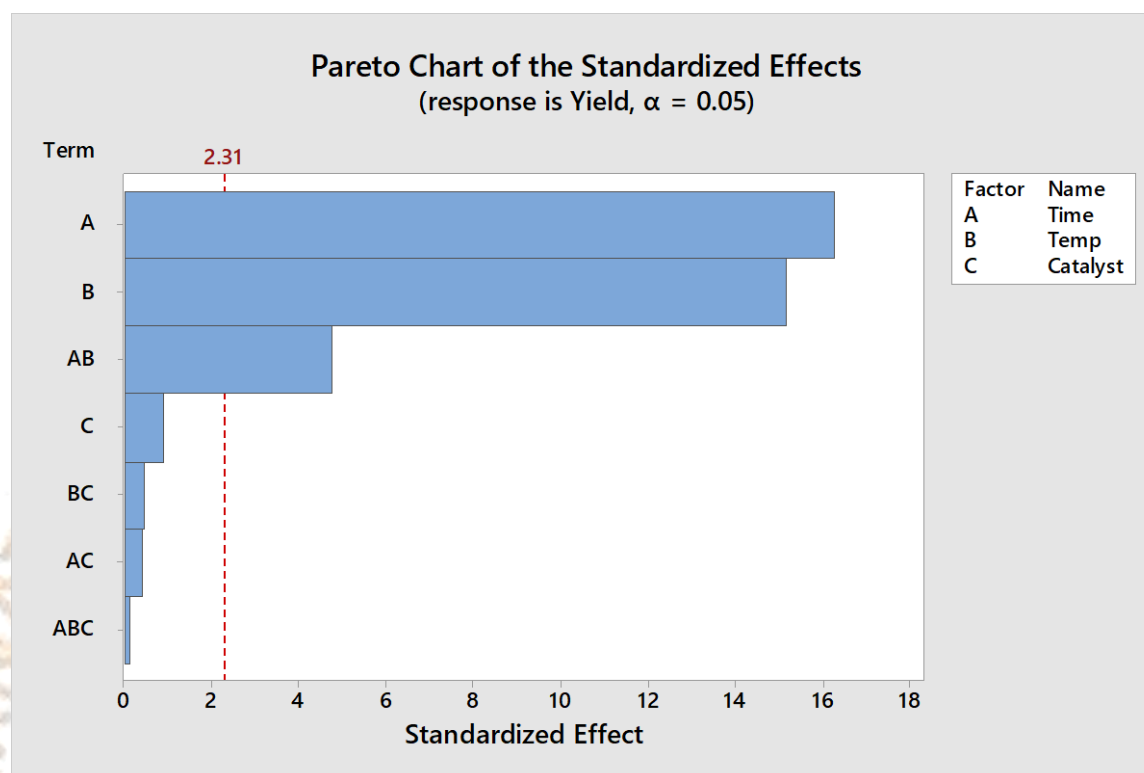

Example of DOE when you Get a Excel Field from External Sources

We get a file called yield which is given below now we want to determine which factors like temp, time and catalyst affect the yield (Production of the Food) and Cost so we do the DOE in Minitab and find out which factors and the combination of factors contribute to the cost and yield of the organic food. Go to Stat→DOE→Create Factorial→2 Level Factorial and select number of factors as 3 after clicking on OK you get a coded form excel sheet with +1 and -1; then you choose Stat→DOE→Analyse factorial and provide the information which column contains the factors (X's) and which Contains response (Y's) to Minitab in response you give Yield and Cost and you get 2 Pareto graphs given below for yield and cost from this we can determine which combinations increases the yield of the fruit. From the Pareto chart it is evident that A, B and the combination AB increases the yield of the fruit as the bars of this factors cross the vertical dotted red line.

For Cost the Pareto Graph depicts that the factors C, B,A, BC, AC contribute to the costing as they cross the dotted vertical red line.

Time	Temp	Catalyst	Yield	Cost
50	200	A	48.4665	31.7457
20	200	A	45.1931	31.0513
50	200	B	49.204	36.8941
50	150	B	45.5991	32.6394
20	150	A	42.7636	27.5306
50	150	A	44.7592	29.3841
20	200	B	44.7077	34.6241
20	150	B	43.3937	30.5424
50	200	A	49.0645	32.3437
50	150	B	45.1531	33.0854
50	200	B	48.672	37.4261
20	200	B	45.3297	35.2461
50	150	A	45.3932	28.7501
20	150	B	43.0617	30.2104
20	150	A	43.2976	28.0646
20	200	A	44.8891	30.7473

Pareto Chart of the Standardized Effects (response is Yield, α = 0.05)

Pareto Chart of the Standardized Effects (response is Cost, α = 0.05)

SMED: A system used to reduce changeover time and improve timely response to demand is based on a method known as single-minute exchange of dies(SMED). SMED is a series of techniques pioneered by Shigeo Shingo for change overs in production machinery in less than 10 minutes. The long term objective is always zero setup, in which changeovers are instantaneous and do not interfere in any way with continuous flow. SMED is also known as Rapid exchange of tooling and dies(RETAD).

13. CONTROL PHASE

Deliverables are Control Charts, Control Plan, Poka-Yoke, Project Closing.

The final **stage** of Six Sigma's DMAIC process is the Control phase. The focus of this phase is to ensure that the action items created in the **Improve** stage are implemented and maintained. Let's take a look at the key events that are carried out in this phase.

This phase begins with defining Implementation and Acceptance Strategy, then it moves ahead to explain the Statistical Process Control and finally concludes with describing the significance of Response Plan and Documentation.

Control phase has four components:

1. **Discipline**: It is very difficult to control the improved processes, if disciplined and proactive processes are not in place.
2. **Documenting the Improvement**: Documentation includes the usage of flowcharts, photographs, charts, videotapes, etc. to document the improvement.
3. **Establishing Ongoing Process Measures**: It refers to identifying key measures that enable the team and process owners to maintain and manage the process over time.
4. **Building a Process Management Plan**:

The plan covers:
- Improved Process Map as a result of project improvement
- Action Alarms
- Emergency Fixes
- Plans for Continuous Improvement

The first phase in Control phase is Implementation and Acceptance Strategy. Let us learn about the Implementation Strategy. The Implementation Strategy is a key element of any program. If implementation is not executed correctly, then not only does the program not work the way it was intended, but also other unintended consequences such as, decreased staff morale and participation in the project as well as increased costs can stop the program entirely.

A good implementation plan should have well defined objectives, incorporation of pilot learning, proper resources, and time frame. Besides, it should also have influence Strategy, control plan, and documentation. Risk Mitigation Plan is an essential element of good implementation planning which identifies potential risks and the corresponding contingency. In addition to all these elements, response plan for each prioritized risk is also an important element of good implementation planning.

The strategic importance of an implementation plan can be explained with the help of the following factors:
- In an implementation plan, staff engagement generates additional input and helps to build its commitment to the end-to-end plan. Staff input provides insight into issues, challenges, concerns, and opportunities which may not have been known or fully understood, and ensure their "buy-in" to help execute the strategies.
- An implementation plan can be successful when a bottom-up and top-down communication approach is taken. In case of bottom-up approach, communication is made to all levels of associates informing them that an implementation plan will be undertaken. It includes how they will be involved in this process. It is followed by the top-down communication. Senior management will share the strategic implementation plan with associates. They will communicate to all on how their engagement will help to ensure success in the execution of these implementation strategies.
- The organizational culture refers to the commonly held attitudes, values, beliefs, and behaviours of its associates. If associates believe that a change is something to be scared of and avoided, then change implementation is often reactive and haphazard. If associates believe that an implementation plan should be aggressively implemented "from top", then change is seldom supported. However, if associates believe that implementation is worthwhile and everyone's responsibility, then change and growth occur with relative ease.

Acceptance strategy in Control phase of DMAIC framework is one of the most important elements of managing change under the umbrella of change management process. It can be used to address and mitigate resistance to change.

For successful implementation of acceptance strategy, you need to identify stakeholders at first. Then you need to identify stakeholder support profile. Thereafter, determine the Influence Strategy which can be used to persuade the stakeholders, and lastly identify the causes for stakeholder resistance.

Key constituents map is a tool to identify stakeholders which includes key customers, shareholders or other owners, senior leaders, middle management, six sigma change agents, the general employee population, and suppliers. It is used for mapping out the size of the stakeholder team that would be affected by the change that is going to be implemented.

Key constituents map tool helps the team to identify what should be the right composition of the implementation team proportional to the key constituents map sections.

Stakeholder analysis helps to identify stakeholder support profile. It helps to provide an insight on the extent of support or resistance that should be expected by the project team during the implementation of the project. It also establishes the requirements for successful implementation for a project team. Using this information, the team would be able to determine which key stakeholders need to be influenced or sought support from during the implementation.

Creating an Influence Strategy involves drawing up a list of all the stakeholders who will be affected by the change, discover how these stakeholders feel about the project and their concerns, and finding the best way to engage stakeholders and communicate with them.

The know-how on the following factors can help a project team to understand their stakeholders:

- Stakeholders' financial or emotional interest in the outcome of the project.
- Stakeholders' need for information from project team
- Stakeholders' opinion about the project work.
- Factors influencing Stakeholders' opinion about the project or project team.

Methods to win stakeholders' support to the improvement projects.

Key Stakeholder	Level of Influence	Level of Interest	Type of Resistance	Underlying Issue	Response Strategy
A	High	High	Technical	Lack of knowledge	Educate and involve in meetings
B	Low	Low	Political	Loss of Control	Emphasize project benefits
C	High	High	Organizational	Desire to control	Stakeholders get credit for solution
D	Low	Low	Individual	Overwork	Educate over time via colleagues

In the Stakeholder Influence Planning and Analysis Chart above, notice some of the types of resistance identified and the corresponding underlying issue or cause of resistance and its counter measure. For Stakeholder A, the level of influence and the level of interest are high, the type of resistance is technical, the underlying issue or cause of resistance is lack of knowledge, and the response strategy is to educate and involve in meetings.

For Stakeholder B, the level of influence and the level of interest are low, the type of resistance is political, the underlying issue or cause of resistance is loss of control, and the response strategy is to emphasize project benefits.

For Stakeholder C, the level of influence and the level of interest are high, the type of resistance is organizational, the underlying issue or cause of resistance is desire to control, and the response strategy is stakeholders get credit for solution

For Stakeholder D, the level of influence and the level of interest are low, the type of resistance is individual, the underlying issue or cause of resistance is overwork, and the response strategy is to educate overtime via colleagues.

We discovered few causes of stakeholders' resistance in the sample Stakeholder Influence Planning and Analysis Chart. Now, let's look at few more causes of stakeholders' resistance. Lack of awareness on why the change is needed, lack of knowledge regarding change impact on current job role, lack of knowledge on organization's past performance with or without change, lack of visible support and commitment from supervisors and managers, and fear of job loss.

Now let us learn how to define the response strategy.

- Resistance from stakeholders can be proactively addressed. However, please note that persistent resistance can threaten any project.
- The change management team identifies, understands and helps leaders to manage resistance throughout the organization.

An effective Implementation Strategy, Acceptance Strategy which comprises key constituents map, stakeholder analysis, Influence Strategy, and Stakeholder Influence Planning and Analysis Chart and effective management tools lead to successful implementation of solutions.Thus, it can be concluded that the cumulative effect of quality solution and acceptance of solution facilitates implementation of solution.

Many Six Sigma belts and teams do a good job in the analyse and improve phase; however, the improvements do not sustain over a long period as certain important requirements of the control phase are not met. Typical causes of the failure to sustain improvements are as follows.

➢ Inadequate training to operators on the changed process or equipment.
➢ Validation of improvement for a short period of time or sample sizes.
➢ Inadequate control plan or audits
➢ Process improvement is qualified without consideration to ' noise factors' which eventually effect the process adversely.

Poka-Yoke is an approach used for risk proofing solutions. Poka means mistake or error and Yoke means to proofing or avoid.So, Poka-Yoke means mistake proofing or avoidance of error. Poka-Yoke concept was created by Shigeo Shongo. Poka-Yoke is a Japanese strategy for mistake proofing, which is a method for avoiding errors in a process. It is considered as the best approach to control a process.

Poka-Yoke solutions can include:

• The addition of a simple physical feature
• The creation of a checklist
• A change in the sequence of operation
• A highlighted field on a form
• A software message that reminds the operator to complete a task, or Any other way of helping to totally reduce or eliminate mistakes.
Let's look at a few examples of Poka – Yoke:

• Computer data entry forms will not let you advance until all the information is input correctly.
• Checklists are used so that items are not inadvertently missed.
• The shape of a connector on a cell phone charger prevents you from connecting it in the wrong place.
• An indicator on a water purifier to change the filter or germ kill kit.

Maintaining Gains

If your project has successfully entered the Monitor and control phase you have to make sure that you maintain this stability, here are some suggested ways to protect hard won gains.

• Policy Changes – Which corporate policies should be changed as a result of the project – have some policies become obsolete are new policies needed
• New Standards- Did the project bring the organization into compliance with a standard. If so having the company adopt the standard might prevent backsliding, there are standards like ISO, ANSI, ASTM etc. from which you can take your pick.
• Modify procedures-procedures describe the way things are supposed to be done, since the project produced better results we can find the best suited procedure which has resulted in better modification or change.
• Change Manufacturing Planning-An organizations manufacturing plan describe in detail how a product is to be processed and produced. Often the Six Sigma team will discover better way of doing things.
• Modify training-personnel need to become familiar with the new way of doing things. Be sure all employees are retrained. Evaluate the existing training materials and revise them as necessary.

Process Audits

The requirement for all processes should be documented. A process audit check list should be prepared and used to determine the condition of the Process prior to production.

