Roll no. - 22236761078

Project Report

on

"PROCESS QUALITY MANAGEMENT"

undertaken at

"C. L. Gupta Exports Ltd."

submitted by

Pranjal Dubey

in

Partial fulfilment of the Requirement of the Degree of

Master of Operational Research

To

Department of Operational Research

Faculty of Mathematical Sciences

New Academic Block

University of Delhi

Delhi – 110007

DEPARTMENT OF OPERATIONAL RESEARCH
FACULTY OF MATHEMATICAL SCIENCES
NEW ACADEMIC BLOCK
UNIVERSITY OF DELHI
DELHI-110007

Name of the Student	:	Pranjal Dubey
Title of the Project	:	Process Quality Management
Date of Commencement of the Project	:	March 22nd, 2024
Date of Submission of the Project	:	May 20th, 2024
Name and Address of the Organization	:	C. L. Gupta Export Ltd. 18 Km. Stone, Delhi Road, Vill. Jivai, Uttar Pradesh 244221
Supervisors from the teaching faculty	:	Prof. Preeti Wanti Srivastava Prof. Chandra Kant Jaggi Prof. P.C. Jha Prof. Pankaj Gupta Prof. K.K. Aggarwal Prof. Anu Gupta Aggarwal Prof. Ompal Singh Prof. Mukesh Kumar Mehlawat Dr. Aditi Khanna Dr. Vandana Khaitan Dr. Abhishek Tandon Dr. Sameer Anand Dr. Shilpi Verma Dr. Adarsh Anand Dr. Kaushal Kumar Dr. Gurjeet Kaur Dr. Jagvinder Singh

CERTIFICATE

This is to certify that the project entitled **"PROCESS QUALITY MANAGEMENT"** is my original work carried out at "C. L. Gupta Exports Ltd.", 18 Km. Stone, Delhi Road, Vill. Jivai, Uttar Pradesh 244221 in the year 2024, and has been submitted for the partial fulfilment of the course Master of Operational Research (MOR).

The project report has not been submitted earlier or in full or in part for any other diploma or degree to any other University or Institute to the best of my knowledge.

Pranjal Dubey
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ACKNOWLEDGEMENT

I would like to thank all those sincerely, who have helped me in successful completion of this project. I would like to express my sincere thanks and appreciation to Prof. Prakash C. Jha for providing us with an opportunity to do the project under his valuable supervision. Without his assistance, I would not have been able to complete my project successfully.

I express my sincere gratitude to our benevolent Professors Prof. Preeti Wanti Srivastava, Prof. Chandra Kant Jaggi, Prof. Prakash C. Jha, Prof. Pankaj Gupta, Prof. K. K. Aggarwal, Prof. Anu Gupta Aggarwal, Prof. Ompal Singh, Dr. Mukesh Kumar Mehlawat, Dr. Aditi Khanna, Dr. Vandana Khaitan, Dr. Abhishek Tandon, Dr. Sameer Anand, Dr. Shilpi Verma, Dr. Adarsh Anand, Dr. Kaushal Kumar, Dr. Gurjeet Kaur and Dr. Jagvinder Singh.

I would also like to thank PhD and M. Phil students for their guidance and co-operation throughout my project. I also would like to thank my family and friends for their kind assistance and silent motivation.

I am grateful to Mr. Priyank Gupta, General Manager, C. L. Gupta Exports Ltd., without whose help this project would have never materialized.

Pranjal Dubey
Master of Operational Research
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CONFIRMATION LETTER

C. L. Gupta Exports Ltd.

18 km before Moradabad - Delhi Highway,
Vill. Jivai, Amroha - 244221, (U.P.) India
CIN : U74999 DL2004 PLC 125090
GSTIN : 09AACCG0992J1ZC

Tel. : +91-591-2477000
Fax : +91-591-2477300
e-mail : mail@clgupta.com
Web : www.clgupta.com

To,
The Head of Department
Department of Operational Research
University of Delhi
Faculty of Mathematical Sciences
Delhi-110007

Date: 22nd March, 2024

Subject: Regarding assignment of project at C. L. Gupta Exports Ltd.

Dear Ma'am,
This is with reference to your request letter received regarding permission to do a project in our company C. L. Gupta Exports Ltd.
We are pleased to inform you that your request has been accepted and the company hereby give permission to Pranjal Dubey from Department of Operational Research, University of Delhi to do a project on Quality Management.
I would like to inform you that the project assignment is for academic purposes only. The data will be kept confidential and used solely for academic purposes. He will be associated with us until the completion of the project and will be provided with all the relevant inputs.

best regards

Priyank Gupta
GM

Manufacturer & Exporters
Brass Art Ware • E.P.N.S. Ware • Wrought Iron Ware • Glass & Crystal Ware • Iron & Steel Ware • Wooden Furniture & Accessories

Regd. Office : DPT 337, DLF PRIME TOWER, OKHLA, PHASE 2, NEW DELHI-110020

COMPLETION LETTER

C.L. Gupta Exports Ltd.

18 km before Moradabad - Delhi Highway,
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CIN : U74999 DL2004 PLC 125090
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Tel. : +91-591-2477000
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Web : www.clgupta.com

To,
The Head of Department
Department of Operational Research
University of Delhi
Faculty of Mathematical Sciences
Delhi-110007

Date: 15th May, 2024

Subject: Completion of Academic Project

Dear Ma'am,
This is to certify that Mr. Pranjal Dubey, student of Master of Operational Research, University of Delhi has successfully completed his academic project for C. L. Gupta Exports Ltd. and submitted the project titled "PROCESS QUALITY MANAGEMENT".

best regards

Priyank Gupta

GM

Manufacturer & Exporters
Brass Art Ware • E.P.N.S. Ware • Wrought Iron Ware • Glass & Crystal Ware • Iron & Steel Ware • Wooden Furniture & Accessories

Regd. Office : DPT 337, DLF PRIME TOWER, OKHLA, PHASE 2, NEW DELHI-110020

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ABSTRACT

In this study, we make use of DMAIC Six-Sigma Model to improve the quality of process of producing cuboidal shaped MS pipes. Manufacturing sector is instrumental in driving economic growth of a country.

Several steps have been taken in the past few years to strengthen the manufacturing capabilities in the country. Besides strengthening the logistic and supply chain infrastructure there is a need to build on the global quality standards and innovation culture for right positioning of Indian produce in the global supply chains.

This study discusses the implementation of a Six Sigma quality improvement project in an Indian MNC organization involved in the manufacturing of MS pipes with an aim to reduce the repairs and rejections. We also illustrate an effective multi-criteria defect prioritization analysis based on AHP methodology to identify the key defects to prioritize the improvement efforts. This method prioritizes the key defect considering various other attributes such as critical to customers rather than only the frequency of defects.

The study also illustrates application of several quality management techniques such as cause and effect analysis, current reality tree, inter- relationship diagram, SIPOC analysis and quality control charts in the DMAIC stages.

Introduction to Operational Research

OPERATIONAL RESEARCH

"The science of better"

As the name implies, operational research involves "research on operations". Thus, operations research is applied to problems that concern how to conduct and coordinate the operations (i.e., the activities) within an organization. Operational Research (OR) is a science which deals with problem, formulation, solutions and finally appropriate decision making. In the decades after the two world wars, the tools of operational research (OR) were more widely applied to problems in business, industry and society. It is often concerned with determining the extreme values of some real-world objective: the maximum (of profit, performance, or yield) or minimum (of loss, risk, or cost). Originating in military efforts before World War II, its techniques have grown to concern problems in a variety of industries. Since that time operational research has expanded into a field widely used in industries ranging from airlines, finance, logistics, and government, moving to a focus on the development of mathematical models that can be used to analyze and optimize complex systems, and has become an area of active academic and industrial research.

Operational Research encompasses the development and use of a wide range of problem-solving techniques and methods applied in the pursuit of improved decision making and efficiency. It is often considered as a sub-field of applied mathematics.

DEFINITIONS

Defining OR is difficult task as its boundaries and content are not yet fixed. It can be regarded as use of mathematical and quantitative techniques to substantiate the decision being taken. Further, it is multidisciplinary which takes tools from subjects like mathematics, statistics, engineering, economics, psychology etc. and uses them to score the consequences of possible alternative actions. Today it has become professional discipline that deals with the application of scientific methods to decision-making. Salient aspects related to definition stressed by various experts on the subject are as follows:

" The high-tech field of OR offers numerous excellent opportunities to boost performance immediately. Yet OR Practitioner time remains to skim the cream before everyone wakes up to the projects. When most do wake up, USA companies that are not taking full advantage of OR will leave serious money on the table and be outflanked competitors."

--Randy Robinson

“Operations Research is the systematic application of quantitative methods, techniques and tools to the analysis of problems involving the operations of systems.”

--Daellanbach and George 1978

“OR is a scientific knowledge through interdisciplinary team effort for the purpose of determining the best utilizations of limited resources.”

--H A Taha

“OR is the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to the problem.”

--C W Churchman, R L Ackoff & E L Arnoff

“Operations Research may be described as a scientific approach to decision- making that involves the operations of organizational system.”

--F S Hiller and G J Lieberman, 1980

“OR is the art of giving bad answers to the problems which otherwise have worse answers.”

--T L Satty

“OR is the scientific approach to problem solving for executive management.”

--H M Wagner

Some other definitions are as follows:

- Operational Research is the application of the methods of science to complex problems in the direction and management of large systems of men, machines, materials and money in industry, business, government and defense. The distinctive approach is to develop a scientific model of the system incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies or controls. The purpose is to help management in determining its policy and actions scientifically.

- Operations Research is the systematic application of quantitative methods, techniques and tools to the analysis of problems involving the operation of systems.

- Operations Research can be characterized as the application of scientific methods, techniques and tools, to problems involving the operations of a system to provide those in control of the operations with optimum solutions to the problems.

- Operations Research is the professional discipline that deals with the application of information technology for informed decision-making. It aims to provide a rational base for decision making by seeking to understand and structure complex situations and to use this understanding to predict system behaviour and improve system performance. Much of this work is done using analytical and numerical techniques to develop and manipulate mathematical and computer models of organizational systems composed of people, machines, and procedures.

OPERATIONS RESEARCH SOCIETY OF INDIA

The Operational Research Society of India was founded in 1957 to provide a forum for the Operational Research Scientists as well as an avenue to widen their horizon by exchange of knowledge and application of techniques from outside the country. To further that end, the Society is affiliated to the International Federation of Operational Research Societies (IFORS). The objectives of the Society shall be the promotion and propagation of knowledge in Operational Research, publication of the journal with original, high quality and state-of-the art papers on Operational Research and allied disciplines and conducting courses /examinations to propagate the knowledge in Operational Research. The Society publishes a quarterly journal OPSEARCH, which brings out high quality and state of the art papers in Operational Research. The journal enjoys a wide spectrum of readership both in the India and aboard covering academics, professionals as well as industrial / service sector organizations.

FEATURES OF OPERATIONS RESEARCH

The objective of the operations research models is to attempt and to locate best or optimal solution under the specified conditions. For the above purpose, it is necessary that a measure of effectiveness has to be defined which must be based on the goals of the organization. These measures can be used to compare the alternative courses of action taken during the analysis.