SPC (Statistical Process Control)

Control Charts

Variable Charts

The Xbar and R Chart is the flagship of the control charts. It is called a variables chart because the data to be plotted result from measurement on a variable on continuous scale. This type of measurement occurs when for each pair of values there are infinite number of values between them. On an inch scale for instance there are infinite number of values between 1.250 and 1.251, values such as 1.2503, 1.2508 and so on. The Xbar and S chart is another variable control chart with this chart sample standard deviation s is used to indicate dispersion instead of the range. The Standard deviation is a better measure of spread especially if the sample size is large so this chart is somewhat more precise than the xbar and R chart. The X bar and S chart should be used when calculation of the standard deviation is feasible. Users who are comfortable with the standard deviation function on a handheld calculator will be able to calculate S almost as easily as R. The Xbar and S chart is also the preferred chart when the chart is constructed using a software package.

The Control charts are in +/- 3 Standard deviation limits which covers approximately 99.73% of the data; points falling within the control limits are due to common cause of variation and points falling outside the control limits are due to special cause of variation.

I – MR Chart is used when data is continuous and when data is not collected in subgroups. We can also do manual calculation of control limits using the process below but it is best to use Minitab as Manual calculation is tedious and cumbersome.

• First of all, calculate the Moving range (MR) that is absolute value of the difference between consecutive measurements
• Calculate the process average ($\bar{x}$) and average of moving range ($\overline{MR}$)
• For I-MR chart n is always equal to 2 (because we are calculating the moving average of two consecutive points, in other words it is basically comparing the current sate with previous state)
• Finally, construct the control charts for Individual and Moving range

$$\bar{X} = \frac{\sum_{i=1}^{k} x_i}{k}$$

$$\overline{MR} = \frac{\sum_{i=1}^{k} |x_i - x_{i-1}|}{k - 1}$$

• Where x_i = value at point i
• k= number of subgroups

The formula for centre line, Lower and Upper control limits for Individuals are:

$$UCL = \bar{X} + E_2\overline{MR} \qquad Center\ line = \bar{X} \qquad LCL = \bar{X} - E_2\overline{MR}$$

$$Where\ E_2 = A_2\sqrt{n}$$

The formula for centre line, Lower and Upper control limits for Moving range are:

$$UCL = D_4\overline{MR} \qquad Center\ line = \overline{MR} \qquad LCL = D_3\overline{MR}$$

Where, D_3, D_4 and E_2 are control chart constants

Example of Manual calculation of Control Limits for I-MR Chart

Use the data provided in the table below and calculate the upper and lower control limits from the formulae: -

Reading	Individual Data Element
1	290
2	288
3	285
4	290
5	291
6	287
7	284
8	290
9	290
10	288

We have Xbar=288.3

$$\bar{X} = \frac{\sum_{i=1}^{k} x_i}{k}$$

$$\overline{MR} = \frac{\sum_{i=1}^{k} |x_i - x_{i-1}|}{k - 1}$$

So | Xi-Xi-1| = 288-290=-2;285-288=-3;290-285=5;291-290=1;287-291=-4;284-287=-3;290-284=6;288-290=-2-Total=26 it is positive because of Mod.

So MRBar =26/9=2.89

So LCLx for Individual = X bar-E2 * MR bar

=288.3- (2.660) (2.89) =280.62 Where E2 is got from Control Charts Constants table

So UCLx for individual = X bar+E2*MR Bar

=288.3+(2.660) (2.89) = 295.98

So Lower Control limit for the Individual Graph is 280.62 and upper Control Limit is 295.98.

Now to Calculate the Lower and upper and Lower control limits of Moving range.

From the formula we have below

The formula for centre line, Lower and Upper control limits for Moving range are:

$$UCL = D_4\overline{MR} \qquad Center\ line = \overline{MR} \qquad LCL = D_3\overline{MR}$$

Where, D_3, D_4 and E_2 are control chart constants

So UCL (Upper Control Limit) = 3.267 * 2.89= 9.44

And LCL (Lower Control limit) =0* 2.89 =0

Example: - A quality engineer monitors the manufacture of liquid detergent and wants to assess whether the process is in control. The engineer measures the pH of 25 consecutive batches of detergent.

Because the data are not collected in subgroups, you can use this data to demonstrate **I-MR Chart**.
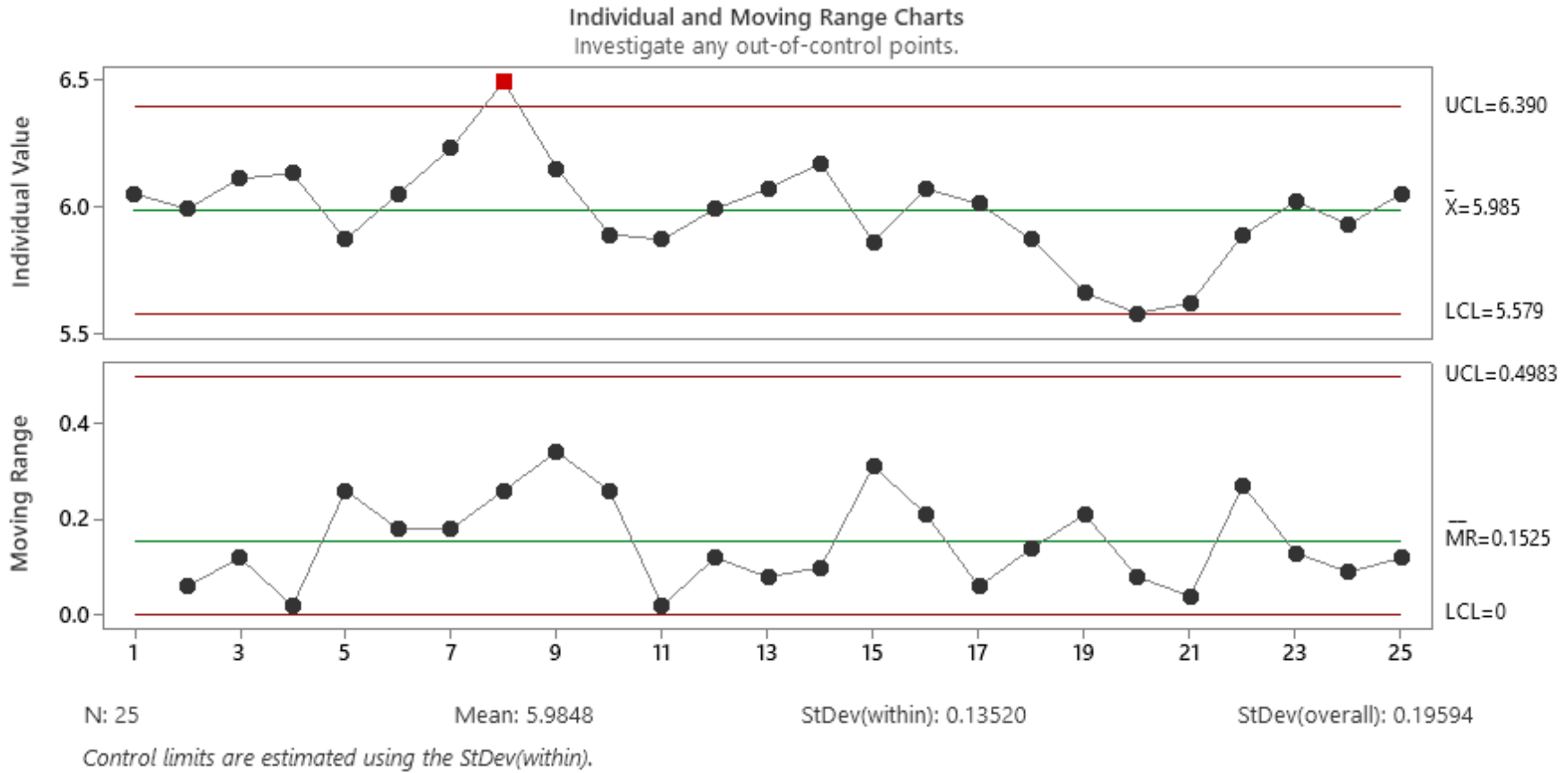
Worksheet column	Description
Batch ID	The batch identifier
pH	The pH of each batch

I-MR Chart of pH
Summary Report

Is the process mean stable?
Evaluate the % of out-of-control points.

0%   > 5%

Yes   No

4.0%
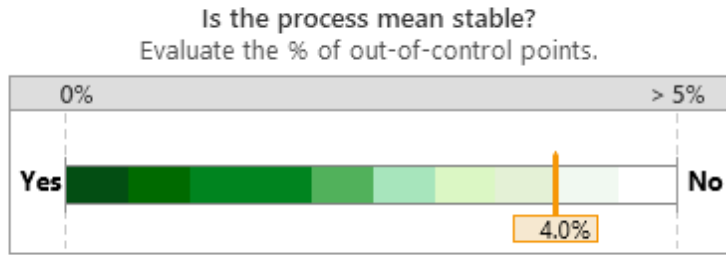
Comments

The process mean may not be stable. 1 (4.0%) data point is out of control on the I chart. Keep in mind that you may see 0.7% out-of-control points by chance, even when the process is stable.

Individual and Moving Range Charts
Investigate any out-of-control points.

UCL=6.390
X̄=5.985
LCL=5.579

UCL=0.4983
M̄R=0.1525
LCL=0

N: 25   Mean: 5.9848   StDev(within): 0.13520   StDev(overall): 0.19594

Control limits are estimated using the StDev(within).

From the above graph we have 2 graphs one is individual value and the other one is moving range that is why it is called as Individual Moving Range graph.

I-MR Chart of pH
Report Card

Check	Status	Description
Stability	⚠️	The process variation is stable. No points are out of control on the MR chart. However, the process mean may not be stable. 1 (4.0%) point is out of control on the I chart (you may see 0.7% out-of-control points by chance, even when the process is stable). You should investigate the out-of-control point and if it has a special cause, omit it from the calculations.
Normality	✅	If the data are nonnormal, you may see an increased number of false alarms. Because fewer than 2 points are outside the control limits on the I chart, the normality test is not needed.
Amount of Data	⚠️	You may not have enough data to estimate precise control limits. At least 100 data points should be included in the calculations.
Correlated Data	✅	If the data are correlated, you may see an increased number of false alarms. Because fewer than 2 data points are outside the control limits on the I chart, the correlation test is not needed.
Alternative Charts	ℹ️	This chart is intended to monitor process control. If your primary objective is to explore your data or compare your process before and after a change, use the Graphical Analysis Control Charts or the Before/After Control Charts.

XBar and R Control Charts:

To get Control charts in Minitab please do the following open Minitab → Click on Assistant?→ Click on Control Charts→ You will get flow chart of various types of Control Charts-> Select the data from the sheet column→ and then specify estimate control limits from the data → you will get the different types of control charts which can determine whether the process is in control.

X bar R chart is to monitor process control for continuous data and samples collected in subgroup should have size 8 or less.

For smaller subgroups, you can use the range to estimate the process variation.

Example

Inspectors at an auto parts company sample wheel rims and measure the diameter of each rim. Every 2 hours, they sample 5 consecutive wheel rims from the production line.

Because the subgroup size is 8 or less, the inspectors can use the range to estimate the variation of the rim diameters.
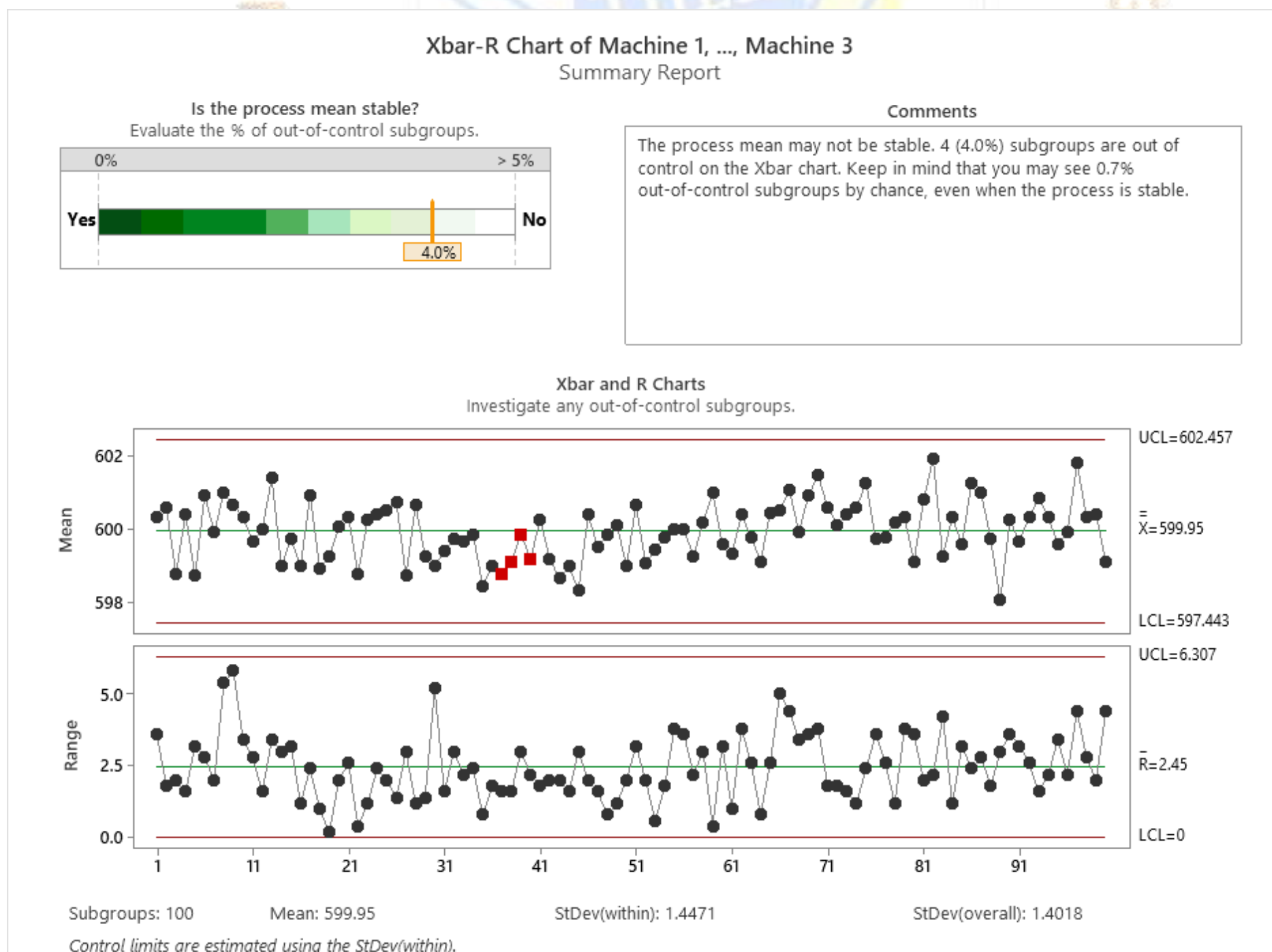
A quality engineer at an automotive parts plant monitors the lengths of camshafts. Three machines manufacture camshafts for three shifts each day. The engineer measures five camshafts from each machine during each shift.