OR utilizes a planned approach following a scientific method and an interdisciplinary team, in order to represent complex functional relationship as mathematical models, for the purpose of providing a quantitative basis for decision-making and uncovering new problems for quantitative analysis. The broad features of OR approach any decision problem are:

- **Interdisciplinary Approach**: This is necessary because one person may not have the complete knowledge of all its aspects. Therefore, a team of individuals specializing in mathematics, statistics, economics, engineering, computer science, psychology, etc., should be organized in a way that each aspect of the problem can be analysed.

- **Scientific Approach**: This method consists of observing and defining the problem; formulating and testing the hypothesis; and analysing the results of the test.

- **Holistic Approach**: While arriving at a decision, an operations research team examines the relative importance of all conflicting and multiple objectives. It also examines the validity of claims of various departments of the organization from the perspective of its implication to the whole organization.

- **Objective** – Oriented Approach: An operations research approach seeks to obtain an optimal solution to the problem under analysis. For this, measure of desirability is defined, based on the objective of organization. A measure of desirability so defined is then used to compare alternative courses of action with respect to their possible outcomes.

<u>OBJECTIVES OF OPERTIONS RESEARCH</u>

- Decision making and improving the objective.
- Identify optimum solutions.
- Integrating optimum solutions.
- Improving the objectivity of analysis.
- Minimizing cost and maximizing profit.

- Improving the productivity.
- Success in competition and market leadership.

ROLE OF OPERATIONS RESEARCH IN DECISION-MAKING

The Operation Research may be considered as a tool which is employed to raise the efficiency of management decisions. OR is the objective complement to the subjective feeling of the administrator (decision maker). Scientific method of the OR is used to comprehend and explain the phenomena of operating system.

The benefits of OR study approach in business and management decision making may be categorize as follows:

- **BETTER CONTROL**

  The management of large concerns finds it much expensive to give continuous executive supervisions over routine decisions. An OR approach directs the executives to dedicate their concentration to more pressing matters. For instance, OR approach handles production scheduling and inventory control.

- **BETTER COORDINATION**

  Sometimes OR has been very helpful in preserving the law-and-order situation out disorder. For instance, an OR based planning model turns out to be a vehicle for coordinating marketing decisions with the restrictions forced on manufacturing capabilities.

- **BETTER SYSTEM**

  OR study is also initiated to examine a particular problem of decision making like setting up a new warehouse. Later OR approach can be more developed into a system to be employed frequently. As a result, the cost of undertaking the first application may get better profits.

- **BETTER DECISIONS**

  OR models regularly give actions that do enhance an intuitive decision making. Sometimes a situation may be so complex that the human mind can never expect to assimilate all the significant factors without the aid of OR and computer analysis.

METHODS OF OPERATIONS RESEARCH

Most of the problems are solved using one of these three techniques:

- Simulation methods
- Optimization methods
- Data analysis methods

SIMULATION METHODS

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviour/functions of the selected physical or abstract system or process. The model represents the system itself, whereas the simulation represents the operation of the system over time. Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training, education, and video games. Often, computer experiments are used to study simulation models. Simulation is also used with scientific modelling of natural systems or human systems to gain insight. Simulation can be used to show the eventual real effects of alternative conditions and courses of action.

OPTIMIZATION METHODS

In mathematics, computer science, economics, or management science, mathematical optimization (alternatively, optimization or mathematical programming) is the selection of a best element (with regard to some criteria) from some set of available alternatives.

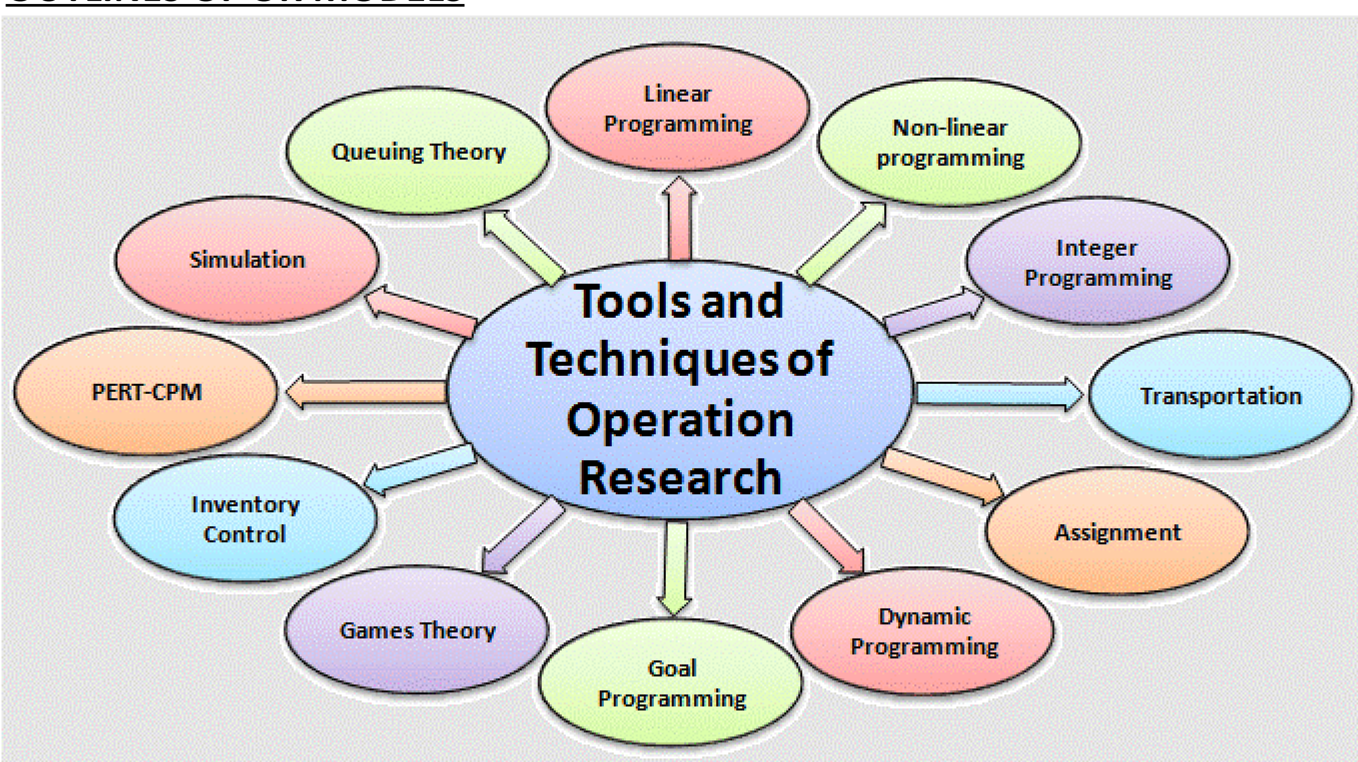
In the simplest case, an optimization problem consists of maximizing or minimizing a real function by systematically choosing input values from within an allowed set and computing the value of the function. The generalization of optimization theory and techniques to other formulations comprises a large area of applied mathematics. More generally, optimization includes finding “best available” values of some objective function given a defined domain (or a set of constraints), including a variety of different types of objective functions and different types of domains.

DATA ANALYSIS METHOD

Analysis of data is a process of inspecting, cleaning, transforming, and modelling data with the goal of discovering useful information, suggesting conclusions, and supporting decision-making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, science, and social science domains.

Data mining is a particular data analysis technique that focuses on modelling and knowledge discovery for predictive rather than purely descriptive purposes. Business intelligence covers data analysis that relies heavily on aggregation, focusing on business information. In statistical applications, some people divide data analysis into descriptive statistics, exploratory data analysis (EDA), and confirmatory data analysis (CDA). EDA focuses on discovering new features in the data and CDA on confirming or falsifying existing hypotheses. Predictive analytics focuses on application of statistical models for predictive forecasting or classification, while text analytics applies statistical, linguistic, and structural techniques to extract and classify information from textual sources, a species of unstructured data.

OUTLINES OF OR MODELS



In OR the problem is expressed in the form of a model. Where, a model is a theoretical abstraction (approximation) of a real-life problem. It can be defined as a simplified representation of an operation or a process in which only the basic aspects or the most important features of a typical problem under investigation are considered. OR analysts have given special impetus to the development and use of techniques like, linear programming, waiting line theory, game theory, inventory controls and simulation. In addition, some other common tools are non-linear programming, integer programming, dynamic programming, sequencing theory, Markov process, network scheduling- PERT and CPM, symbolic logic, information theory and utility/value theory. The list, of course, is not exclusive.

The detailed discussion on above will be presented in appropriate chapters, however, brief explanation of these is given below:

(i) Linear Programming (L.P.):

Linear programming is basically a constrained optimization technique which tries to optimize some criterion within some constraints. It consists of an objective function which is some measure of effectiveness like profit, loss or return on investment and several boundary conditions putting restriction on the use of resources. Objective function and boundary conditions are linear in nature. There are methods available to solve a linear programming problem.

(ii) Waiting Line or Queueing Theory:

Waiting line deals with the situation in which queue is formed or the customers have to wait for service or machines wait for repairmen and therefore concept of a queue is involved. If we assume that there are costs associated with waiting in line, and if there are costs of adding more service facilities, we want to minimize the sum of costs of waiting and the costs of providing service facilities. Waiting line theory helps to make calculations like number of expected member of people in queue, expected waiting time in the queue, expected idle time for the server, etc. These calculations then can be used to determine the desirable number of service facilities or number of servers.

(iii) Game Theory:

Game theory is used for decision-making under conflicting situations where there are one or more opponents. The opponents, in game theory, are called players. The motives of the players are dictomized. The success of one player tends to be at the cost of others and hence they are in conflict. Game theory models, a conflict situation arises and helps to improve the decision process by formulating appropriate strategy.

(iv) Inventory Control Models:

Inventory control models deal with the quantities which are either to be purchased or stocked since each factor involves cost. The purchase and material managers are normally encounter such situations. Therefore, inventory models provide rational answer to these questions in different situations of supply and demand for different kind of materials. Inventory control models help managers to decide ordering time, reordering level and optimal ordering quantity. The approach is to prepare a mathematical model of the situation that expressed total inventory costs in terms of demand, size of order, possible over or under stocking and other relevant factors and then to determine optimal order size, optimum order level etc. using calculus or some other technique.

(v) Simulation:

It is basically data generating technique, where sometimes it is risky, cumbersome, or time consuming to conduct real study or experiment to know more about situation or problem. The available analytical methods cannot be used in all situations due to large number of variables or large number of interrelationships among the variables and the complexity of relationship; it is not possible to develop an analytical model representing the real situation. Sometimes, even building of model is possible but its solution may not be possible. Under such situations simulation is used. It should be noted that simulation does not solve the problem by itself, but it only generates the required information or data needed for decision problem or decision making.

(vi) Non- Linear Programming:

Non-Linear models may be used when either the objective function or some of the constraints are not linear in nature. Non-linearity may be introduced by such factors as discount on price of purchase of large quantities and graduated income tax etc. Linear programming may be employed to approximate the non-linear conditions, but the approximation becomes poorer as the range is extended. Non-linear methods may be used to determine the approximate area in which a solution lies, and linear methods may be used to obtain a more exact solution.

(vii) Integer Programming:

Integer programming method can be used when one or more of the variables can only take integer values. Examples are the number of trucks in a fleet, the number of generators in a power house and so on. Approximate solutions can be obtained without using integer programming methods, but the approximation generally becomes poorer as the number becomes smaller. There are techniques to obtain solution of integer programming problems.

(viii) Dynamic Programming:

This is a method of analysing multistage decision processes, in which each elementary decision is dependent upon those preceding it as well as upon external factors. It drastically reduces the computational efforts otherwise necessary to analyse results of all possible combinations of elementary decisions.

(ix) Sequencing Theory:

Sequencing theory is related to waiting line theory and is applicable when the facilities are fixed, but the order of servicing may be controlled. The scheduling of service or the sequencing of jobs is done to minimize the relevant costs and time.

(x) Markov Process:

Markov process is used for decision-making in situations where various states are defined. The probability of going from one state to another is known and depends on the present state and is independent of how we have arrived at that state. Theory of 18 Markov process helps us to calculate long run probability of being in a particular state (steady state probability), which is used for decision-making.

(xi) Network Scheduling:

PERT and CPM These techniques are used to plan, schedule and monitor large projects such as building construction, maintenance of computer system installation, research and development design etc. The technique aims at minimizing trouble spots, such as, delays, interruptions and production bottlenecks, by identifying critical factors and coordinating various parts of overall job/project. The project/job is diagrammatically represented with the help of network made of arrows representing different activities and interrelationships among them. Such a representation is used for identifying critical activities and critical path. Two basic techniques in network scheduling are Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM). CPM is used when time taken by activities in a project are known for sure and PERT is used when activities time is not known for sure—only probabilistic estimate of time is available to the users.

(xii) Symbolic Logic:

Symbolic logic deals with substituting symbols for words, classes of things or functional systems. Symbolic logic involves rules, algebra of logic and propositions. There have been only limited attempts to apply this technique to business problems; however, has had extensive application in the design of computing machinery.

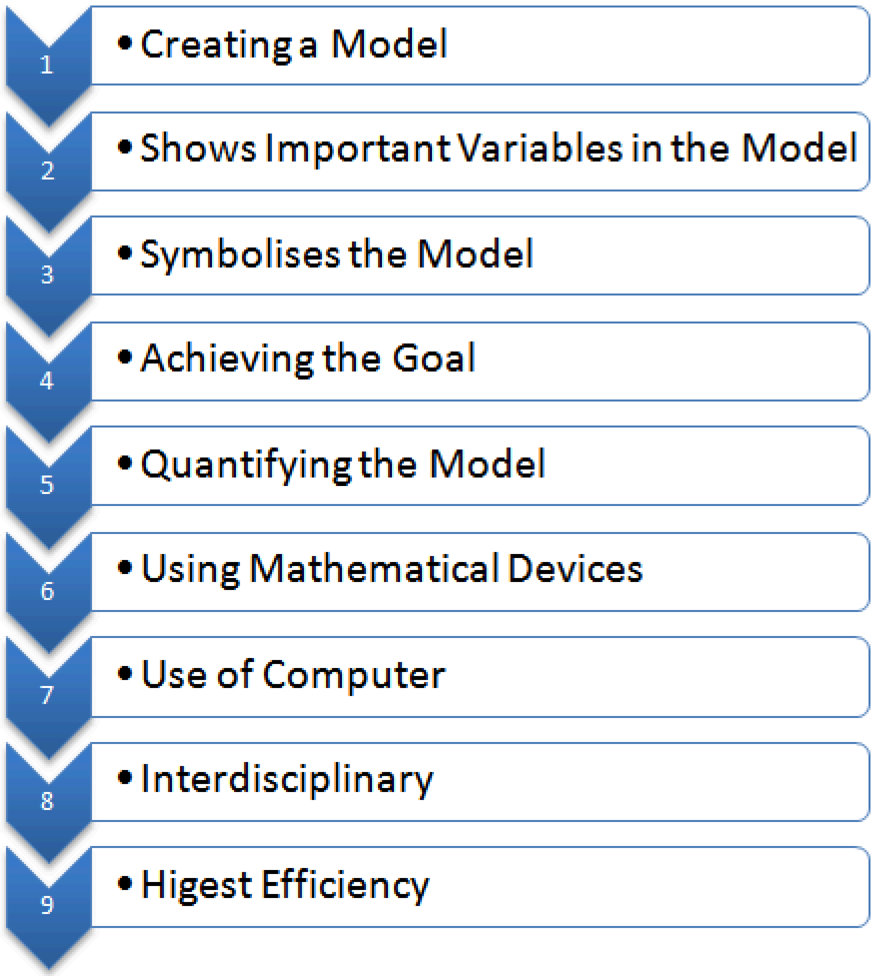
(xiii) Information Theory:

Information theory is an analytical process transferred from the electrical communications field to operations research. It seeks to evaluate the effectiveness of information flow within a given system. Despite its application mainly to communication networks, it has had an indirect influence in simulating the examination of business organizational structures with a view to improving information or communication flow.

(xiv) Utility/Value Theory:

Utility/Value theory deals with assigning numerical significance to the worth of alternative choices. To date, this has been only a concept and is in the stage of elementary model formulation and experimentation and can be useful in decision making process.

PHASES OF OPERATIONS RESEARCH STUDY



FORMULATE THE PROBLEM:

This is the most important phase of study and is generally the most time consuming. The activities that constitute this phase are visits, research, observations etc. With the help of such activities, the OR scientists get sufficient information and support to proceed and is better prepared to formulate the problem. This process starts with understanding of organizational climate, its objectives and expectations. Further, the alternative courses of action are discovered in this step.

DEVELOP A MODEL:

Once a model is formulated, the next step is to express the model into mathematical model that represents systems, processes or environment in the form of equations, relations or formulas. We have to identify both static and structural elements and device mathematical formulas to represent interrelationships among elements. The proposed model may be field tested and modified in order to work under stated environmental constraints. A model may also be modified if the management is not satisfied with the answer that it gives.

SELECT APPROPRIATE DATA INPUT:
Garbage in and garbage out is a famous saying. No model will work appropriately if data input is not correct. The purpose of this step is to have proper input to test the model appropriately.

SOLUTION OF THE MODEL:
After finding appropriate data input for the model, the next step is to find a solution. If the model is not working properly then modification and update are considered in this step

VALIDATION OF THE MODEL:
A model is said to be validated if it can provide a reliable prediction of the system's performance. A model must be applicable for a long time and can be updated from time to time taking into consideration the past, present and future aspects of the problem.

IMPLEMENTATION OF THE MODEL:
Implementation of the solution many behavioural issues and the implementing society is responsible for resolving these issues. The gap between who solves the model and who wishes to use it should be eliminated. To achieve this, OR scientist and the management will play a positive role. A properly working solution obtained through OR techniques result in improved working and managerial support.

SCOPE OF OPERATIONS RESEARCH

As presented in the earlier paragraphs, the scope of OR is not only confined to any specific agency like defence services but today it is widely used in all industrial organizations. It can be used to find the best solution to any problem be it simple or complex. It is useful in every field of human activities, where optimization of resources is required in the best way. Thus, it attempts to resolve the conflicts of interest among the components of organization in a way that is best for the organization as a whole. The main fields where OR is extensively used are given below, however, this list is not exhaustive but only illustrative.

(i) NATIONAL PLANNING AND BUDGETING:

Operation Research is used for the preparation of Five-Year Plans, annual budgets, forecasting of income and expenditure, scheduling of major projects of national importance, estimation of GNP, GDP, population, employment and generation of agriculture yields etc.

(ii) DEFENCE SERVICES BASICALLY FORMULATION OF OR:

Started from USA army, so it has wide application in the areas such as: Development of new technology, optimization of cost and time, tender evaluation, setting and layouts of defence projects, assessment of "Threat analysis", strategy of battle, effective maintenance and replacement of equipment, inventory control, transportation and supply depots etc.

(iii) INDUSTRIAL ESTABLISHMENT AND PRIVATE SECTOR UNITS:

Operation Research can be effectively used in plant location and setting finance planning, product and process planning, facility planning and construction, production planning and control, purchasing, maintenance management and personnel management etc. to name a few.

(iv) R & D AND ENGINEERING:

Research and development being the heart of technological growth, OR has wide scope for and can be applied in technology forecasting and evaluation, technology and project management, preparation of tender and negotiation, value engineering, work/method study and so on.

(v) BUSINESS MANAGEMENT AND COMPETITION:

Operation Research can help in taking business decisions under risk and uncertainty, capital investment and returns, business strategy formation, optimum advertisement outlay, optimum sales force and their distribution, market survey and analysis and market research techniques etc.

(vi) AGRICULTURE AND IRRIGATION:

In the area of agriculture and irrigation also OR can be useful for project management, construction of major dams at minimum cost, optimum allocation of supply and collection points for fertilizer/seeds and agriculture outputs and optimum mix of fertilizers for better yield.

(vii) EDUCATION AND TRAINING:

Operation Research can be used for obtaining optimum number of schools with their locations, optimum mix of students/teacher student ratio, optimum financial outlay and other relevant information in training of graduates to meet out the national requirements.

(viii) TRANSPORTATION:

Transportation models of OR can be applied to real life problems to forecast public transport requirements, optimum routing, forecasting of income and expenses, project management for railways, railway network distribution, etc. In the same way it can be useful in the field of communication.

(ix) HOME MANAGEMENT AND BUDGETING:

OR can be effectively used for control of expenses to maximize savings, time management, work study methods for all related works. Investment of surplus budget, appropriate insurance of life and properties and estimate of depreciation and optimum premium of insurance etc.

USES OF OPERATIONAL RESEARCH

Formulation of industrial problems may be generalized into different groups of classical problems, the package program for which is available for mechanization and manual solutions. Various problem of optimization can be brought to the model of linear program for which solution is available? While formulating the problem, the class of the problem is to be decided and the parameters are to be defined accordingly. Inventory control, production planning, product mix, transportation problem, etc. are very common to the industries. The cost reduction with the help of these tools is very much powerful in comparison to any other conventional method. We can enumerate the advantages of these techniques as:

(i) Optimum use of production factors:

Linear programming techniques indicate how a manager can most effectively employ his production factors by more efficiently selecting and distributing these elements.

(ii) Improved quality of decision:

The computation table gives a clear picture of happenings within the basic restriction and the possibilities of compound behaviour of the elements involved in the problems. The effect on the profitability due to changes in the production pattern will be clearly indicated in the table e.g., simplex table.

(iii) Preparations of future managers:
These methods substitute a means for improving knowledge and skills of your manager.

(iv) Modification of mathematical solution:
Operation Research presents a possible practical solution when one exists, but it is always a responsibility of the manager to accept or modify the solution before its use. The effects of these modifications may be evaluated from the computational steps and tables.

(v) Alternative solution:
Operational Research techniques will suggest all the alternative solution available for the same profit so that the management may decide based on its strategies.