You can use this data to demonstrate **Xbar-R Chart** and other analyses that compare multiple time series variables.

You can create three control charts with this data to monitor each machine.

Worksheet column	Description
Machine 1	The length of the camshafts from Machine 1
Machine 2	The length of the camshafts from Machine 2
Machine 3	The length of the camshafts from Machine 3
Subgroup ID	The subgroup identification number

The output in Minitab shows 2 graphs one is Xbar and the other is the range ; that is why it is called X bar R Chart , subgroup 29-40 are out of control as they are shown in red dots and you should investigate the samples from this group.

Xbar-R Chart of Machine 1, ..., Machine 3
Summary Report

Xbar-R Chart of Machine 1, ..., Machine 3
Report Card

Check	Status	Description
Stability	⚠️	The process variation is stable. No subgroups are out of control on the R chart. However, the process mean may not be stable. 4 (4.0%) subgroups are out of control on the Xbar chart (you may see 0.7% out-of-control subgroups by chance, even when the process is stable). You should investigate out-of-control subgroups and omit those with special causes from the calculations.
Amount of Data	✅	You do not need to be concerned about the precision of your control limits because 80 or more data points are included in the calculations.
Correlated Data	✅	If the data are correlated, you may see an increased number of false alarms. Because less than 2% of the subgroups are outside the control limits on the Xbar chart, the correlation test is not needed.
Alternative Charts	ℹ️	This chart is intended to monitor process control. If your primary objective is to explore your data or compare your process before and after a change, use the Graphical Analysis Control Charts or the Before/After Control Charts.

X-Bar S Chart is used when the Subgroup size is greater than 8 and it uses standard deviation which is better when the subgroup size is greater than 8.

As the subgroup size increases, the standard deviation is an increasingly better estimator of the process variation than the range.

How to calculate the control limits of X Bar and S chart?

Compute X bar and S values

1. Measure the average of each subgroup i.e X bar, then compute grand average of all X bar value, this will be center line for X bar chart.
2. Compute the standard deviation of each subgroup, then measure grand averages of all standard values ie S bar and this will be the center line for S chart.

Example

Inspectors at a canning company sample cans of food and weigh each can. They sample 10 cans every 30 minutes.

Because the subgroup size is greater than 8, the inspectors use the standard deviation to estimate the variation of the can weights.

A quality engineer at a canning company assesses whether the can-filling process is in control. Each hour, the engineer collects a subgroup of 10 cans. To minimize the within-subgroup (can-to-can) variation, the engineer collects the cans for a given subgroup in a short period of time.

You can use this data to demonstrate **Xbar-S Chart**.

Worksheet column	Description
Subgroup ID	The subgroup identification number
Weight	The weight of each can

Xbar-S Chart of Weight
Summary Report

Is the process mean stable?
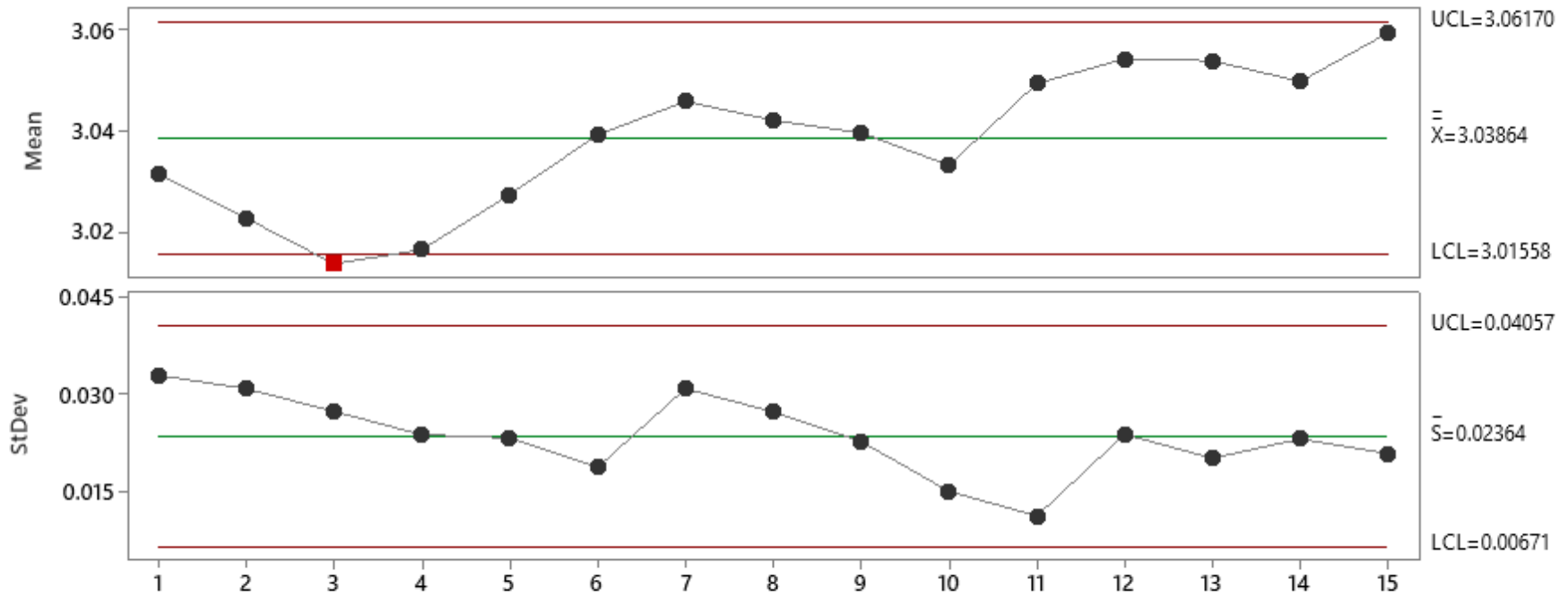Evaluate the % of out-of-control subgroups.
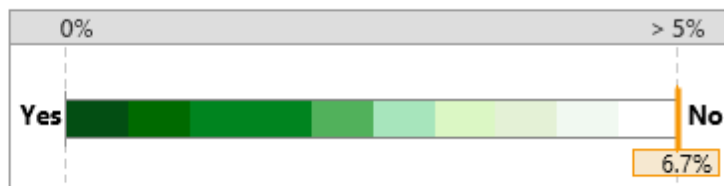
Comments

The process mean may not be stable. 1 (6.7%) subgroup is out of control on the Xbar chart. Keep in mind that you may see 0.7% out-of-control subgroups by chance, even when the process is stable.

Xbar and S Charts
Investigate any out-of-control subgroups.

Subgroups: 15	Mean: 3.0386	StDev(within): 0.024303	StDev(overall): 0.026868

Control limits are estimated using the StDev(within).

There are 15 Subgroups in the above example and we find that the process mean is not stable as the subgroup 3 which is highlighted in red is going outside the lower control limit.

Xbar-S Chart of Weight
Report Card

Check	Status	Description
Stability	⚠️	The process variation is stable. No subgroups are out of control on the S chart. However, the process mean may not be stable. 1 (6.7%) subgroup is out of control on the Xbar chart (you may see 0.7% out-of-control subgroups by chance, even when the process is stable). You should investigate the out-of-control subgroup and if it has a special cause, omit it from the calculations.
Amount of Data	✅	You do not need to be concerned about the precision of your control limits because 60 or more data points are included in the calculations.
Correlated Data	✅	If the data are correlated, you may see an increased number of false alarms. Because fewer than 2 subgroups are outside the control limits on the Xbar chart, the correlation test is not needed.
Alternative Charts	ℹ️	This chart is intended to monitor process control. If your primary objective is to explore your data or compare your process before and after a change, use the Graphical Analysis Control Charts or the Before/After Control Charts.

Manual Calculation of Control Limits formulas and Constants used by these formulas are given in the table below. Control limits are calculated from the process data and therefore represent the voice of the process, they are set at +/- 3 Standard Deviations. Normally manual calculation of control limits is tedious so we use Minitab to automate it for a very large set of data.

Tables of Constants for Control charts							
Table 8A - Variable Data				ref : AIAG manual for SPC			
X bar and R Charts				X bar and s charts			
Chart for Averages	Chart for Ranges (R)			Chart for Averages	Chart for Standard Deviation (s)		
	Control Limits Factor	Divisors to Estimate σ_x	Factors for Control Limits		Control Limits Factor	Divisors to estimate σ_x	Factors for Control Limits	
Subgroup size (n)	A_2	d_2	D_3	D_4	A_3	c_4	B_3	B_4
2	1.880	1.128	-	3.267	2.659	0.7979	-	3.267
3	1.023	1.693	-	2.574	1.954	0.8862	-	2.568
4	0.729	2.059	-	2.282	1.628	0.9213	-	2.266
5	0.577	2.326	-	2.114	1.427	0.9400	-	2.089
6	0.483	2.534	-	2.004	1.287	0.9515	0.030	1.970
7	0.419	2.704	0.076	1.924	1.182	0.9594	0.118	1.882
8	0.373	2.847	0.136	1.864	1.099	0.9650	0.185	1.815
9	0.337	2.970	0.184	1.816	1.032	0.9693	0.239	1.761
10	0.308	3.078	0.223	1.777	0.975	0.9727	0.284	1.716
15	0.223	3.472	0.347	1.653	0.789	0.9823	0.428	1.572
25	0.153	3.931	0.459	1.541	0.606	0.9896	0.565	1.435

	Centerline	Control Limits		σ_x
X bar and R Charts	$CL_{\overline{X}} = \overline{\overline{X}}$	$UCL_{\overline{X}} = \overline{\overline{X}} + A_2 \overline{R}$	$LCL_{\overline{X}} = \overline{\overline{X}} - A_2 \overline{R}$	$\dfrac{\overline{R}}{d_2}$
	$CL_R = \overline{R}$	$UCL_R = D_4 \overline{R}$	$LCL_R = D_3 \overline{R}$	
X bar and s Charts	$CL_{\overline{X}} = \overline{\overline{X}}$	$UCL_{\overline{X}} = \overline{\overline{X}} + A_3 \overline{S}$	$LCL_{\overline{X}} = \overline{\overline{X}} - A_3 \overline{S}$	$\dfrac{\overline{s}}{c_4}$
	$CL_s = \overline{s}$	$UCL_s = B_4 \overline{s}$	$LCL_s = B_3 \overline{s}$	

X Double Bar is the average; R is the range (Max-Min) in a subgroup and s is the standard deviation; A2, A3, D3,B3 are constants mapped to the subgroup of respective size. List of Control chart Constants like A2, A3, D3,B3 which are used in the formula and mapped to the subgroup size is given below.