LIMITATIONS OF OPERATIONAL RESEARCH

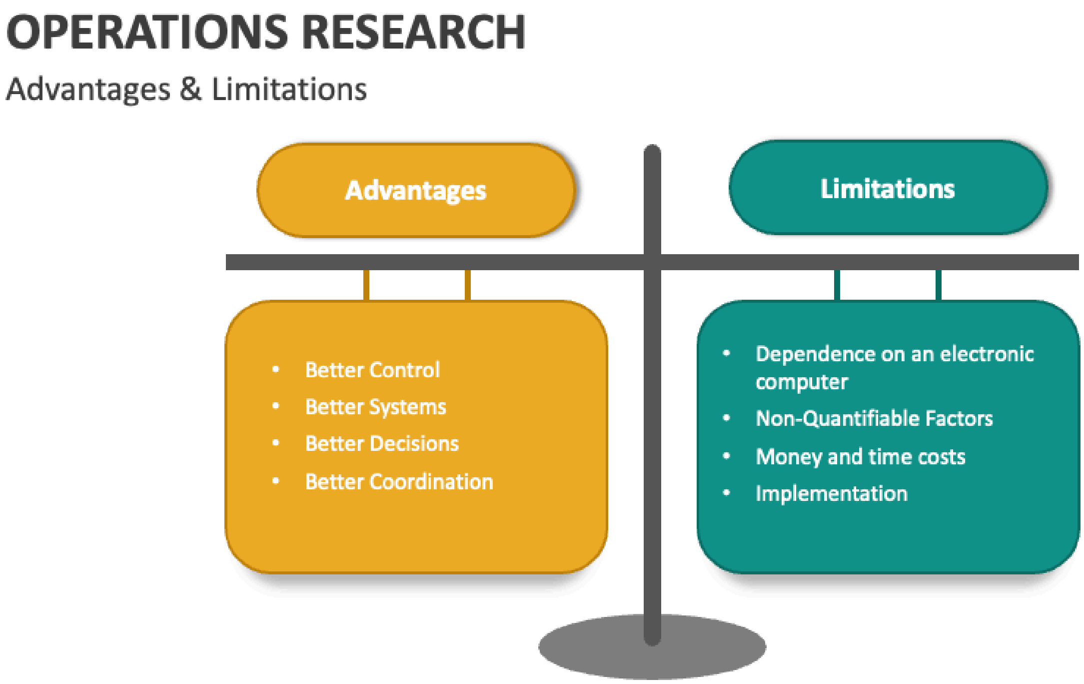
Operational Research has certain limitations. These limitations are as follows: -

(i) Magnitude of computations:
Operation Research tries to find out the optimal solution taking all the factors into account. In the modern society, these factors are numerous and expressing them in quantity and establishing relationship among these requires huge calculations. All these calculations cannot be handled manually and require electronic computers which bear a very heavy cost. Thus, the use of OR is limited to only very large organizations.

(ii) Absence of qualification:
Operation Research provides solution only when all the elements related to a problem can be quantified. The tangible factors such as product, price, etc., can be expressed in terms of quantity, but intangible factors such as human relations etc. cannot be quantified. Thus, these intangible elements of the problem are excluded from the study, though these might be equal or more important than quantifiable intangible factors as far as possible.

(iii) Distance between managers and operations research:

Operation Research being specialist job requires a mathematician or a statistician, who might not be aware of business problems. Similarly, a manager may fail to understand the complex working of OR. Thus, there is a gap between one who provides the solution and one who uses a solution. This problem is mainly of training. Both the persons should have a working knowledge of each other's job to have better understanding of insights of the problem and its optimal solution.



Quality

Quality has been the primary consideration in the origin and policy of the business. The commitment to quality required investment in people and equipment, including appropriate facilities for receiving, handling, and storage under safe and hygienic conditions. Strict adherence to, and implementation of, quality measures assured that products procured and dis tributed by the company always matched high quality standards. Products are sourced from suppliers with international standards accreditation such as ISO and with whom ongoing contact was maintained. Quality is closely monitored to the point of the end users. The commitment to customers was ensured with adequate inventory, reliable distribution networks. and new product offerings.

"Quality is not an art, it is a habit."

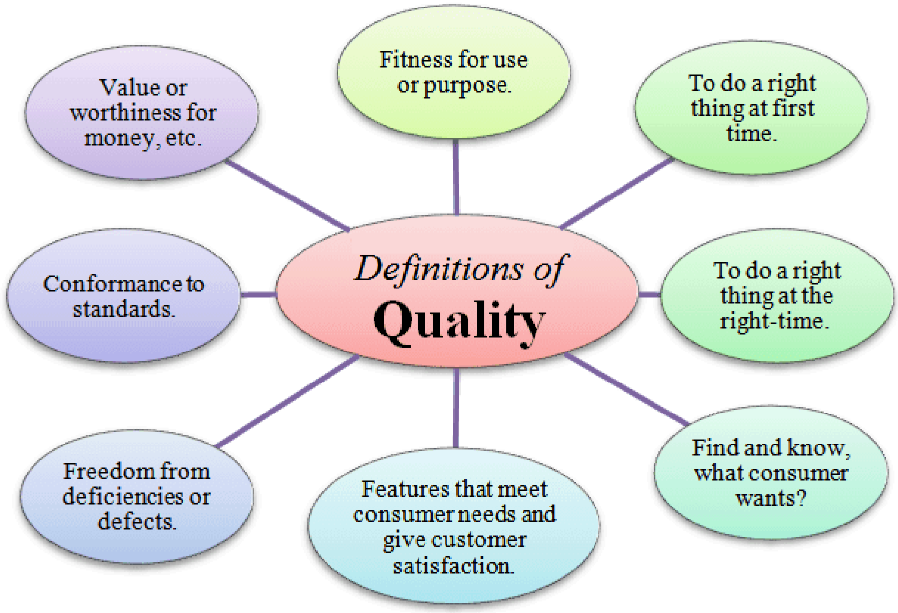
The word "quality" has diverse definitions, ranging from the conventional to those that are strategic. Conventional definitions of quality usually describe a quality item as one that wears well, is well constructed and will last for a long time. However, managers competing in the fierce international marketplace are increasingly concerned with the strategic definition of quality—meeting customer requirements.

Definition of quality

Quality is meeting and exceeding the present and future requirements of the customer on a continuous basis.

-Poornima Charantimath

"Philip Crosby"	• Quality is conformance to requirements.
"Dr Edward Deming "	• Quality is a predictable degree of uniformity and dependability, at low cost and suited to the market.
"Dr Juran"	• Quality is fitness for use/purpose.
"R J Mortiboys"	• Quality is synonymous with customer needs and expectations.



Customer driven definition of Quality

- **Value for price paid**: Quality is defined in terms of the utility of the product or service for the price paid.

- **Support services**: Quality is defined in terms of the support provided after the product or service is purchased.

- **Psychological criteria**: A way of defining quality that focuses on judgemental evaluations of what constitutes product or service excellence.

Garvin's Approaches to Defining Quality

David Garvin identified five major approaches to defining quality.

The five approaches are as follows:

1. **The Transcendent Approach**
   Quality is recognized through learning and experience defined in terms of innate excellence. In this view "quality is synonymous with 'innate excellence' and is absolute and universally recognizable." This is the approach which aligns most closely with Socrates' question "What is the fine?" from Greater Hippias. This approach implies that there is a construct called quality that is universally applicable. This is the

approach that forms the basis for Bird's-eye view: Quality is important to businesses but can be quite hard to define. A good definition of quality is: "Quality is about meeting the needs and expectations of customers". Some say it is of little practical utility. Others argue that the transcendent approach is "the fundamentally most important approach to thinking about quality—particularly in the quality of design of breakthrough products and services."

2. **5The Product-based Approach**
   Quality is precise and measurable; it can be ranked on various attributes and is an inherent part of the product. In this regard, quality is "a precise and measurable variable" which is a composite of all the attributes that describe the degree of excellence of a product. This approach is illustrated by a draft of the ISO 8402 standard which stated that "quality is the degree to which a product possesses a specified set of attributes necessary to fulfill a stated purpose."

3. **The User-based Approach**
   This is an approach to assure that the customer's voice is incorporated during product design and is reflected in consumer demand curves. While this approach has been practical in the design of products based on incremental innovations, it is of limited value in designing products based on radical innovations. Products based on radical innovation enter a market that may not exist and where customers may not be able to articulate their needs. In the case of radical innovation, the transcendent approach may be of more than just philosophical interest.

4. **The Manufacturing-based Approach**
   Quality is defined as conformance to specifications; reduce costs by reducing the number of deviations with a focus on engineering and manufacturing practices. W. Edwards Deming criticizes this approach as "the absurdity of meeting specifications." "Specifications don't tell you what you need…Just to meet specifications—what you think the customer requires—no. That won't keep you in business." Taguchi argues that the manufacturing-based approach is fundamentally flawed. He says that simply meeting specifications is not good enough. He developed the quadratic loss function, which showed that losses increased exponentially as a parameter deviated from its target value.

5. The Value-based Approach

Quality is defined as performance or conformance at an acceptable cost. In this approach, quality is defined in terms of costs and prices. A quality product is one that provides performance at an acceptable price or conformance at an acceptable cost. Philip Crosby also endorses this approach. This blends the value-based approach with the manufacturing based approach.

Dimension of quality

The quality of a product can be described and evaluated in several ways. It is often very important to differentiate these different dimensions of quality. Garvin (1987) provides an excellent discussion of eight components or dimensions of quality. We summarize his key points concerning these dimensions of quality as follows:

1. Performance

(Will the product do the intended job?) Potential customers usually evaluate a product to determine if it will perform certain specific functions and determine how well it performs them. For example, you could evaluate spreadsheet software packages for a PC to determine which data manipulation operations they perform. You may discover that one outperforms another with respect to the execution speed.

2. **Reliability**
   (How often does the product fail?) Complex products, such as many appliances, automobiles, or airplanes, will usually require some repair over their service life. For example, you should expect that an automobile will require occasional repair, but if the car requires frequent repair, we say that it is unreliable. There are many industries in which the customer's view of quality is greatly impacted by the reliability dimension of quality.

3. **Durability**
   (How long does the product last?) This is the effective service life of the product. Customers obviously want products that perform satisfactorily over a long period of time. The automobile and major appliance industries are examples of businesses where this dimension of quality is very important to most customers.

4. **Serviceability**
   (How easy is it to repair the product?) There are many industries in which the customer's view of quality is directly influenced by how quickly and economically a repair or routine maintenance activity can be accomplished. Examples include the appliance and automobile industries and many types of service industries (how long did it take a credit card company to correct an error in your bill?).

5. **Aesthetics**
   (What does the product look like?) This is the visual appeal of the product, often taking into account factors such as style, color, shape, packaging alternatives, tac tile characteristics, and other sensory features. For example, soft-drink beverage manufacturers have relied on the visual appeal of their packaging to differentiate their prod uct from other competitors.

6. **Features**
   (What does the product do?) Usually, customers associate high quality with products that have added features; that is, those that have features beyond the basic performance of the competition. For example, you might consider a spreadsheet software package to be of superior quality if it had built-in statistical analysis features while its competitors did not.

7. **Perceived Quality**
   (What is the reputation of the company or its product?) In many cases, customers rely on the past reputation of the company concerning quality of its products. This reputation is directly influenced by failures of the product that are highly visible to the

public or that require product recalls, and by how the customer is treated when a quality-related problem with the product is reported. Perceived quality, customer loyalty, and repeated business are closely interconnected. For example, if you make regular business trips using a particular airline, and the flight almost always arrives on time and the airline company does not lose or damage your luggage, you will probably prefer to fly on that carrier instead of its competitors.

8. **Conformance to Standards**
   (Is the product made exactly as the designer intended?) We usually think of a high-quality product as one that exactly meets the requirements placed on it. For example, how well does the hood fit on a new car? Is it perfectly flush with the fender height, and is the gap exactly the same on all sides? Manufactured parts that do not exactly meet the designer's requirements can cause significant quality problems when they are used as the components of a more complex assembly. An automobile consists of several thousand parts. If each one is just slightly too big or too small, many of the components will not fit together properly, and the vehicle (or its major subsystems) may not perform as the designer intended.

Total Quality Management

Quality management is a method for ensuring that all the activities necessary for the design, development and implementation of a product or service are effective and efficient with respect to the system and its performance. Quality control, quality assurance and quality improvement are the three main components of quality management. Quality management focuses not only on product quality, but also on the means to achieve it. Quality management, therefore, uses quality assurance and the control of processes as well as products to achieve more consistent quality.

Total Quality Management (TQM) is an organizational management approach that focuses on producing quality products and services to fulfill customer needs. As a quality management technique, TQM involves all workers to maintain high standards of work across the entire company. Implementing TQM can help improve employee productivity, increase customer satisfaction, and achieve competitive advantage.

Importance of Total quality management

Total Quality Management is often referred to as the antecedent of many quality management methodologies such as **Six Sigma** and **Lean**. Some concepts of ISO 9001, the world's most recognized Quality Management System (QMS) standard, can also be traced back to TQM principles. Total Quality Management is important because it provides an agile framework to implement effective quality and productivity initiatives in every aspect of business operations.

7 Principles of TQM by ISO/TC 176

ISO/TC 176 is the Technical Committee of the International Organization for Standardization (ISO), which develops and maintains quality management standards such as ISO 9000.

- **Customer Focus:** The primary focus of quality management is to meet customer requirements and to strive to exceed customer expectations. An example of a tool used to integrate customer needs into the overall process is Quality Function Deployment (QFD).

- **Leadership:** Leaders at all levels establish unity of purpose and direction and create conditions in which people are engaged in achieving the organization's quality objectives.

- **Engagement of People:** Competent, empowered and engaged people at all levels throughout the organization are essential to enhance its capability to create and deliver value

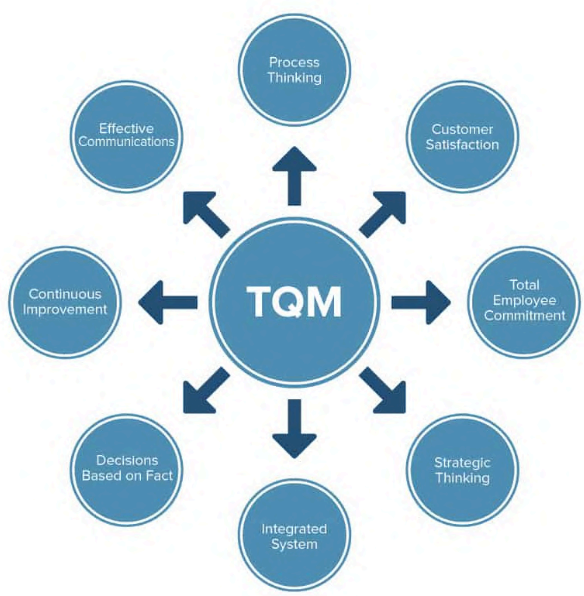
- **Process Approach:** Consistent and predictable results are achieved more effectively and efficiently when activities are understood and managed as interrelated processes that function as a coherent system.

- **Improvement:** Successful organizations have an ongoing focus on improvement.

- **Evidence-based Decision-making:** Decisions based on the analysis and evaluation of data and information are more likely to produce desired results.

- **Relationship Management:** For sustained success, an organization manages its relationships with interested parties, such as suppliers.

Benefits of total quality management



The benefits arising from the implementation of a Total Quality Management in an organization are:

- This will increase the awareness of quality culture within the organization.
- A special emphasis on teamwork will be achieved.
- TQM will lead to a commitment towards continuous improvement.

Statistical Process Control

If a product is to meet or exceed customer expectations, generally it should be produced by a process that is stable or repeatable. More precisely, the process must be capable of operating with little variability around the target or nominal dimensions of the product's quality characteristics. Statistical process control (SPC) is a powerful collection of problem-solving tools useful in achieving process stability and improving capability through the reduction of variability.

Statistical process control (SPC) is a method of quality control which uses statistical methods. SPC is applied in order to monitor and control a process. Monitoring and controlling the process ensures that it operates at its full potential. At its full potential, the process can make as much conforming product as possible with a minimum (if not an elimination) of waste (rework or scrap). SPC can be applied to any process where the "conforming product" (product meeting specifications) output can be measured. Key tools used in SPC include control charts; a focus on continuous improvement; and the design of experiments. An example of a process where SPC is applied is manufacturing lines.

Statistical Process Control (SPC) is an industry-standard methodology for measuring and controlling quality during the manufacturing process. Quality data in the form of Product or Process measurements are obtained in real-time during manufacturing. This data is then plotted on a graph with pre-determined control limits. Control limits are determined by the capability of the process, whereas specification limits are determined by the client's needs.

Data that falls within the control limits indicates that everything is operating as expected. Any variation within the control limits is likely due to a common cause— the natural variation that is expected as part of the process. If data falls outside of the control limits, this indicates that an assignable cause is likely the source of the product variation, and something within the process should be changed to fix the issue before defects occur.

With real-time SPC you can:

• Dramatically reduce variability and scrap
• Scientifically improve productivity
• Reduce costs
• Uncover hidden process personalities
• Instantly react to process changes

Make real-time decisions on the shop floor If the variation in the process is due to common causes alone, then the process is under statistical control. A practical definition of statistical control is that both the process averages and variances are constant over time. SPC relies on control charts.

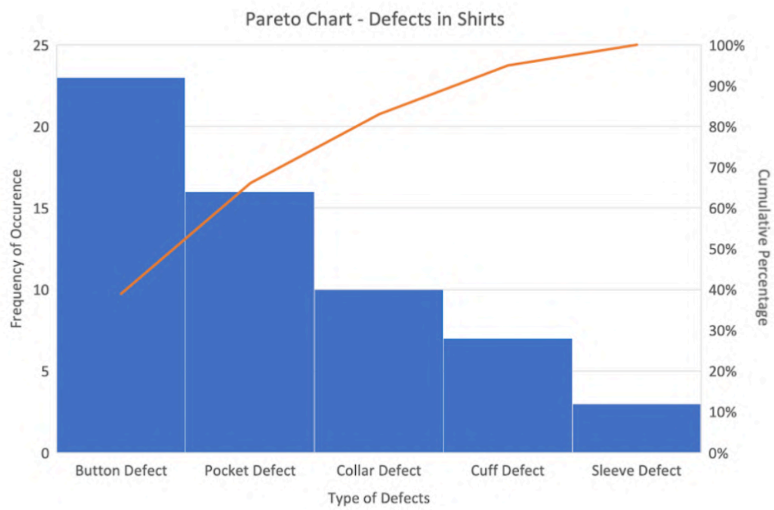
SPC is one of the greatest technological developments of the twentieth century because it is based on sound underlying principles, is easy to use, has significant impact, and can be applied to any process. **Its seven major tools are**

1. Pareto chart
2. Cause-and-effect diagram
3. Check sheet
4. Histogram
5. Scatter diagram
6. Control charts
7. Graphs

Pareto chart

A Pareto chart is a special bar graph, the lengths of which represent frequency or cost (time or money) and are arranged with the longest bars on the left and the shortest to the right. Thus, the chart visually depicts the relative importance of problems or conditions.

Through this chart, the user can quickly and visually identify the most frequently occurring types of defects. For example below figure indicates that incorrect dimensions, parts damaged, and machining are the most commonly encountered defects. Thus the causes of these defect types probably should be identified and attacked first.



Note that the Pareto chart does not automatically identify the most important defects, but only the most frequent.

These are often referred to as the 80–20 Rule. Pareto analysis is a statistical technique in decision making that is used for the selection of a limited number of tasks that produce a significant overall effect.2 The Pareto effect also operates in the domain of quality improvement. According to the Pareto effect, 80 per cent of the problems usually stem from 20 per cent of the causes. This is also termed as the theory of the vital few and the trivial many.

Steps in constructing the pareto chart

The following steps can be used to construct a Pareto chart:

1. List the activities or causes in a table and their frequency of occurrence

2. Place these in descending order of magnitude in the table.

3. Calculate the total for the whole list.

4. Calculate the percentage of the total that each cause represents.

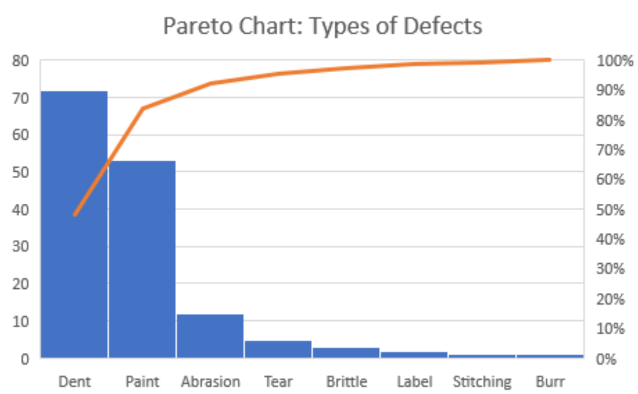
5. Add a cumulative percentage column to the table.

6. Draw a Pareto chart plotting the causes on the X-axis and the cumulative percentage on the Y-axis. The cumulative percentage from all causes can be shown by drawing a cumulative curve.

7. On the same chart, plot a bar graph with the causes on the X-axis and the percentage frequency on the Y-axis.

8. Analyse the diagram. Look for the break-point on the cumulative per cent graph. It can be identified by a marked change in the slope of the graph. This separates the significant few from the trivial many.

Example of pareto chart:



Cause and effect diagram

The cause-and-effect diagram, also termed as the fishbone diagram or the Ishikawa diagram, was the brainchild of Kaoru Ishikawa. The fishbone diagram identifies many possible causes for a problem or an effect. It can be used to structure a brainstorming session. It immediately sorts ideas into useful categories. This diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). The causes are arranged according to their levels of importance or detail, resulting in a depiction of relationships and hierarchy of events. This diagram can also be used to search for root causes, identify areas where there may be problems and compare the relative importance of different causes.

Steps in Constructing a Cause-and-effect Diagram

1. Write the issue (problem or process condition) on the centre-right side of the cause and-effect diagram.

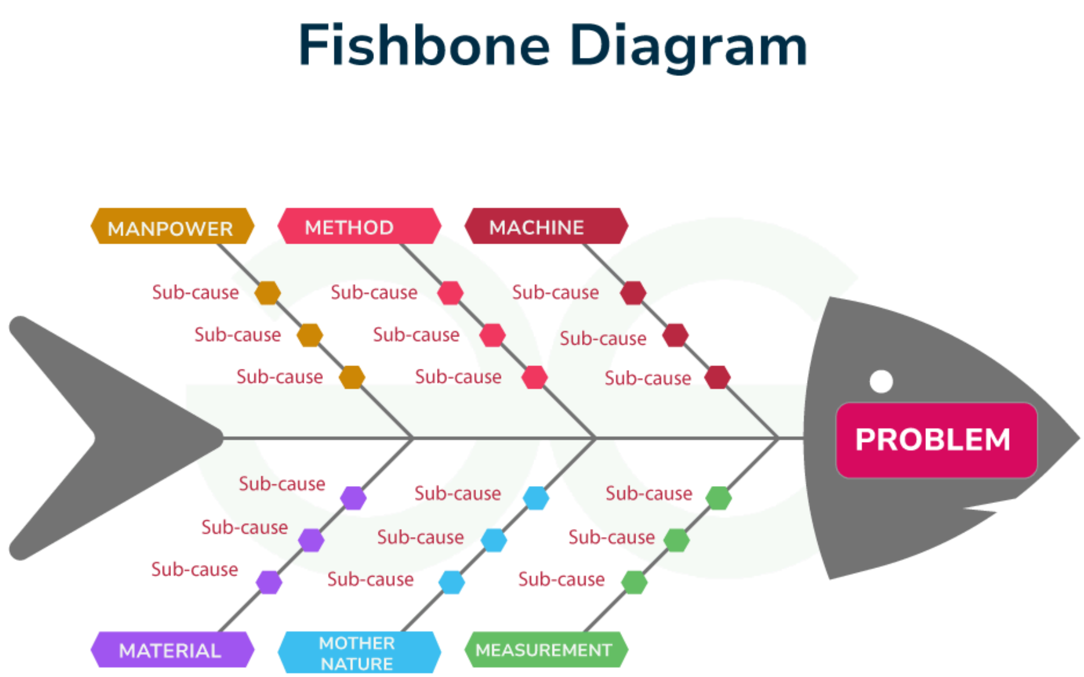
2. Identify the major cause categories and write them in the four boxes on the cause and-effect diagram. The causes may be summarized under various categories.