n	A	A₁	A₂	A₃	A₄	A₅	A₆	A₈	A₉	A10	B₁	B₂	B₃	B₄	B₅	B₆	n
2	2.121	3.760	1.881	2.659	2.224	4.447				3.143	0.000	1.843	0.000	3.266	0.000	2.606	2
3	1.732	2.394	1.023	1.954	1.091	2.547	1.187	2.010	1.265	2.082	0.000	1.858	0.000	2.568	0.000	2.276	3
4	1.500	1.880	0.729	1.628	0.758	1.951				1.689	0.000	1.808	0.000	2.266	0.000	2.088	4
5	1.342	1.596	0.577	1.427	0.594	1.638	0.691	1.607	0.712	1.465	0.000	1.757	0.000	2.089	0.000	1.964	5
6	1.225	1.410	0.483	1.287	0.495	1.438				1.313	0.026	1.711	0.030	1.970	0.029	1.874	6
7	1.134	1.277	0.419	1.182	0.429	1.297	0.509	1.377	0.520	1.201	0.104	1.672	0.118	1.882	0.113	1.806	7
8	1.061	1.175	0.373	1.099	0.380	1.190				1.114	0.167	1.638	0.185	1.815	0.178	1.752	8
9	1.000	1.094	0.337	1.032	0.343	1.107	0.412	1.223	0.419	1.044	0.219	1.609	0.239	1.761	0.232	1.707	9
10	0.949	1.028	0.308	0.975	0.314	1.039				0.985	0.261	1.584	0.284	1.716	0.277	1.669	10
11	0.905	0.973	0.285	0.927	0.290	0.982	0.350	1.110	0.356	0.936	0.299	1.561	0.322	1.678	0.314	1.637	11
12	0.866	0.925	0.266	0.886	0.270	0.933				0.893	0.330	1.542	0.354	1.646	0.346	1.609	12
13	0.832	0.884	0.249	0.850	0.253	0.891	0.308	1.026	0.312	0.856	0.359	1.523	0.381	1.619	0.374	1.585	13
14	0.802	0.848	0.235	0.817	0.239	0.854				0.823	0.384	1.506	0.407	1.593	0.399	1.563	14
15	0.775	0.816	0.223	0.789	0.226	0.821	0.276	0.958	0.280	0.794	0.406	1.492	0.428	1.572	0.420	1.544	15
16	0.750	0.788	0.212	0.763	0.215						0.427	1.477	0.448	1.552	0.441	1.526	16
17	0.728	0.762	0.203	0.739	0.206						0.445	1.466	0.466	1.534	0.458	1.511	17
18	0.707	0.738	0.194	0.718	0.197						0.461	1.455	0.482	1.518	0.475	1.496	18
19	0.688	0.717	0.187	0.698	0.189						0.477	1.443	0.496	1.504	0.490	1.483	19
20	0.671	0.697	0.180	0.680	0.182						0.490	1.434	0.510	1.490	0.503	1.471	20
21	0.655	0.679	0.173	0.663	0.176						0.504	1.423	0.523	1.477	0.517	1.459	21
22	0.640	0.662	0.167	0.647	0.170						0.517	1.414	0.535	1.465	0.529	1.448	22
23	0.626	0.647	0.162	0.633	0.164						0.528	1.406	0.545	1.455	0.539	1.438	23
24	0.612	0.632	0.157	0.619	0.159						0.539	1.398	0.555	1.445	0.549	1.429	24
25	0.600	0.619	0.153	0.606	0.155						0.544	1.395	0.564	1.436	0.558	1.421	25

Notes: Only odd values of n are given for A_6, A_8, and A_9. Otherwise, the median for an even n is simply the average of the two middle values of the subgroup.

Example: - A production process is supposed to generate pistons that weight 10 kg each. Samples of 5 pistons are taken at time intervals of 45 min for inspection and the mean weights of the samples are plotted on the control chart from the output we see that every sample mean has fallen within the control limits until sample 33 was plotted. Since the mean of the sample is way outside control limits something special must have happened to cause that sample way out of control. The production process needs to be stopped so that the special causes of variation can be investigated and corrections made. The cause of that variation can be anything from a defective or unattended machine to an operator's mistake. Once the correction is made the process should be back in control.

Manual calculation of Control Limits for np, c and u charts respectively which are attribute charts

Attribute Charts

Attribute Charts are used for Count Data

In attribute Control Charts every item would be either in one or two categories such as "good" or "bad", count of defective.

Control Limit manual calculation of np chart

Np chart is used when sample size is constant. We use this chart to plot the number of defectives

Example Packages containing 1000 light bulbs are randomly selected and all 1000 bulbs are light tested the results of the tests are given in the table below.

Date	Number of Defectives	Sample size
8-Sep	9	1000
9-Sep	12	1000
10-Sep	13	1000
11-Sep	12	1000
12-Sep	11	1000
13-Sep	9	1000
14-Sep	7	1000
15-Sep	0	1000
16-Sep	12	1000
17-Sep	8	1000
18-Sep	9	1000
19-Sep	7	1000
20-Sep	11	1000

The formula for the centre line and the upper and lower control limits for the np chart are
P bar = sum of number of defectives/ sum of sample size which is 120/13000=0.00923.

Np bar = n * sum of number of defectives/ sum of sample size where n is the sample size.

So substituting the value we get npbar =1000 * 120/13000=9.23

Now calculating the lower control limits formula LCLnp=npbar-3 √npbar (1-pbar)

Substituting the values in the formula we get LCL np= 9.23 -3 √(1000)(0.00923)(1 − 0.00923) = 0.16

Now calculating the upper control limits formula LCLnp=npbar+ 3 √npbar (1-pbar)

Substituting the values in the formula we get LCL np= 9.23 + 3 √(1000)(0.00923)(1 − 0.00923) =18.30

So the lower control limit is 0.16 and the upper control limit is 18.30

Control Limit manual calculation for c chart

C chart is used when sample size is constant. we use this chart to plot the number of defects.

Example: - Panes of Glass are inspected for defects such as bubbles, scratches, chips, inclusions, waves and dips. The result of the inspection is given in the table below

Date	Number of Defects	Sample Size
15-June	19	150
16-June	12	150
17-June	13	150
18-June	12	150
19-June	18	150
20-June	19	150
21-June	17	150
22-June	20	150
23-June	22	150
24-June	18	150
25-June	19	150
26-June	17	150
27-June	11	150

C bar = Sum of Defects Column/subgroup size which is 217/13=16.69

UCL = cbar + 3 * √cbar

Which is 16.69 + 3 √16.69=28.95 so the upper control limit is 28.95

Where cbar = centre line

LCL = cbar -3 * √cbar

Which is 16.69 – 3 √16.69= 4.44 so the lower control limit is 4.44

Control limit manual calculation of P control charts

The P Chart is used to chart Binary Data where each item is in one or two categories. This chart would be the appropriate chart for plotting number of defectives and when the sample size varies.

Example: - A test was conducted to determine the presence of Rh factor in 13 samples of donated blood. The results of the test are given in the table below.

Date	Number of Defectives	Sample Size
8-July	12	115
9-July	14	125
10-July	18	111
11-July	13	133
12-July	17	120
13-July	15	118
14-July	15	137
15-July	16	108
16-July	11	110
17-July	14	124
18-July	13	128
19-July	14	144
20-July	17	141

Pbar = Sum of number of defectives/ Sum of sample Sizes so from the table we have Pbar = 189/1614=0.1171

Where nbar = Sum of Sample Sizes / Number of samples which is 1614/13 = 124.1538

UCL for P Chart = PBar + 3 √pBar(1-pBar)/ nbar so substituting the values in the formula we have UCL=0.1171 +3 √0.1171(1-0.1171)/124.1538 = 0.1983

LCL for P Chart = PBar – 3 √Pbar (1-PBar)/ nbar
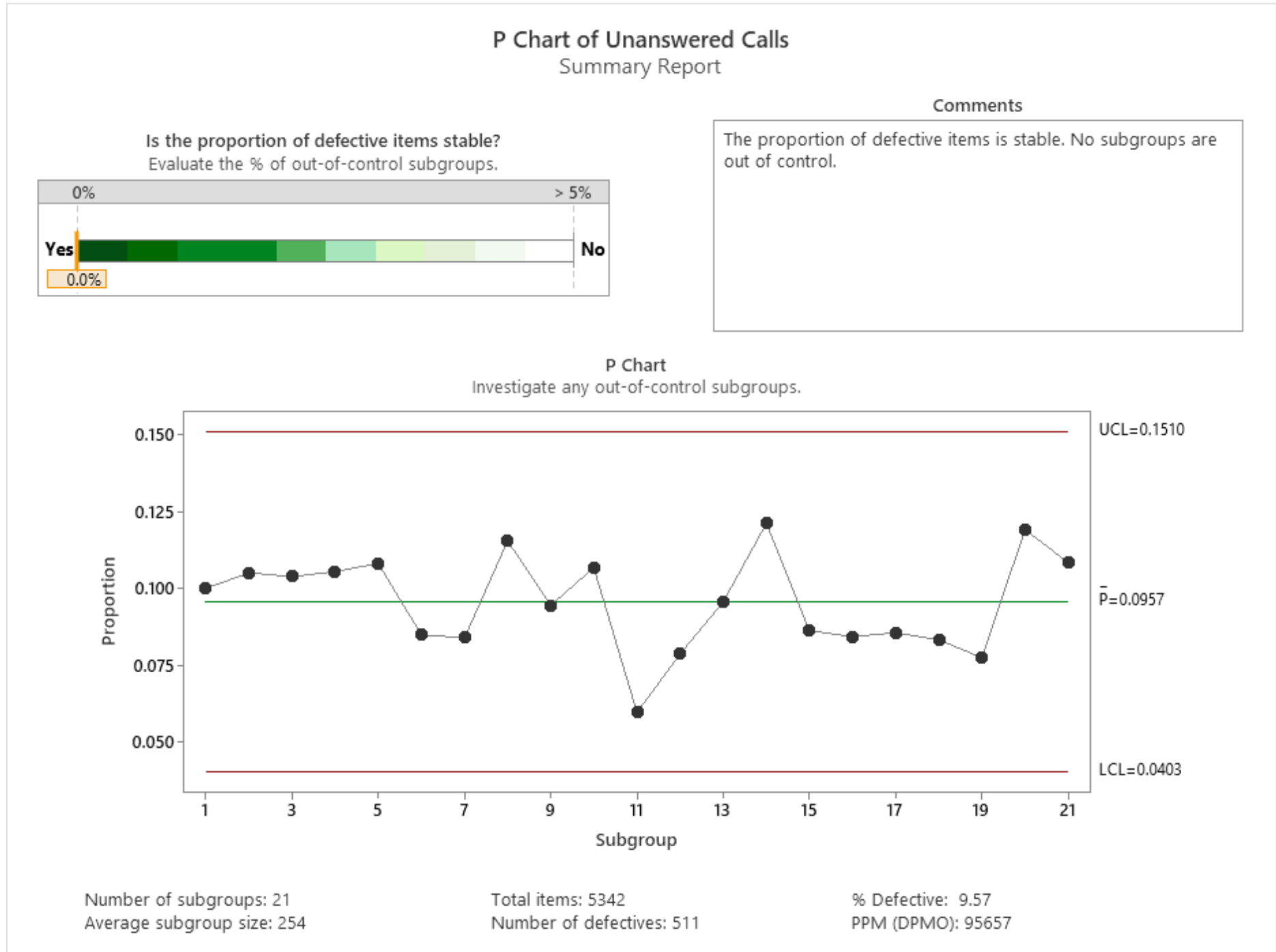
0.1171 -3 √0.1171(1-0.1171)/124.1538 = 0.0359

So the lower control limit is 0.0359 and upper control limit is 0.1983.

Example of P Chart for Process Control in Minitab: -

The supervisor for a call center wants to determine whether the call answering process is in control. The supervisor records the total number of incoming calls and the number of unanswered calls for 21 days. In the defective option enter the data from the column unanswered calls and in the subgroup option enter the total calls.

Because this data contains counts of defectives, you can use it to demonstrate **P Chart** and **Binomial Capability Analysis**.

Worksheet column	Description
Total Calls	The total number of calls each day. This column contains the subgroup sizes.
Unanswered Calls	The total number of unanswered calls each day. Each unanswered call is a defective.

P Chart of Unanswered Calls
Summary Report

P Chart of Unanswered Calls
Report Card

Check	Status	Description
Stability	✔	The proportion of defective items is stable. No subgroups are out of control.
Number of Subgroups	✔	You do not need to be concerned about the precision of your control limits because more than 10 subgroups are included in the calculations.
Subgroup Size	✔	You do not need to be concerned about the accuracy of your control limits because all subgroups have at least 6 items.
Expected Variation	✔	The variation in your data is close to the expected variation. Your data do not exhibit overdispersion or underdispersion. If these conditions exist, you may see an increased number of false alarms or have a chart that rarely signals.
Alternative Charts	ⓘ	This chart is intended to monitor process control. If your primary objective is to explore your data or compare your process before and after a change, use the Graphical Analysis Control Charts or the Before/After Control Charts.

Np Control Charts

If defectives are being counted and the sample size remains Constant the np chart can be used the np chart also has definite formulas to Calculate the upper and lower control limits.

Example of NP Chart

A quality engineer assesses whether the process used to manufacture light bulbs is in control. The engineer tests 500 light bulbs each hour for three 8-hour shifts and records the number of bulbs that did not light (defectives).

The engineer creates an NP chart to monitor the number of defective light bulbs.

1.   Open the sample data, **DefectiveLightBulbs.MTW**.

2.   Choose **Stat** > **Control Charts** > **Attributes Charts** > **NP**.

3.   In **Variables**, enter *Defectives*.

4.   In **Subgroup sizes**, enter *500*.

5.   Click **NP Chart Options**.

6.   On the **Tests** tab, select **1 point > K standard deviations from centre line** (Test 1) and **K points in a row on same side of center line** (Test 2).

If you are not sure which tests apply in your specific situation, use Tests 1 and 2 when you first establish the control limits based on your data.

7.   Click **OK** in each dialog box.

Interpret the results

One point is out of control on the NP chart. The engineer concludes that the process is not stable and should be improved.
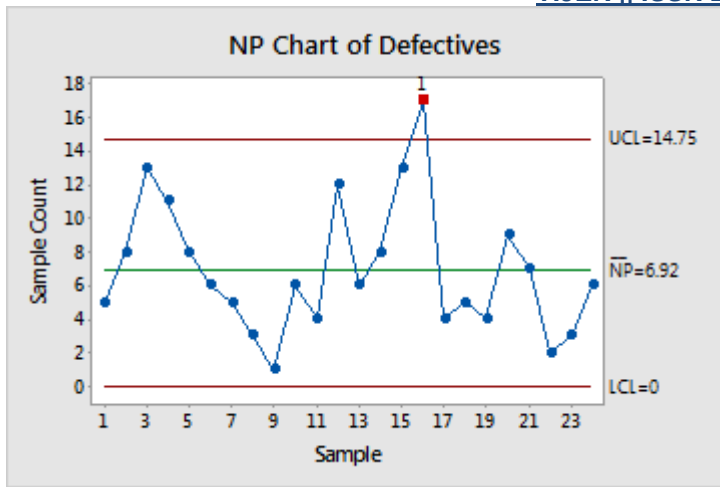
NP Chart of Defectives

Test Results for NP Chart of Defectives

TEST 1. One point more than 3.00 standard deviations from centre line.