3. The potential causes of the problem need to be brainstormed. Decide where to place the possible causes on the cause-and-effect diagram. It is acceptable to list a possible cause under more than one major category.

4. Review each major cause category. Circle the most likely causes on the diagram.

5. Review the causes that are circled and question, “why?” Asking “why” will help to get to the root of the problem.

6. Arrive at an agreement on the most probable cause(s).



Check-sheet

Check sheets are also termed as defect concentration diagrams. A check sheet is a structured, prepared form for collecting and analysing data.3 This is a generic tool that can be adapted for a wide variety of purposes. The function of a check sheet is to present information in an efficient, graphical format. This may be accomplished with a simple listing of items. However, the utility of check sheets may be significantly enhanced in some instances by incorporating a depiction of the system under analysis into the form.

Steps in constructing check-sheet

The following steps can be used to create a check sheet:

1. Clarify the measurement objectives. Raise questions such as “What is the problem?”, “Why should data be collected?”, “Who will use the information being collected?”, “Who will collect the data?”

2. Prepare a form for collecting data. Determine the specific things that will be measured and write this down on the left side of the check sheet. Determine the time or place being measured and write this across the top of the columns.

3. Collect the data for the items being measured. Record each occurrence directly on the check sheet as it happens.

4. Tally the data by totaling the number of occurrences for each category being measured.

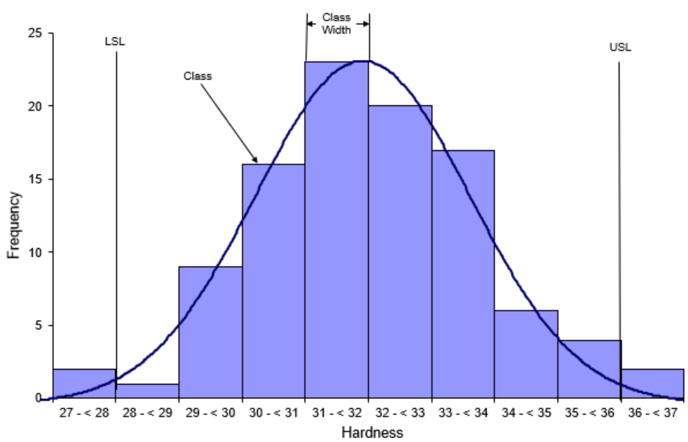
Example of check sheet:

Defect Types ? (Major/ Minor)	Defects in Supplied Items							Total Count
	Sun	Mon	Tue	Wed	Thu	Fri	Sat	
Rusted Items		□□□□	□□		□□	□		9
Items with Scratch	□							1
Dirty		□		□□□		□□		6
Broken/ Cracks			□□				□	3
Main Body Dent					□□□			3
Missing Components		□□		□□			□	5
Labelling Error					□	□□□		4
Damage in Packaging			□□					2
Wrong Item Issued					□□		□	3
Film on Parts			□□□□					4
Voids in Casting	□					□	□□	4
Incorrect Dimensions			□□	□	□□			5
Failed to pass the quality test		□□				□		3
Total Count	2	9	12	6	10	8	5	52

Histogram

Histograms provide a simple graphical view of accumulated data, including its dispersion and central tendency. It is the most commonly used graph to show frequency distributions. In addition to the ease with which they can be constructed, histograms provide the easiest way to evaluate the distribution of data. A frequency distribution graph shows how often each different value in a set of data occurs. A histogram is a specialized type of bar chart. Individual data points are grouped together in classes, so that one can get an idea of how frequently data in each class occur in the data set. High bars indicate more points in a class, and low bars indicate fewer points.

The strength of a histogram lies in the easy-to-read picture it projects of the location and variation in a data set. There are; however, two weaknesses of histograms that need to be understood. Histograms can be manipulated to show different pictures. It can prove to be misleading if too many or too few bars are used. This is an area that requires some judgement and perhaps some experimentation, based on the analyst's experience.



There are five types of histograms based on five different types of distributions. Each indicates a very different type of behaviour. The various types of distributions are bell-shaped distribution, double-peaked distribution, plateau distribution, comb distribution and skewed distribution.

Scatter diagram

A scatter diagram is also termed the scatter plot or the X–Y graph. It is a quality tool used to display the type and degree of relationship between variables. If the variables are correlated, the points will fall along a line or curve. The better the correlation, the tighter the points will hug the line. The scatter diagram also shows the pattern of relationships between two variables. Some examples of relationships are cutting speed and tool life, breakdowns and equipment age, training and errors, speed and gas mileage, production speed and number of defective parts. Scatter diagrams are used to investigate a possible relationship between two variables that both relate to the same event. A straight line of best fit (using the least-squares method) is often included in this.

Steps in constructing scatter diagram

The following steps can be used to construct a scatter diagram:

1. Collect data on causes and effects for variables

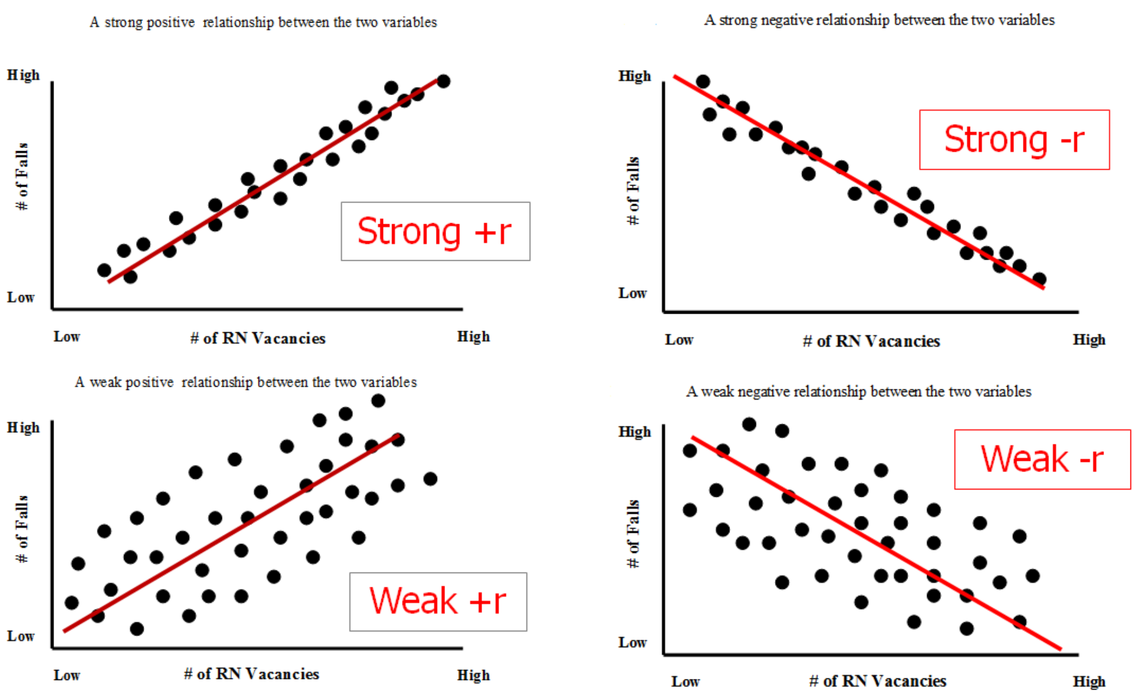
2. Draw the causes on the X–axis

3. Draw the effect on the Y–axis

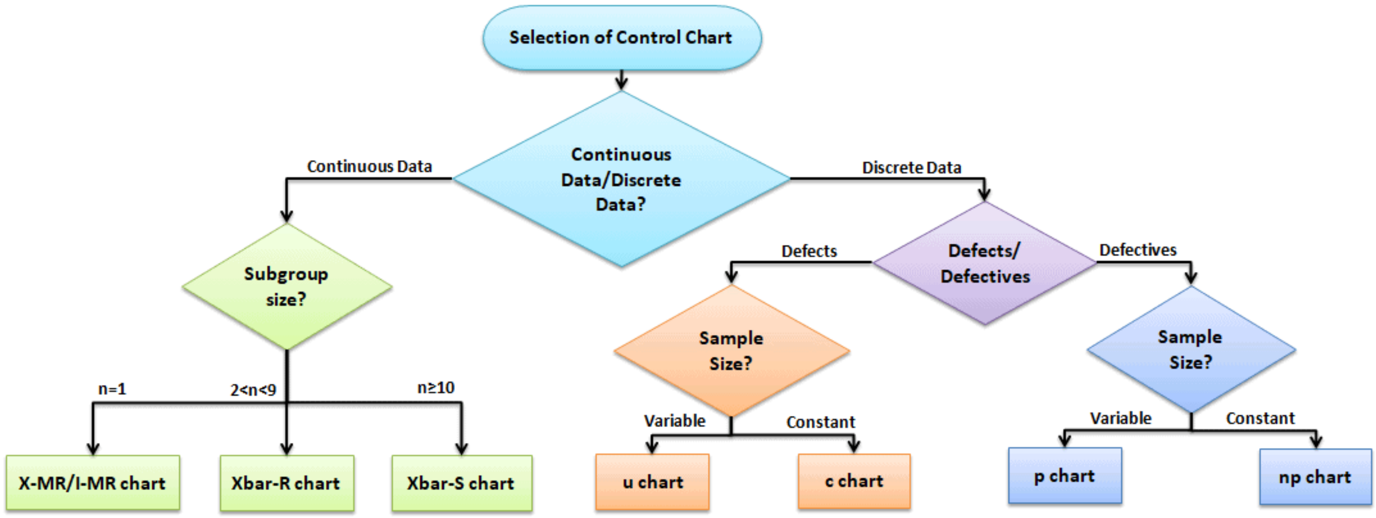
4. Plot the data pairs on the diagram by placing a dot at the intersection of the X and Y coordinates for each data pair

5. Interpret the scatter diagram for direction and strength

Example of scatter diagram:



Control charts



The control chart is a fundamental tool of statistical process control (SPC), as it indicates the range of variability that is built into a system (known as common cause variation). Thus, it helps determine whether or not a process is operating consistently or if a special cause has occurred to change the process mean or variance.

SPC is used to measure the performance of a process.4 It relates to the application of sta tistical techniques to determine whether the output of a process conforms to the product or service design. All processes are subject to a certain degree of variability. Usually, variations are of two types—natural variations and assignable variations.

Natural variations

Natural variations affect almost every production process and are to be expected as inherent in the process. These variations are due to common causes, which are purely random, or unidentifiable sources of variation. These causes are unavoidable in the current processes, which are in statistical control. As long as the output measurements remain within specified limits, the process is said to be “in control” and natural variations are tolerated

Assignable variations

Assignable variations in a process can be traced to a specific reason known as assignable cause variation. Factors such as machine or tool wear, maladjusted equipment, a fatigued or untrained worker or new batches of raw materials are potential sources of assignable variations.

A process is said to be operating under statistical control when common causes are the only source of variations. The process is said to be “out of control” when assignable causes of variation enter the process. The process must be brought into statistical control by detecting and eliminating special or assignable causes of variation. Only then the ability of the process to meet customer expectations can be assessed.

The control chart is a very useful process monitoring technique; when unusual sources of variability are present, sample averages will plot outside the control limits. This is a signal that some investigation of the process should be made and corrective action to remove these unusual sources of variability taken. Systematic use of a control chart is an excellent way to reduce variability.

Control charts are prepared to look at variation, seek assignable causes and track common causes. Assignable causes can be spotted using several tests such as one data point falling outside the control limits, six or more points in a row steadily increasing or decreasing, eight or more points in a row on one side of the central line and 14 or more points alternating up and down. A control chart is a line chart with control limits. By mathematically constructing control limits at three standard deviations above and below the average, one can determine which variation is due to normal ongoing causes (common causes) and which is produced by unique events (assignable causes). Eliminating the assignable causes first and then reducing common causes can improve quality.

The bounds of the control chart are marked by upper and lower control limits that are calculated by applying statistical formulas to data derived from the process. Data points that fall outside these bounds represent variations due to special causes that can typically be found and eliminated. On the other hand, improvements in common cause variation require fundamental changes in the process.

Types of errors

Control limits on a control chart are commonly drawn at Three Sigma from the central line because Three Sigma limits are a good balance point between two types of errors:

- **Type I or alpha errors** occur when a point falls outside the control limits even though no special cause is operating. This results in a witch hunt for special causes and adjustment of things. The tampering usually distorts a stable process as well as wastes time and energy.

- **Type II or beta errors** occur when you miss a special cause because the chart isn't sensitive enough to detect it. In this case, you will go along unaware that the problem exists and thus will be unable to root it out.

All process control is vulnerable to these two types of errors. The reason that Three Sigma control limits balance the risk of error is that for normally distributed data, data points will fall inside the Three Sigma limits 99.7 per cent of the time when a process is in control. This makes the witch hunts infrequent but still makes it likely that unusual causes of variation will be detected.

Steps in construction of control charts

1. Draw the X-axis. This axis represents the time order of subgroups. Subgroups represent samples of data taken from a process. It is critical that the integrity of the time dimension be maintained when plotting control charts.

2. Draw the Y-axis. This axis represents the measured value of the quality characteristic under consideration when using variables charts. This axis is used to quantify defectives or defects when attributes charts are used.

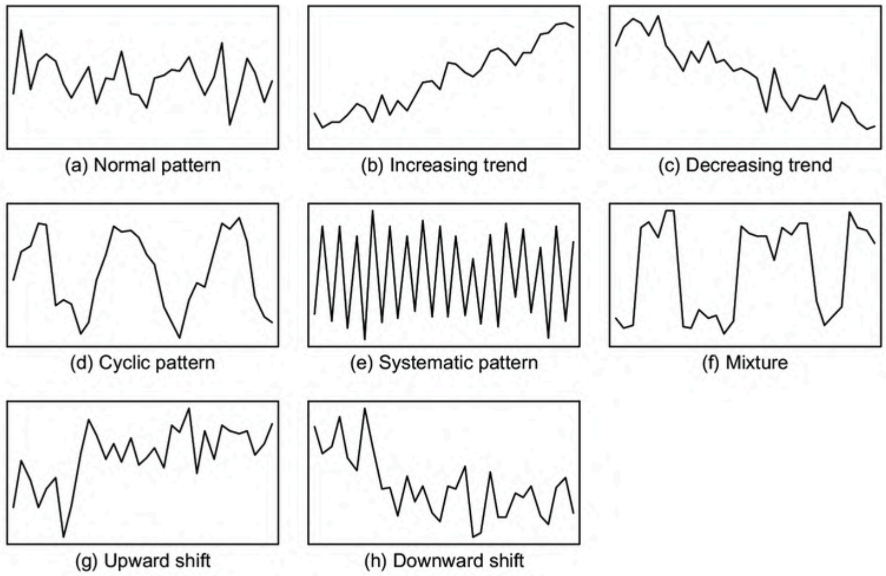
3. Draw the central line on the chart. The central line represents the process average value of the quality characteristic corresponding to the in-control state.

4. Draw two other horizontal lines called the upper control limit (UCL) and the lower control limit (LCL), typically appearing at ±3-Sigma from the process average.

5. The next step is analysis and interpretation. As long as the points fall within the control limits, the process is assumed to be in control and no action is necessary. In case, the points are outside the control limits, there is evidence that the process is out of control, and investigation and corrective action is required to find and eliminate them.

6. Use the control chart data to determine process capability if desired.

Analysis of pattern of the control chart



A control chart may indicate an out-of-control condition either when one or more points fall beyond the control limits, or when the plotted points exhibit some non-random patterns of behaviour. A control chart that has not triggered any out-of-control condition is considered stable, predictable and operating in a state of statistical control. The variation depicted on the chart is due to common-cause variation.

Points falling outside the limits are attributed to special cause variations. Such points, regardless of whether they constitute “good” or “bad” occurrences, should be investigated immediately while the cause-and-effect relationships and access to documentation for process changes is readily available.

Many quality characteristics cannot be conveniently represented numerically. In such cases, each item inspected is classified as either conforming or non-conforming to the specifications of that quality characteristic. Quality characteristics of this type are called attributes. Examples are non-functional semiconductor chips, warped connecting rods, etc.

<u>Types of control charts</u>

Control charts are broadly classified into two types:

1. **Control charts for variables**:

(a) Mean chart—X bar chart

(b) Range chart—R chart

(c) Standard deviation chart—s chart

2. **Control charts for attributes**:

(a) p Chart

(b) np Chart

(c) c Chart

(d) u Chart

Control chart for attributes

Many quality characteristics cannot be conveniently represented numerically. In such cases, each item inspected is classified as either conforming or non-conforming to the specifications of that quality characteristic. The attributes data assume only two values— good or bad, pass or fail, defective or non-defective and so on. Attributes usually cannot be measured but they can be observed and counted and are useful in many practical situations.

Attribute control charts are used when items are compared with some standard and are then classified as to whether they meet the standard or not. The control chart is used to determine if the rate of the non-conforming product is stable and detects when a deviation from stability has occurred. The argument can be made that a LCL should not exist, since rates of non-conforming product outside the LCL is a good thing. We want low rates of nonconforming products. However, if we treat these LCL violations as simply another search for an assignable cause, we may learn the reason for the drop in the rate of non-conformities and be able to permanently improve the process.

The two major types of control charts for attributes are:

1. “Number of defectives” charts

2. “Number of defects” charts

The “number of defective charts” are of two types—

(a) p chart or fraction defectives chart for varying sample size or constant samples size and

(b) np chart or chart for the number for constant sample size only.

p-charts(chart for defectives)

The p chart is an attribute control chart. It is designed to control the percentage or proportion of defectives per sample. This chart is best suited in cases where inspection is carried out with a view to classifying an article as accepted or rejected. This chart shows the fraction of non-conforming or defective products produced by a manufacturing process. It is also termed the control chart for fraction non-conformance. p Charts can be used when the subgroups are not of equal size. The np chart is used in the more limited case of equal subgroup.

Steps in construction of p chart

: The following steps can be used to construct a p chart.

1. Determine the size of the subgroups needed. The size, n(i), has to be sufficiently large to have defects present in the subgroup. If we are aware of the historical rate of non-conformance, p, we can use the following formula to estimate the subgroup size:

$$n = 3/p$$

2. Record the data for each subgroup on the number inspected and the number of defectives

3. Determine the rate of non-conformities in each subgroup by using:

$$\hat{p}(i) = x(i)/n(i)$$

where = The rate of non-conformities in subgroup i

x(i) = The number of non-conformities in subgroup i and

n(i) = the size of subgroup i

4. Find ; there are k subgroups:

$$\overline{p} = \frac{1}{k}\sum \hat{p}(i)$$

5. Estimate if needed and determine the UCL and LCL:

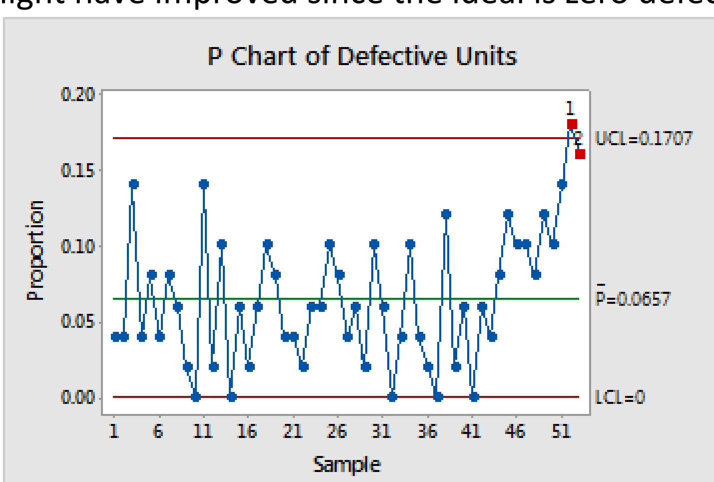
$$\hat{\sigma}_p = \sqrt{\frac{\overline{p}(1-\overline{p})}{n}}$$

$$\begin{aligned} \mathrm{UCL} &= \overline{p} + 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n(i)}} \\ &= \overline{p} + 3\hat{\sigma}_p \end{aligned}$$

$$\begin{aligned} \mathrm{LCL} &= \overline{p} - 3\sqrt{\frac{\overline{p}(1-\overline{p})}{n(i)}} \\ &= \overline{p} - 3\hat{\sigma}_p \end{aligned}$$

6. Plot the central line, p bar, the LCL and UCL and the process measurements.

7. Interpret the data to determine if the process is in control. Points outside the control limits signify an out of control situation. Patterns and trends should also be sought to identify special or assignable causes. However, a point on a p chart below the LCL or the development of a trend below the central line indicates that the process might have improved since the ideal is zero defectives.



<u>u-chart (chart for defects)</u>

A defect is a single non-conforming characteristic of an item. A defective product has one or more defects. In some situations, quality assurance personnel may be interested in knowing not only whether an item is defective, but also how many defects it has. Two charts can be applied in such situations:

1. The c chart that is used to control the total number of defects per unit, when the subgroup size is constant.

2. The u chart that is used to control the average number of defects per unit, when the

sub group sizes are constant or variable. When the subgroup size is constant, the c chart is preferred over the u chart.

This chart shows the non-conformities per unit produced by a manufacturing process. The u chart is used when it is not possible to have an inspection unit of a fixed size (e.g. 12 defects counted in one square foot). The number of non-conformities is per inspection unit where the inspection unit may not be exactly one square foot. Rather, it may be an intact panel or other object, different in size than exactly one square foot. When it is converted into a ratio per square foot, or some other measure, it may be controlled with a u chart.