Test Failed at points: 16

* WARNING * If graph is updated with new data, the results above may no longer

be correct.

U Control Chart Charts:

Example of U Chart

A manager for a transcription company wants to assess the quality of the transcription service. The manager randomly selects 25 sets of pages from consecutive orders and counts the number of typographical errors (defects). Each set has a different number of pages.

The manager creates a U chart to monitor the number of errors.

1.   Open the sample data, **TranscriptionErrors.MTW**.
2.   Choose **Stat** > **Control Charts** > **Attributes Charts** > **U**.
3.   In **Variables**, enter *Errors*.
4.   In **Subgroup sizes**, enter *Number of Pages*.
5.   Click **U Chart Options**.
6.   On the **Tests** tab, select **1 point > K standard deviations from center line** (Test 1) and **K points in a row on same side of center line** (Test 2).
7.   Click **OK** in each dialog box.

If you are not sure which tests apply in your specific situation, use Tests 1 and 2 when you first establish the control limits based on your data.

Interpret the results

Because the sample sizes are unequal, the control limits vary. The average number of defects per set of pages is 0.238. Subgroups 6 and 18 failed Test 1 because they are outside of the control limits. Thus, the process is out of control. The manager should identify and correct any factors that contribute to the special-cause variation.

Tests are performed with unequal sample sizes.
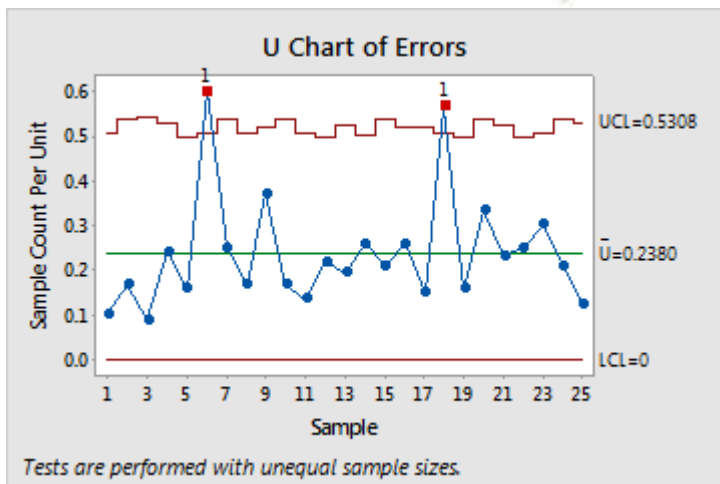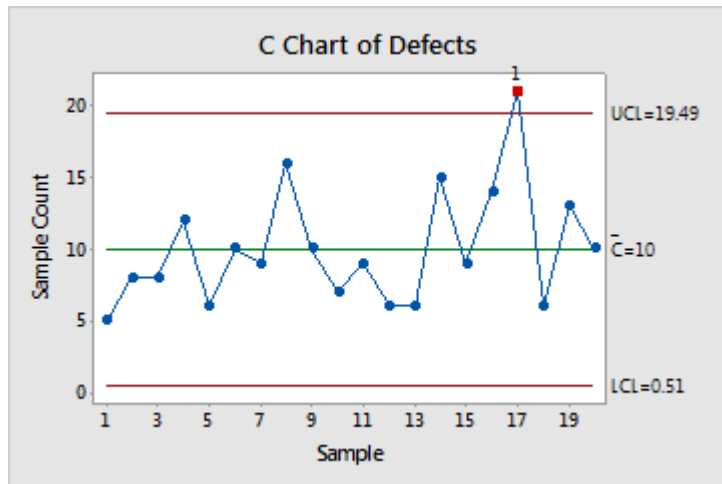
C Control Charts

When defects are counted and the sample size is constant the c chart maybe used instead of U CHART.

Overview for C Chart

Use C Chart to monitor the number of defects where each item can have multiple defects. You should use a C chart only when your subgroups are the same size. Use this control chart to monitor process stability over time so that you can identify and correct instabilities in a process.

For example, an LCD manufacturer wants to monitor defects on 17-inch LCD screens. Technicians record the number of dead pixels for each subgroup of 10 screens per hour and use a C chart to monitor the number of dead pixels.

The chart shows that, on average, technicians find 10 dead pixels in each sample. Sample 17 is out of control. The technicians should identify any special causes that contribute to the unusually high number of dead pixels.

Where to find this control chart

To create a C chart, choose **Stat** > **Control Charts** > **Attributes Charts** > **C**.

A Process is said to be out of Control if

1] One or more data points fall outside the control limit.

2] Seven Consecutive data points increasing or decreasing.

3] Eight consecutive data points are on one side of average.

4] Fourteen Consecutive data points alternating up and down.

EWMA Control Charts in Many cases individual control chart (I Chart) will give results comparable to the EWMA control chart when this is the case it is better to opt for the simpler I Chart.

Overview for EWMA Chart

Use EWMA Chart to detect small shifts in the process mean, without influence by low and high values. The EWMA chart monitors exponentially weighted moving averages, which remove the influence of low and high values. The observations can be individual measurements or subgroup means. An advantage of EWMA charts is that they are not greatly influenced by low or high values.

For example, a manufacturer of centrifuge rotors wants to track the diameter of all rotors produced during a week. The diameters must be close to the target because even small shifts cause problems.
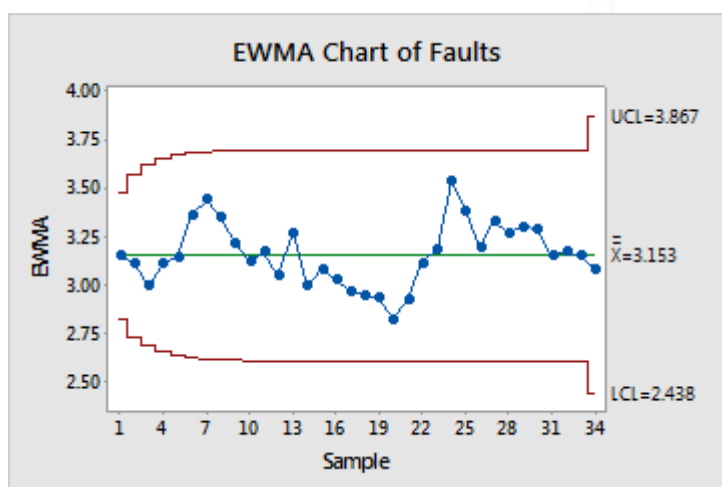
The points appear to vary randomly around the center line and are within the control limits. No trends or patterns are shown. The variability in the rotor diameter appears stable.

Where to find this control chart

To create an EWMA chart, choose **Stat** > **Control Charts** > **Time-Weighted Charts** > **EWMA**.

CUSUM chart

A type of time-weighted control chart that displays the cumulative sums (CUSUMs) of the deviations of each sample value from the target value. Because it is cumulative, even minor drifting in the process mean will lead to steadily increasing (or decreasing) cumulative deviation values. Therefore, this chart is especially useful in detecting processes that are slowly slipping away from the target value due to machine wear, calibration issues, etc. The points on the CUSUM chart should fluctuate randomly around zero. If a trend develops upwards or downwards, it should be considered as evidence that the process mean has shifted, and you should look for special causes.

Minitab Navigation:- Stat→Control Charts→Time Weighted Charts→Cusum Chart this Chart is to detect small Shifts which cause variation.

Overview for CUSUM chart

Use CUSUM Chart to detect small shifts in your process. The CUSUM chart plots the cumulative sums (CUSUMs) of the deviations of each sample value from the target value. Because the CUSUM chart is cumulative, even minor drifting in the process mean will cause steadily increasing (or decreasing) cumulative deviation values. The observations can be individual measurements or subgroup means.

For example, a manufacturer of centrifuge rotors wants to monitor the deviations from the target diameter of all rotors produced during a week. The diameters must be close to the target because even small shifts cause problems.
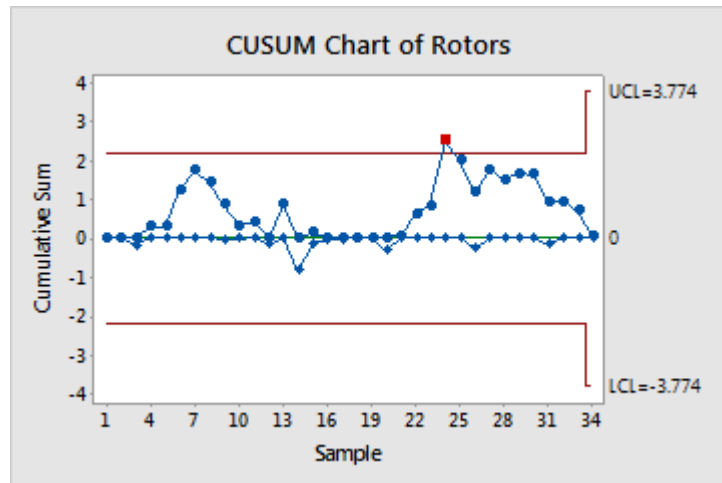
The points appear to vary randomly around the center line and are within the control limits, with the exception of one point. No trends or patterns are shown. The variability in the rotor diameter appears to be stable, but the out-of-control point should be investigated.

Where to find this control chart

To create a CUSUM chart, choose **Stat** > **Control Charts** > **Time-Weighted Charts** > **CUSUM**.

Natural variation or common cause variation cannot be eliminated. No 2 snowflakes are identical. The best we can hope for is to reduce it to a level where we can no longer measure it. This is probably not practical. Almost every book on process control will make a statement like this, "In any production process, regardless of how well designed or carefully maintained it is, a certain amount of inherent or natural variability will always exist.

If we really work to reduce it, we might use some of the traditional quality tools, such as a fishbone chart. Then use a Pareto chart to determine the influence of different causes and attack them one by one. However, when we have eliminated them all, time itself may be one cause we cannot eliminate.

Variation can be classified as common cause variation or special cause variation. Common cause variation is due to natural variation of the process; that is variation due to the way process was designed. An Example of common cause variation is the variation that might be seen by having several people working in the process. Each Person might do things slightly differently. Common cause of variation are expected, predictable and random.

Special cause variation that is due to assignable causes. An example of special cause variation is the variation that might result if someone untrained allowed to work in the process. Special cause variation is variation that can be assigned a reason. A Control chart like I-MR,X-bar etc. can detect special cause variation by points falling below the lower specification limit or higher specification limit. Special cause of variation are also unexpected, unpredictable, not normal, not random.

 Poka Yoke are Mistake proofing devices which can be used to reduce variation in a process for example introduction of speed bumper in a junction which has lots of accidents or fitting a sophisticated device in the factory to inform of gas leaks in a factory, spell check in Microsoft Word etc.

The Deliverables of the Control Phase are:

- **Solution Implementation Plan.**
- **Successful Solution**
- **Process Control Plan.**

The four techniques used for process control plans are:

- Standardization
- Documentation
- Monitoring Plan
- Response Plan

Standardization:
Standardization of the "should-be" process steps is required to ensure all responsible for execution have the same understanding. Standardizing the should-be process helps answer queries like:

- What are the steps in the process?
- Who does these steps in the process and when?
- Where more detailed work instructions can be found?

Documentation:
Documentation is a necessary step to insure that the learning gained via improvement is institutionalized and shared across the team by having it documented with proper work procedures. Often the live processes have a tendency to evolve in an ad-hoc manner. How to accomplish each process activity is usually left up to the individuals and thus, much of the organizational knowledge resides only in the minds of all those responsible for execution. Procedure: A procedure is the documented sequence of steps & other instructions necessary to carry out an activity for a process.

Monitoring Plan:
Monitoring: It helps detect changes as and when they occur in the process and assure that improvements continue to hold for us to be able to meet customer requirements over a period of time. While observing a process a monitoring plan helps define:

- Key process and output measures for ongoing measurement of the improved process
- When data is to be collected and at how often
- Define the method for gathering, recording, and reporting data on the measures

Response Plan:
Response plan helps identify the next steps on what needs to be done if one detects a change in the process while monitoring. For each of the measure in the monitoring plan, the response plan helps define:

- What actions will be taken for an out-of-control event occurrence with a timeframe for the action
- Who takes action based on the monitoring data
- Where to find trouble-shooting procedures to fix problem.

The key elements of a full scale implementation plan are:

- Clear Objectives
- Pilot Learning's Incorporated
- Implementation Milestones
- Resource Needs
- Influence Strategy
- Implementation Budget
- Process Control Plan
- Process Documentation

A Solution Plan Should include the following Components:

1. Potential Problem Analysis

2. **Solution Implementation Schedule.** Since the solution implementation will be on larger scale than the pilot implementation, the schedule activities for the implementation will also need to be more detailed and may potentially require involvement of more people.

3. **Training Plan.**

Bee and Bee (1994) suggest that a viable training plan should comprise three critical components:

• *Statement of policy.* This constitutes a statement of direction for the time period covered by the training plan. For example, there may be a specific focus of training such as qualification or certification training, leadership or first-line supervisory training, interpersonal skills training versus professional or technical skills training, and so on. In addition, this part of the plan might include the following: – Challenges and opportunities facing the organization. Recall the SWOT analysis discussed earlier.

– Strategies and tactics for dealing with the challenges.

– Required and desired competencies to achieve organizational goals.

– The training system the organization needs and how it will evolve to keep pace with the learning needs. This system should reflect the needs of the various target groups. It should not be cast as a

one-size-fits-all system. – Training's strategic role in helping the organization develop required competencies. – Training's strategic goals and objectives. This should address how training supports the human resources strategic plan, which in turn supports the organization's strategic plan.

• *Training budget.* This would include all costs associated with developing and executing the training plans. Also, it is important to specify how training is paid. Some organizations charge it as a general overhead expense while others charge directly to the organization whose employees are to receive the training. This latter method is sometimes known as "re-charging." Each method has its own advantages and disadvantages, as suggested by Newby (1992). The overhead method tends to focus on a longer-term view of training, but also tends "to encourage the inertia of running a standard menu of courses from year to year with little attempt to review training provision against business needs." the re-charging method encourages "line management interest on selecting the right people for the right training as they are being charged for the training need."

• *Operational plan.* This covers all aspects of timing and non-financial resources. For example:

– Identify the need

– State objectives and outcomes

– Determine content and sequence of instruction, if designed internally, or select from qualified external suppliers

– Identify the target groups

– Develop schedules for all aspects of training such as development, delivery, evaluation, and so on

– Specify resource requirements such as instructors, facilities, equipment, materials

– Establish measurements

– Select training delivery methods, if delivered by internal instructor as assessed, or select from qualified external suppliers

– Train instructors

– Deliver training

– Evaluate outcomes

– Modify training as needed

– Conduct lessons learned

– Add documentation to the organization's knowledge database

Remember, executing the training plan should be treated as any other project. That is, it should be managed properly using the appropriate project management tools and techniques. Therefore, planning for training should closely resemble the planning done for any other project.

4. **Communication Plan.** The team has already developed a communication plan for the pilot implementation. This plan will need to be adjusted for the larger audience with the solution implementation. Lessons learnt from the pilot should be incorporated in the new plan. The Communication plan should address:

- Who needs what information
- When they need it
- How they will get it
- Who will give it to them

Effective vs. Efficient Communication

Effective communication means information to the right audience; at the right time; in the right format

Efficient Communication means providing only the information needed and avoiding information overload.

Plan Communication Management table is given below:

Inputs	Tools & techniques	Outputs
Project Management Plan	Communication requirement analysis	Communication Management Plan
Stakeholder Register which contains potentially important stakeholders	Communication technology	Control Plan Document Updates
Enterprise Environmental factors	Communication Models	
Organizational Process assets	Communication Methods and Meetings	

To calculate communication channels the formula is Nos of Channels = N (N-1)/2 where N = Number of resources

5. Costs and Benefits.

Table listed below gives Summary of key deployment questions related to candidates and costs/benefits.

Candidates	Costs/benefits
What are the criteria for selecting candidates?	Will the Six Sigma deployment organization be self-sustaining or underwritten?
Where will the candidates come from?	Will belts be hired or developed from within?
How long will the candidates/belts be away from their jobs?	Will training be purchased or developed from within?
Will the candidates be assigned full- or part-time?	Have cost savings categories been clearly defined and are they mutually exclusive?
Will the candidates' positions be backfilled?	Is there a minimum expectation of cost savings per year or project associated with a specific belt level?
Will candidates cover all organizational geographies?	
How will the situation be handled if a candidate drops out?	How are cost savings validated and by whom?
To whom will the candidates/belts report?	Who provides key data inputs used to facilitate cost savings calculations?
What will be the career path for belts?	What is the time frame associated with the cost savings?
Have the expectations of belts been established?	How does a unit's cost savings impact its budget?
How will the performance of candidates/ belts be assessed?	Will suppliers be trained?
Are candidates expected to achieve certification?	Are the cost savings real or have they just be reallocated?
	Will certification be developed and handled internally or externally?

When teams include the appropriate individuals in the process, a solutions selection matrix is very adept at identifying the best possible solutions for implementation. Leadership councils and executive sponsors often want more information about the costs and benefits expected for a solution, though, so teams should be prepared to create a cost benefit analysis. Black Belts often have many of the elements required for such an analysis after the measure and analyse phases, but teams might also need to work with accounting, finance, or business planning departments to gain accurate financial details required.

The goal of a cost benefits analysis is to compare the costs of implementing a solution with the monetary benefits expected from the solution. Costs include expenses such as software development or purchase, equipment purchase, building development or renovation, additional labour or hiring, training expenses, additional supplies, and any losses associated with disruption as the solution is implemented. Benefits might include an increase in product margin, increase in revenue, cost savings or avoidance, and intangible benefits such as increase to staff morale or customer retention.

Six Sigma teams usually aren't in a position to handle detailed cost benefit analysis such as might be completed by a certified accountant, but they can create an idea of cost benefit relationships via the payback method of analysis. This is the simplest way to approach such an analysis and provides leadership with an estimated time before a project "pays off."

Payback, or Pay Off, Analysis

To conduct a payback analysis, Six Sigma teams must have an estimated cost for the project as well as the estimated financial benefit per year. Remember, financial benefits don't just include increases in revenue. Cost savings, new customers, or mitigation of customer loss can all be considered as contributing to benefits each year. The team also needs to understand the estimated operating costs of an improvement for each year.

The formula for this analysis is:

(Cost of implementing solution) / (Annual financial benefits – annual costs)

If a project costs $50,000 to implement and $2,000 per year in extra labour, and the team expects the project to generate $15,000 in financial benefits each year, then the calculation is:

$50,000 / ($15,000 - $2,000)

$50,000/$13,000

Or, approximately 3.84 years until the project pays for itself.

Obviously, organizational leaders are looking for payback calculations that are as short as possible, but if the solution will solve a major problem or set a foundation for extraordinary success in the future, a longer payback time doesn't necessarily keep a solution off the table.

6. **Transfer to Owner** as the team concludes the project, steps need to be taken to ensure the new improved process will continue as intended. Without attention and monitoring things tend to revert to the initial stage. To make sure the gains are maintained, clear ownership and responsibilities needs to be established for the process. Tools to help monitor and control the process also need to be institutionalized. The team should consider the following points below: -
- Process Control to document the new process
- Review meetings to communicate the state of the process
- Updated flow charts
- Updated Procedures
- Control Charts to monitor the process
- Out of control action plans to define how irregularities in the process are handled.

Toll Gate Review

Tollgate reviews are a necessary part of the DMAIC infrastructure. They exist as a check and balance to ensure that teams are ready to transition from one phase to the next in an orderly manner.

The *tollgate review* is a formal review process conducted by a champion who asks a series of focused questions aimed at ensuring that the team has performed diligently during this phase. The end result of a tollgate is a "go" or "no-go" decision. The "go" decision allows the team to move forward to the next phase. If it is in the last phase, the "go" decision" brings about project closure. If the decision is "no-go," the team must remain in the phase, retreat to an earlier phase (in some instances), or perhaps the project is terminated or suspended.

Effective tollgate reviews are usually characterized by an objective evaluation of the work performed by the team during the phase and the willingness to identify and resolve problems during the reviews. Poor preparation, incomplete documentation, champions desiring to change the scope, and champions delegating replacements typically characterize poor tollgate reviews.

Many thoughts exist regarding the purpose of tollgates, who should attend them, what questions should be asked, and what are the exit criteria from the toll-gate phase. Table listed below provides a summary of one viewpoint. The "questions to address" are minimal in the table, but they are critical. Notice that the first question asked is "Is the project consistent with the goals of the organization?" Project alignment to the strategy and subsequently the goals and objectives of the organization has been a recurring theme throughout this book. This question appears in every phase because of the highly dynamic nature of organizations. When the answer is "no," it is incumbent upon the champion to shut the project down and allow the project

resources to be allocated elsewhere. However, notice there is something particularly unique about this question. Unlike the others in the table, this question should be both asked and answered by the champion for it is simply a rhetorical question posed to the team. It is the champion who is in the position to have direct access to the proper resources to be able to answer this question. The champion should come prepared at each and every tollgate to address this critical question.

Tollgate reviews, when executed well, provide real value to the Lean Six Sigma deployment. They keep projects focused and on track, and executives and champions engaged.

Additional questions to be asked by the champion during tollgate reviews.

Phase	Questions
Define	• Who are the stakeholders? • What are the primary and secondary measures? • Are you facing any barriers or obstacles I can help with? • Are we on schedule/budget?
Measure	• What is the process capability? • What data still remain to be collected? • What did the FMEA show? • What questions still remain to be answered about the process? • Are you facing any barriers or obstacles I can help with? • Are we on schedule/budget?
Analyze	• What are the critical X's? • What are the root causes? • Are you facing any barriers or obstacles I can help with? • Are we on schedule/budget?
Improve	• What is the process capability of the revised process? • What criteria will be used to select the optimum solution from the set of solutions? • Will we run a pilot? • Are you facing any barriers or obstacles I can help with? • Are we on schedule/budget?
Control	• Is the process documented? • Is the control plan completed? • Has the process been transitioned back to the process owner? • What lessons have we learned? • Do we know where we might be able to replicate our new process across the organization? • Are you facing any barriers or obstacles I can help with? • Are we on schedule/budget?

Source: Adapted and compiled from Phillips and Stone (2002).

Total Production Maintenance: -

What is TPM? TPM Stands for total production Maintenance and builds a close relationship between Maintenance and productivity showing how good care and up-keep of equipment will result in higher productivity, which will result in Creating more capability in Existing resources. It is a philosophy of continuous improvement that creates a sense of ownership in the operator(s) of each machine as well as in their supervisor. It is a process of maintenance management that empowers the organization with a progressive, continuous philosophy of enabling all manpower resources to work together to accomplish the mutual goal of manufacturing efficiency.

Below listed is the diagram of 8 Pillars of TPM.
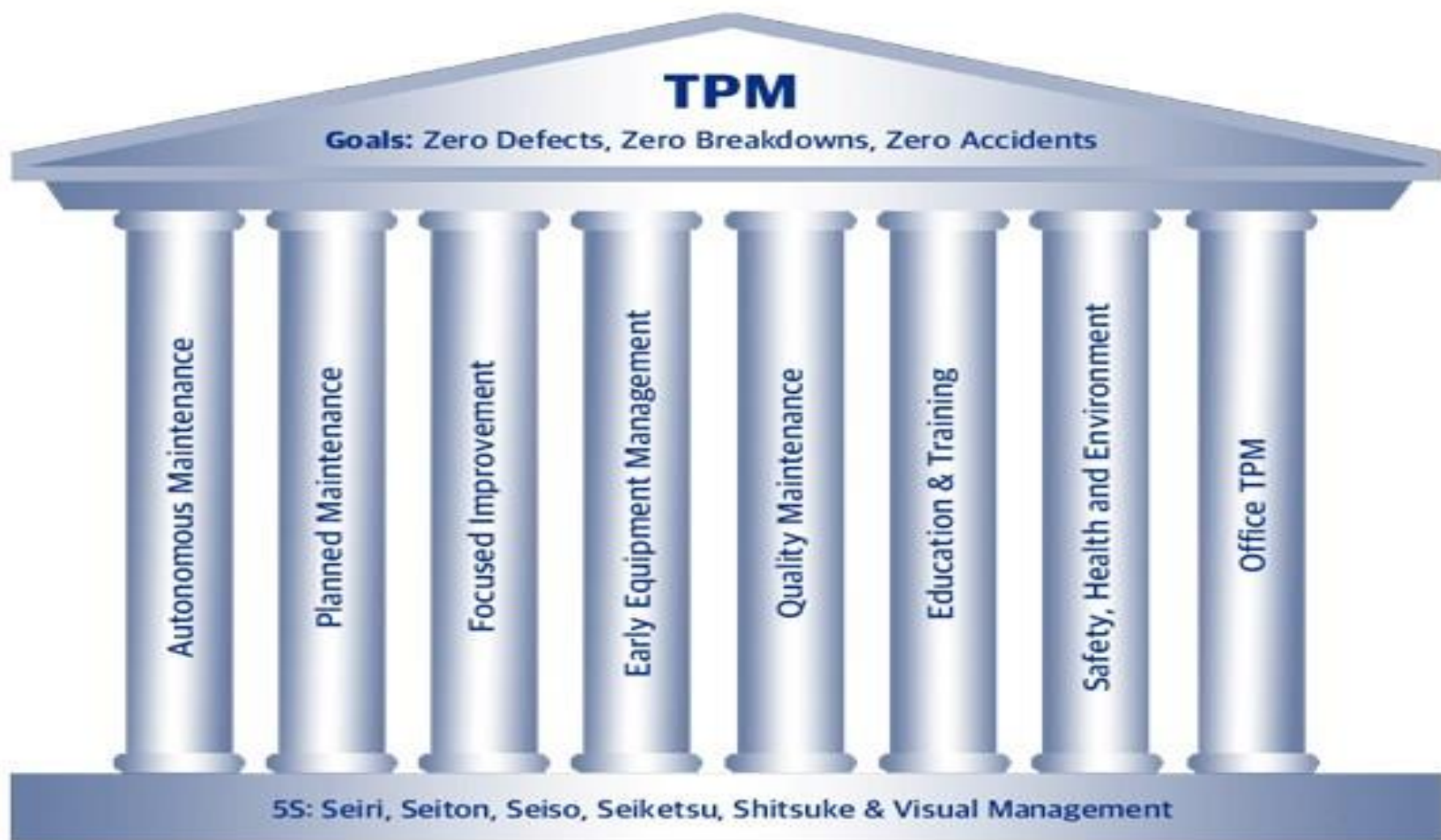
16 Major Loses Defined In TPM is Given Below :-
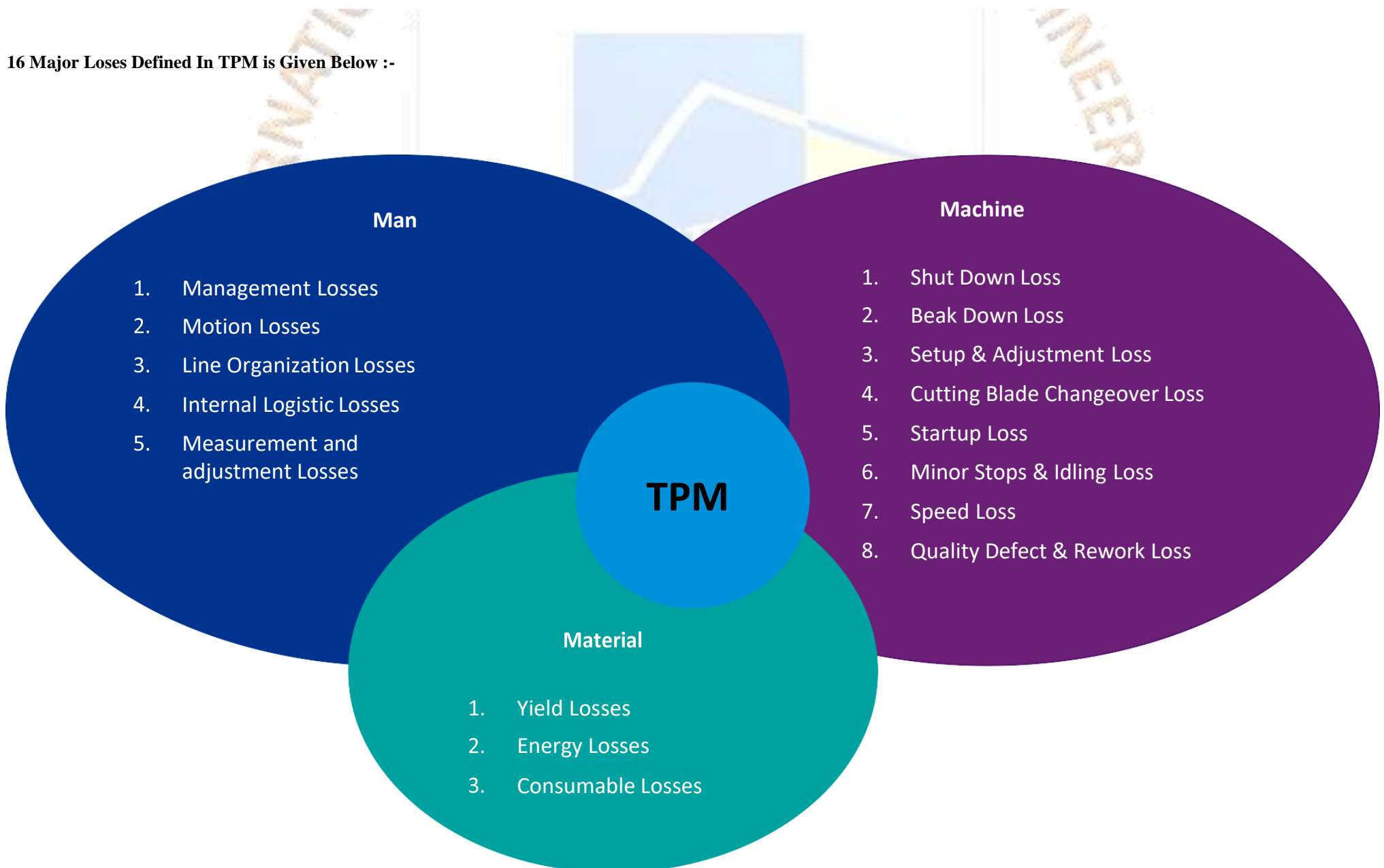
Define Phase Questions – Management Perspective

Pre-Project Launch

1. Who is the customer and how will this project benefit the customer?

2. What is the impact on the business?

3. What is your problem or opportunity statement- What are you trying to fix or avoid?

4. How will the project help the business?

5. Has the project been narrowed to complete in an appropriate time frame?

6. Are there sufficient resources in place to ensure project success?

7. Taking into account the opportunity statement, goals and scope outlined what is the teams charter?

Post Project Launch

8. Describe what you learned from the as-is process mapping.

9. What are the critical to customer requirements?

a. How did you determine them?

b. How are you measuring them?

c. How good is the measurement system?

d. Have you verified them with the customer?

e. Do the current specifications reflect them?

10. What are the critical to business requirements?

11. What are the quick wins?

12. Has the team put together a communication plan to let relevant people in the organization know what is happening and to regularly solicit inputs?

13. What are the next steps?

Measure Phase Questions – Management perspective

1. What are the key goals for this project?

2. What is the impact on the business? What strategic objectives will be impacted and how?

Questions about Metrics and Measurement

3. What critical to quality metric has been identified and how do they know the customer is impacted by them?

4. What critical to process metrics are important to the business?

5. Which ctq's / ctp's does this project focus on? why?

6. How do you know the data collected are representative of the process?

7. Is the team rigorously following the appropriate methodology?

8. Do they adequate resources to complete the project?

Questions relevant to six sigma teams

9. What have they learned about the source of the variation from the initial data gathered? Is the process in control?

10. What is the current process sigma?

Questions for all teams

11. Did the team re-scope the project as a result of the measurement phase?

12. What are the next steps?

Questions in the Analyse Phase

1. What is the statement of the problem in terms of cause and effect?

2. What are the vital few factors causing variation in the output?

3. What analysis exist to verify the root cause?

4. Are you being open minded and creative in your team thinking about causes?

Questions mostly relevant to six sigma teams

5. How much of the problem is explained with the vital X's? How much unexplained variation exists?

6. Are the vital few X's statistically significant? are the effects of practical significance?

Questions for all teams

7. Are any of the current learnings transferrable across the business?

8. Do you have adequate resources to complete the project?

9. What are the next steps?

Improve phase – Management Perspective

Questions for all teams

1. What is the alternative solutions did the team consider for solving the problem?

2. How was the current solution selected?

3. What are the expected benefits from the solution? What are costs?

4. How will you communicate the solution to the organization?

5. Will the team make use of pilot project teams or do they have a complete fix?

6. Do you have adequate resources to complete the project?

7. What are the next steps?

Control Phase – Management Perspective

Questions for all teams

1. Did the team conduct a pilot of the new process? What was learned and changed as a result of the pilot?

2. What is the new process result(Sigma)? Has the project achieved its goals? has the team demonstrated the new result with the data?

3. Is the learning transferrable across the business? What is the action plan for spreading the best practice? What lessons did the team learn?

4. What are the variables being monitored to assure that the process performance improvement continues?

5. What training has been conducted to assure the new process runs as expected? How are new habits or behaviours being learned?

6. What are the financial results of the project? How they have been calculated and documented? What change is the customer seeing?

7. What are next steps?

14.SIX SIGMA PROJECT EVALUATIONS

Project name	Date of Assessment		
Black belt	Master Black Belt		
Weighted overall project score	Project Number		
Criteria	Score	Weight	Weighted Score
Sponsorship			
Benefits (Specify Main Beneficiary)			
External Customer			
Shareholder			
Employee or Internal Customer			
Other (e.g. Supplier, Environment)			
Availability of resources other than team			
Scope in terms of black belt effort			
Deliverable			
Time to Complete			
Team membership			
Project Charter			
Value of Six Sigma Approach			
TOTAL (Sum of Weighted Score Column)			
Note any criterion scores of zero must be addressed before the project is approved			
Weighted Score = Project Score for each criterion times the weight			

1.0 Sponsor Ship

Score	
9	Director-level Sponsor Identified , duties specified, Sufficient time committed and scheduled
3	Director-Level sponsor identified duties specified and sufficient time committed but not scheduled
1	Willing Director-Level sponsor who has accepted charter statement
0	Director-level sponsor not identified or sponsor has not accepted the charter

2.0 Stakeholder Benefits

2.1 Stakeholder: External Customer

2.1.1 Customer Satisfaction

Score	Interpretation
9	Substantial and statistically significant increase in overall customer satisfaction or loyalty
3	Substantial and statistically Significant increase in major subcategory of customer satisfaction
1	Substantial and statistically Significant increase in focussed area of customer satisfaction
0	Unclear or non-existent customer satisfaction impact

2.1.2 Quality Improvement (CTQ)

Score	Interpretation
9	10 x or Greater is critical to quality (CTQ) Metric
5	5 x to 10 x improvement in CTQ Metric
3	2x to 5 x improvement in CTQ Metric
1	Statistically significant improvement in CTQ metric but less than 2 x magnitude
0	Project's impact on CTQ metrics undefined or unclear

2.2 Stakeholder Shareholder

Score	Interpretation
9	Hard Net Savings (Budget or Bid Model Change greater than $ 500 K Excellent ROI
5	Hard Net Savings Between $ 150 K and $ 500 K Excellent ROI
3	Hard net savings between $ 50 K and $ 150 K or cost avoidance greater than $ 500 K Good ROI
1	Hard savings of at least $ 50 K or cost avoidance between $ 150 K and $ 500 K Acceptable ROI
0	Project claims a financial benefit but has hard savings less than $ 50K cost avoidance less than $ 150 K it becomes unclear financial benefits achieved

2.2.2 Cycle Time Reduction

Score	Interpretation
9	Cycle Time reduction that improves revenue , bid model or budget by more than $ 500 K Excellent ROI
5	Cycle Time reduction that improves revenue , bid model or budget by $ 150 K to $ 500 K Excellent ROI
3	Cycle Time reduction that improves revenue , bid model or budget by $ 50 K to $ 150 K Creates a cost avoidance of more than $ 500 K . Good ROI
1	Cycle time reduction that results in cost avoidance between $ 150 K and $ 500 K acceptable ROI
0	Project Claims a cycle time improvement but has hard savings less than $ 50 K , cost avoidance less than $ 150 K or unclear financial benefits from the improvement in cycle time

2.2.3 Revenue Enhancement

Score	Interpretation
9	Significant increase in Revenue , Excellent ROI
3	Moderate Increase in Revenue , Good ROI
1	Increase in revenue with acceptable ROI
0	Unclear or non-existent revenue impact

2.3 Stake Holder , Employee or Internal Customer

2.3.1 Employee Satisfaction

Score	Interpretation
9	Substantial and statistically significant increase in overall employee satisfaction
3	Substantial and statistically significant increase in major element of employee satisfaction
1	Substantial and statistically significant increase in focussed area of employee satisfaction
0	Unclear or non-existent employee satisfaction impact

2.4 Stakeholder : Other

2.4.1 Specify Stakeholder …………………………………………………

Benefits

Score	Interpretation
9	
5	
3	
1	
0	Unclear or Non-Existent Benefits

3.0 Availability of resources other than team

Score	Interpretation
9	Needed Resources available when needed
3	Limited or low priority access to resources
0	Resources not available or excessive restrictions on access to resources

4.0 Scope in terms of Black Belt Effort

Score	Interpretation
9	Projected returns substantially exceed required returns
3	Projected return exceeds required return
1	Projected Return approximately equals required return
0	Projected return not commensurate with required return

5.0 Deliverable (Scope)

Score	Interpretation
9	New or improved process, product or service to be created is clearly and completely defined
3	New or improved process, product or service to be created is defined
0	Deliverable is poorly or incorrectly defined for example a "deliverable" that is really a tool such as process map

6.0 Time to Complete

Score	Interpretation
9	Results realized in less than 3 months
3	Results realized in between 3 and 6 months
1	Results realized in 7 to 12 months
0	Results take more than 12 months to be realized

7.0 Team membership

Score	Interpretation
9	Correct Team members recruited and time commitments scheduled
3	Correct team members recruited time committed but not scheduled
1	Correct team members recruited
0	Team members not recruited or not available

8.0 Project Charter

Score	Interpretation
9	All elements of the project charter are complete and acceptable. Linkage between project activities and deliverable is clear
3	Project charter acceptable with minor modifications
0	Project charter requires major revisions

9.0 Value of Six Sigma Approach (DMAIC or Equivalent)

9	Six Sigma approach essential to success of the project. Black Belt/Green Belt skill set required for success
3	Six Sigma approach helpful but not essential. Black Belt/Green Belt skill set can be applied
0	Usefulness of Six Sigma Approach not apparent. Specific Black Belt or Green Belt Skills are not necessary.

15.SIX SIGMA BUSINESS SCORECARD

The six sigma business scorecard provides the intellectual framework for measuring a comprehensive view of the organizational performance. The six sigma business scorecard was developed by Motorola University Consultant Praveen Gupta, in response to organizations need to measure and track the progress of all aspects of a business employing six sigma. The six sigma business aligns departmental performance to the customer expectations of better, faster and cheaper products or services.
The seven elements of six sigma scorecard are given below

➢ Leadership and profitability(LNP)

➢ Management and Improvement(MAI)

➢ Employees and innovation(EAI)

➢ Purchasing and Supplier management(PSM)

➢ Operational Execution(OPE)

➢ Sales and Distribution(SND)

➢ Service and growth(SAG)

Category	Objective	Areas of Measurement Metric
Leadership and Profitability(LNP)	Lead Company to wellness and Profitability	Communication Inspiration Planning Accuracy Community Perception Employee Perception Employee Recognition Compensation Asset utilization Return on investment Debt to Equity Ratio Profitability Shareholder's Value Growth
Management and Improvement(MAI)	Drive Dramatic Improvement	Goal Setting Rate of Improvement Planning for Improvement
Employees and Innovation(EAI)	Involve Employees Intellectually	Innovative Recommendations per employee Investment per employee Number of patents or publications per employee
Purchasing and Supplier Management(PSM)	Reduce cost of goods or services	Material Acceptance Total spent/sale Supplier Defect rates (Sigma) Cost of Goods/Services Sold
Operational Execution	Achieve Performance Excellence	Operational Cycle Time Process Defect Rate (Sigma) Customer Defects, Total Defects
Sales and Distribution(SND)	Manager Customer relations and Generate revenue	Number of Inquiries, New Business Dollars/Total Sales Profit margin($)/Sales
Service and growth(SAG)	Gain Competitive advantage and grow	Customer satisfaction Customer retention Repeat business ($)/Total Sales New Product or services patents or trademark

LEAN SIX SIGMA FOR YOUR SUPPLY CHAIN

Lean Six Sigma improves your production process in many different ways. Lean's singular focus on eradicating all types of waste and Six Sigma's dedication to eliminating defects by reducing process variance makes the combination a powerful tool for creating continuous process improvement.

Organizations are now using Lean Six Sigma to eliminate waste and reduce variance in their supply chains. Lean Six Sigma helps increase efficiency in several ways:

Decreasing Order Fulfilment Time

Using Lean Six Sigma to review the organization's order fulfilment system helps project teams spot areas with high degrees of waste and variance. Once identified, inefficiencies in the order fulfilment process can be corrected by reducing paperwork, automating picking and shipping planning, and automating shipment verification. The Six Sigma DMAIC cycle helps enhance an existing order fulfilment process, and DMADV helps create a new process.

Building a Responsive Supply Chain

An organization's supply chain must be agile and quickly responsive to the changing needs of its customers. Companies that are attuned to their customer's changing needs have completed a vital first step in creating a supply chain that fulfils these needs. The define phase of Six Sigma requires organizations to measure their progress in terms that customers consider to be critical to quality (CTQ).

Reducing Errors to Zero

Supply chains made inefficiently with high error rates need Lean Six Sigma. Many points in the supply chain can benefit from the Lean technique of Poka-Yoke. This is a mistake-proofing procedure that prevents human error by forcing the user to complete the task correctly. For example, a software enabled drill counts the number of holes drilled into a work piece; a buzzer sounds if the work piece is removed before the correct number of holes has been drilled.

The 5S Lean principle also reduces errors by eliminating the wastes that can cause them. The 5S method stands for Sort out, Set in order, Shine, Standardize and Sustain. It helps to create a clean, safe, efficient and uncluttered environment that reduces the odds of human error.

Optimizing Order Fulfilment

Orders are filled to completion when they arrive on time, with full and accurate documentation and no delivery damage. Six Sigma does its part to optimize order fulfilment by spotting problems in the system like an outdated planning processes or inefficient execution. Lean then comes into play to reduce waste and improve order fulfilment.

Reducing Waste

Lean eliminates activities that don't add value to the customer, a.k.a. waste. Lean eliminates non-value added processing to help supply chains function more efficiently. Lean targets the greatest sources of waste.

- **Over-production** – Building up a greater inventory that customers demand based on speculative forecasting. This results in high inventory costs.
- **Transportation** – Moving materials around more than needed causes increased production costs and cycle time.
- **Non-value added processing** – Additional work that adds no value to the product is frequently caused by a poor production facility layout. When Lean simplifies production, the supply chain operates more efficiently.

Lean Six Sigma helps the companies improve the performance of their supply chains. An efficient supply chain provides a sustainable competitive advantage and increases revenue.

Assessing for Lean Six Sigma Implementation and Success

Successful corporate initiatives such as Lean Six Sigma require proper planning, prioritization, resource allocation, budgeting, training, and proper review and reward mechanics. These initiatives also must consider the stability, accuracy and maturity of the core processes, measurement systems and the people they will affect.

In most organizations there is a wide range of both experience and infrastructure to deal with such issues. This variation can be attributed to a variety of causes including – organizational structure (e.g., centralized versus decentralized), organization size, geographical diversity, previous initiative rollout experience, management style/culture, management infrastructure (e.g., tools to enable clear and concise communication, measurement and reward/recognition) and contention for the best resources. Within this dynamic environment of moving parts lies the groundwork for a highly successful initiative or – at the other end of the spectrum – a train wreck.

Understanding these processes and systems enables an organization to logically build out an implementation plan while mitigating potential risks of failure. This is the concept behind a readiness assessment used to drive successful initiative planning and rollout.

Use What's Already Available

Several factors must be considered when deciding when, how and just how much assessment to do. Mature organizations may already have in place a variety of comprehensive and regularly scheduled assessments, from which much of the necessary information may already be available. These may include assessments and audits such as the ISO Series (ISO9000), CMM/CMMi®, national or state quality awards, or a company's own existing assessment program. While each of these assessments may have been created for a purpose other than determining readiness for a Six Sigma initiative, many of their attributes are useful in determining readiness or maturity.

Assessment Goals

- Validate critical business measures and selection high leverage projects (from existing clusters).
- Identify leverage points and areas of opportunity in upcoming projects and existing processes.
- Identify potential obstacles and mitigation strategies.
- Recommend a set of next steps and tune Six Sigma deployment plan accordingly.
- Minimize risk and improve cycle time of deployment (especially project selection).

Existing strategy documentation, goals and objectives, policies, procedures, process documentation, data, organizational charts and other pertinent plans and information will provide a basis for evaluating both the scope of the prospective assessment and serve to help in the planning and preparation for the assessment.

Communicate to Avoid Organizational Resistance

Any assessment can be a source of trepidation for an organization. Without communicating the purpose of the assessment, the schedule, the roles and responsibilities of individuals during the assessment, the confidentiality of statements and documentation, and what will be done with the results, organizational resistance can create an environment where gleaning accurate information will be nearly impossible. Generally speaking, any assessment should be communicated to the organization well in advance of when people will be required to respond.

Communications also may be repeated a few times to reinforce its importance. It is usually best if senior management details the assessment purpose, scope, context, size, location(s), dates and intended follow-up. This communication also should state a firm commitment to the process, a solicitation for full forthright cooperation and an assurance of confidentiality. This type of communication when reinforced in regularly scheduled meetings and informal communications will help to reduce organizational resistance and assure a free flow of accurate information.

Post-assessment communications also should be scheduled. Sharing information with the people who participated helps develop buy-in for the results and subsequent actions to be taken.

Planning Essential for Assessment Success

Planning for an assessment will be gated by the scope and context of the initiative and the organization. Most readiness assessments involve either interviewing or surveying of a cross-functional and/or cross-organizational group of people. One way to envision the survey/interview population is by imagining a diagonal slice of the organization. Given this view, the company needs to be sure it elicits information from all constituencies in a way that provides a balanced view of what is going on (from strategic/organizational elements to tactical/operational elements).

If an organization is organized by product line, similarly, it needs to acquire equally distributed information across all product lines. Practically speaking this means, everyone from senior executives to process participants must be interviewed. These views will help to characterize and highlight the alignment of the organizations strategies, goals, programs, processes and metrics. This alignment is important to test for, as strong alignment contributes significantly to the strength and longevity of a successful initiative. **Lack of alignment means that communications, priorities and actions will become clouded and subject to drift or ambiguity.**

This distribution also provides a clear view of the aggregate organization with visibility into "leverage able strengths" and/or specific opportunities for improvement. For these reasons some level of "randomness" must be assured in the case of developing a sample population to survey or interview.

One of the primary inputs to the assessment process is what people in the organization actually do in the performance of their daily work. Deciding how, how many and who that information is elicited from is a critical decision in the process. When considering the survey or interview populations, several choices should be considered:

Sample size (how many and from where) – This is often determined by the size of the organization and whether or not web-based technology is used. If assessing an organization of 500-5,000 associates and utilizing an interview-based model, sample sizes should be 3 to 5 percent of the population. When using web-based technology, a sample size of 100 percent is not out of the question. Web-based assessments while missing on actual observation and dialog, add the capability to collect, process and store a large amount of data quickly, which enhances the ability to reuse and drill down in the detailed data.

Demographics (various locations, cultures and or geographies) – Demographics are important to learn about in an assessment. Often locally tuned processes and practices are getting results and thus may be ripe for adoption by the organization at large. Sometimes certain geographies are required to comply with local laws or requirements. A supply chain view also is worth considering. It can be highly desirable to include several customers, clients or even suppliers in the assessment. This is a great way to see how external sources view the strengths and weaknesses of a process.

Availability of information (from other sources including other audits and assessments) – If a recent and rich source of information exists (previous audit or assessment) it only stands to reason that this information is useful. Even if it appears to be in conflict with other things discovered. This often happens when things are being done in a vacuum or pocket of excellence. All are useful things to learn.

Use of technology (specifically, web-based survey and assessment tools) – Web-based tools for assessments are gaining popularity and accuracy. It is important to differentiate between "survey only" and assessment tools. Assessment tools usually have some type of intelligence built in to generate comparative and gap analysis

automatically. They typically can trap user comments and opinions, which can then be stored for quick retrieval and summarization. There are many advantages to web-based systems but no web-based system can observe actual behavior. Usually some combination of web technology and observation-based validation provides the most accurate result.

Timing (of the initiative and other things going on in the organization) – All efforts should be made to plan an assessment in concert with the initiative scheduling process. Sometimes when senior management announces a timeline for an initiative it does not consider the assessment. The assessment becomes an afterthought and then must be rushed. While not the optimum way to execute, good planning and frequent communication can help overcome this shortfall.

Organizational culture (receptiveness or resistance to assessment) – If this is the first time an organization has undergone a formal assessment, it is normal to see significant organizational resistance. The best way to overcome this is by meticulous planning and frequent communication. Organizations used to such events will be able to move faster with less communication.

Availability of people (resource bandwidth given the type of work being performed) – Careful consideration should be given to make people available to participate without any negative consequences. Typically, a survey or interview will require an hour or so of preparation and an hour in an actual interview or survey. Management must create a safe ground for employees to participate.

Once the above is understood and agreed to by the target organization and the assessment team, development of the interview schedule, or in the case of a web-based tool, a deployment plan should commence. Schedules need to be specific about times, locations, names, titles and functional responsibility. The organization being assessed typically provides an administrative resource to manage and communicate the master schedule and changes which may occur during the course of interviews.

Assembling the Results of Assessment

A typical readiness assessment is conducted by a team of two or more assessors with a goal of deriving an objective and unbiased expert characterization of an organization based on the information collected. Consensus between assessors is critical to drive out error and bias and fully examine all points of view. The examiner training used by the Malcolm Baldrige National Quality Award program provides an excellent model for assessment teams to build and derive consensus leading to valid conclusions. Generally a documented body of knowledge (quality, Six Sigma, management, software, etc.) is tapped to help identify organizations' leverageable strengths, opportunities for improvement and priorities for the pending initiative.

Examples of typical results might point to (as a leverage able strength) "a strong sense of pervasive process focus and documentation as evidenced by procedures and the rigor with which they are used." It is a strength because the organization recognizes the need and importance of process focus and has an established system with which to keep them documented. It is leverage able because best practices suggest process rigor and documentation are a critical success factor to institutionalize and control an optimized system or process.

A corresponding opportunity for improvement may indicate, "The measurement system is inconsistently used and the collection and characterization of data is highly variable." This might suggest that a significant effort using measurement system analysis (MSA) would be required to validate both project selection criteria and the execution of the projects themselves. Additionally, pockets of excellence (places where excellent measurement systems have been validated and are in use) may indicate areas ripe for early adoption of more advanced techniques. These characterizations are usually completed process-by-process, scored and aggregated into an organization-wide baseline.

Process Maturity Assessment (One per Core Process)

Conclusion: Creating Action and Deployment Plans

Communication and use of the assessment results require careful interpretation and discussion amongst the core deployment team. Identified gaps and opportunities for improvement may indicate places to avoid for early adoption until fundamental and systematic changes can be implemented (e.g., establishment of a process management system or establishment of a measurement system). On the other hand, leverage able strengths and pockets of excellence may provide rich early adoption process and project opportunities. Action plans and deployment plans can now be intelligently prepared, communicated, prioritized and implemented.

The assessment process also helps to identify and validate initial project clusters for consideration as Lean or Six Sigma projects. These will need to be qualified, quantified, scoped and prioritized accordingly as the program rolls out.

It is important that everyone involved in the assessment be kept abreast of what the results are and what is being done with the results. This keeps an organization engaged in the process and helps to develop buy-in for the plan. In many cases the organization may elect to perform a follow-up assessment one or two years later to observe changes in the baseline. Many times an organization becomes either satisfied with the great results of the early part of the program (low hanging fruit) or becomes distracted and complacent. In this case, major savings opportunities may be missed and cause the program to fade.

Supplementing a readiness assessment with a deployment assessment enables an organization to keep the initiative on track and monitor organizational behaviours and performance related to the initiative's critical success factors.

References

The Certified Master Black belt by Kubiak; DFSS by Klaus Hogreve;Delivering Successful projects with TSP and Six Sigma by Mukesh Jain;lean Six Sigma by Lawton; Six Sigma for Business Excellence by Hemant Urdhwareshe; Six Sigma Handbook by Thomas Pyzdek and Paul Keller, Six Sigma Black Belt Handbook by Thomas Mc Carry-Michael Bremer & Praveen Gupta; Kaner & Walter P. Bond-Software Engineering Metrics-What do they Measure and How do we Know; Google Search Engine, Microsoft Bing Search Engine & articles from academia.edu.
Reference Software Free Trial Used: 30 Days-Minitab19; SigmaXL; Companion by Minitab Version 5 Software & Minitab Workspace.
Statistical Tables used as Reference to do critical Statistic Calculation: T-Table; Mann Whitney Table; Chi-Square Table; F- ANOVA table which are available in Google search.