Steps in construction of u-chart

The following steps can be used to construct a u chart:

1. Find the number of non-conformities, c(i) and the number of inspection units, n(i), in each sample i.

2. Compute

3. Determine the central line of the u chart:

$$\bar{u} = \frac{\text{Total Non-conformities in } k \text{ Subgroups}}{\text{Total Number of Inspection Units}}$$

$$\bar{u} = \frac{c_1 + c_2 + \cdots + c_k}{n_1 + n_2 + \cdots + n_k}$$

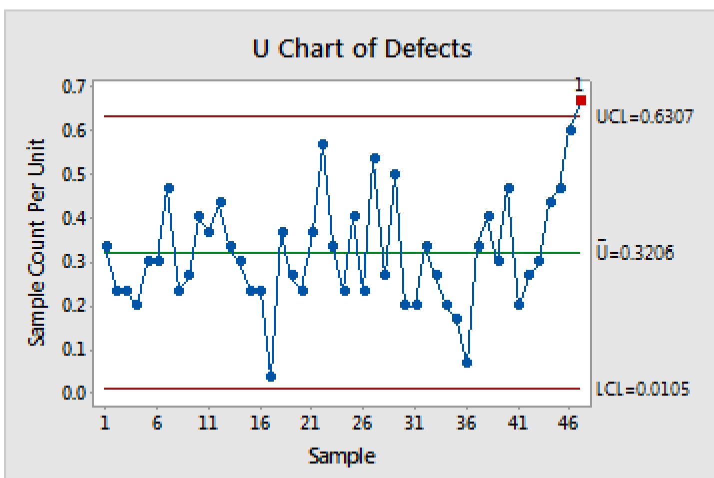
4. The u chart has individual control limits for each subgroup i.

$$\mathrm{UCL} = \bar{u} + 3\sqrt{\frac{\bar{u}}{n(i)}}$$

$$\mathrm{UCL} = \bar{u} - 3\sqrt{\frac{\bar{u}}{n(i)}}$$

5. Plot the central line, u bar , the individual LCLs and UCLs and the process measurements, u(i).

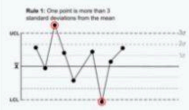
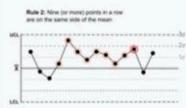
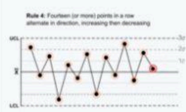
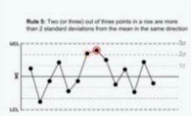
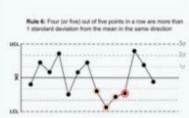
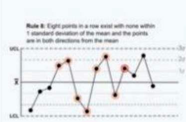
6. Interpret the control chart.



Nelson Rules

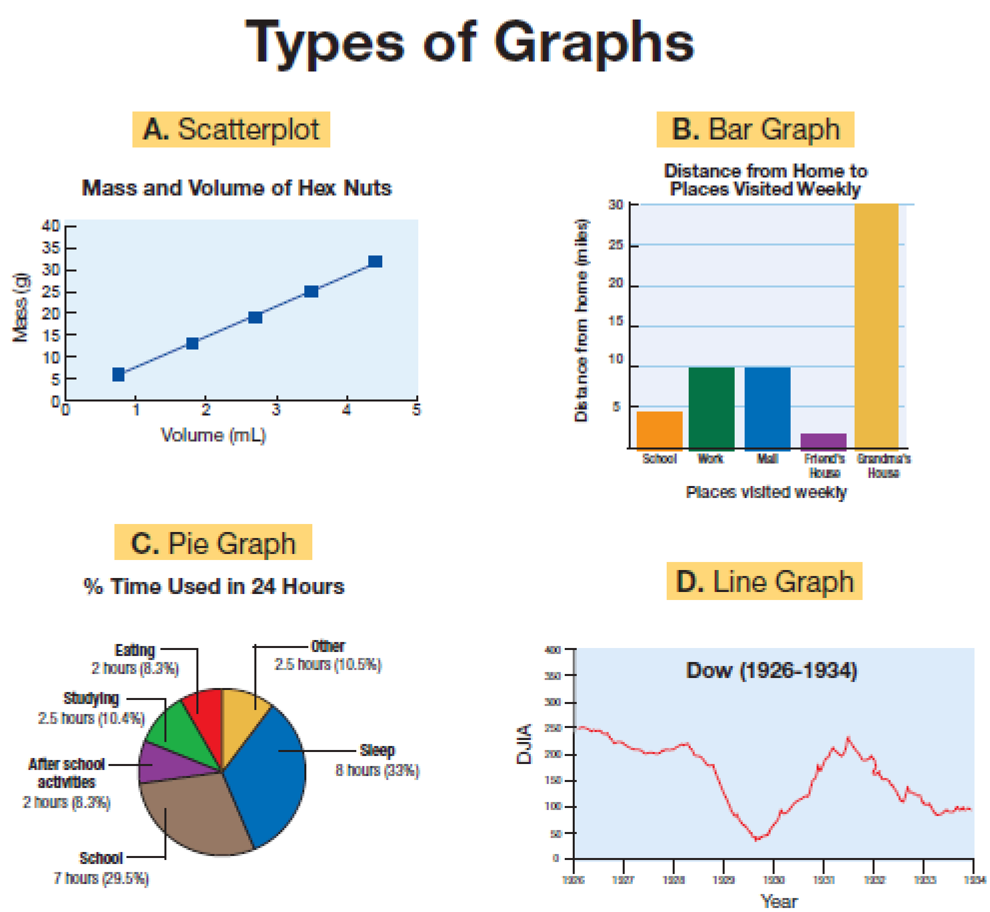
Nelson rules are a method in process control of determining whether some measured variable is out of control (unpredictable versus consistent). Rules for detecting "out-of-control" or non-random conditions were first postulated by Walter A. Shewhart in the 1920s.

The rules are applied to a control chart on which the magnitude of some variable is plotted against time. The rules are based on the mean value and the standard deviation of the samples.

Rule	Description	Chart Example	Problem Indicated
Rule 1	One point is more than 3 standard deviations from the mean.		One sample (two shown in this case) is grossly out of control.
Rule 2	Nine (or more) points in a row are on the same side of the mean.		Some prolonged bias exists.
Rule 3	Six (or more) points in a row are continually increasing (or decreasing).		A trend exists.
Rule 4	Fourteen (or more) points in a row alternate in direction, increasing then decreasing.		This much oscillation is beyond noise. Note that the rule is concerned with directionality only. The position of the mean and the size of the standard deviation have no bearing.
Rule 5	Two (or three) out of three points in a row are more than 2 standard deviations from the mean in the same direction.		There is a medium tendency for samples to be mediumly out of control. The side of the mean for the third point is unspecified.
Rule 6	Four (or five) out of five points in a row are more than 1 standard deviation from the mean in the same direction.		There is a strong tendency for samples to be slightly out of control. The side of the mean for the fifth point is unspecified.
Rule 7	Fifteen points in a row are all within 1 standard deviation of the mean on either side of the mean.		With 1 standard deviation, greater variation would be expected.
Rule 8	Eight points in a row exist, but none within 1 standard deviation of the mean, and the points are in both directions from the mean.		Jumping from above to below while missing the first standard deviation band is rarely random.

Graphs

Graphs are used depending on the shape desired and the purpose of analysis. Bar graphs compare values via parallel bars, while line graphs are used to illustrate variations over a period of time. Circle graphs indicate the categorical breakdown of values, and radar charts assist in the analysis of previously evaluated.



Six Sigma

Six Sigma is a widely practiced, systematic and structured methodology embedded with statistical methods and managerial philosophies for quality improvement by large firms along with small firms in the industrialized economies. Six Sigma is a set of techniques and tools for process improvement. It was developed by Motorolain 1986. Jack Welch made it central to his business strategy at General Electric in 1995.Six Sigma seeks to improve the quality of process outputs by identifying and removing the causes of defects (errors) and minimizing variability in manufacturing and business processes. It uses a set of quality management methods, mainly empirical, statistical methods, and creates a special infrastructure of people within the organization ("Champions", "Black Belts", "Green Belts", "Yellow Belts", etc.) who are experts in these methods.

The maturity of a manufacturing process can be described by a sigma rating indicating its yield or the percentage of defect-free products it creates. A six-sigma process is one in which 99.99966% of all opportunities to produce some features of a part are statistically expected to be free of defects (3.4 defective features / million opportunities), this defect level corresponds to only a 4.5 sigma level.

Basically, you have achieved six sigma when your processes deliver only 3.4 defects per million opportunities (DPMO). For example, this would mean that out of one million bags checked in at the airport luggage counter, only 3.4 would be lost. In other words, your processes are working almost perfectly.

Sigma	DPMO	% Yield
6.00	3.4	99.9997
5.51	30.4	99.9970
5.00	233	99.9770
4.50	1350	99.8650
4.00	6210	99.3790
3.50	22750	97.7300
3.00	66807	93.3200
2.50	158655	84.2000
2.00	308538	69.2000
1.50	500000	50.0000
1.00	691462	31.0000
0.51	838913	16.0000
0.09	920730	8.0000

Six Sigma is a business-driven, multi-dimensional structured approach for: -

• Improving Processes

• Lowering Defects

• Reducing process variability

• Reducing costs

• Increasing customer satisfaction

• Increased profits

KEY CONCEPTS OF SIX SIGMA

At its core, Six Sigma revolves around a few key concepts.

- Critical to Quality: Attributes most important to the customer.
- Defect: Failing to deliver what the customer wants.

- Process Capability: What your process can deliver.

- Variation: What the customer sees and feels.

- Stable Operations: Ensuring consistent, predictable processes to improve what the customer sees and feels.

- Design for Six Sigma: Designing to meet customer needs and process capability

Our Customers Feel the Variance, Not the Mean. So Six Sigma focuses first on reducing process variation and then on improving the process capability.

THE BASIC COMPONENTS OF SIX SIGMA

There are three basic concepts that are common to all businesses that Six Sigma addresses:

processes, defects, and variation.

Process

A fundamental concept of Six Sigma is process. A process is any set of repetitive steps—in any manufacturing, services, or transactional environment to achieve some result. There are processes for all core business activities and functions. They are the steps that the people in an organization go through to do their jobs and deliver your products or services. You may not have thought much about them, but they're there nevertheless. Understanding them and making them work at the highest level possible is the goal of Six Sigma.

Examples:

• Steps taken in billing a customers

• Taking customer orders

• Fulfilling customer orders

Defects

Part of the Six Sigma methodology includes measuring a process in terms of defects. Six Sigma helps you eliminate those defects so you can consistently and profitably produce and deliver products or services that meet and exceed your customers' expectations. Sometimes, it's not unusual for a business to have a minimum of 10 percent of its net income being wasted by process defects.

In other words, those defects are profit wasted! Here are typical defects we have all experienced:

• Scheduling defect at doctor's office

• Waiting in line at drive-through (wrong food, too much time)

• Waiting too long to get the restaurant bill

• Not getting paid on time

• Bank statement errors

• Telephone bill errors

Variation
The Six Sigma methodology reduces variations in business processes. It seems obvious, but one can't consistently produce a high-quality product or service if there are variations in the processes, right? Basically, you have achieved six sigma when your processes deliver only 3.4 defects per million opportunities (DPMO). For example, this would mean that out of one million bags checked in at the airport luggage counter, only 3.4 would be lost. In other words, your processes are working almost perfectly.

Six Sigma can be implemented in any business, regardless of what a business is or how small-scale it is. Six Sigma is about problem-solving, and problems are everywhere. It doesn't matter what type or size of business this breakthrough methodology is applied to. A person might be a wholesaler, a retailer, a manufacturer, or a service organization. He might have three employees, or maybe 300. No matter, Six Sigma will work for everyone.

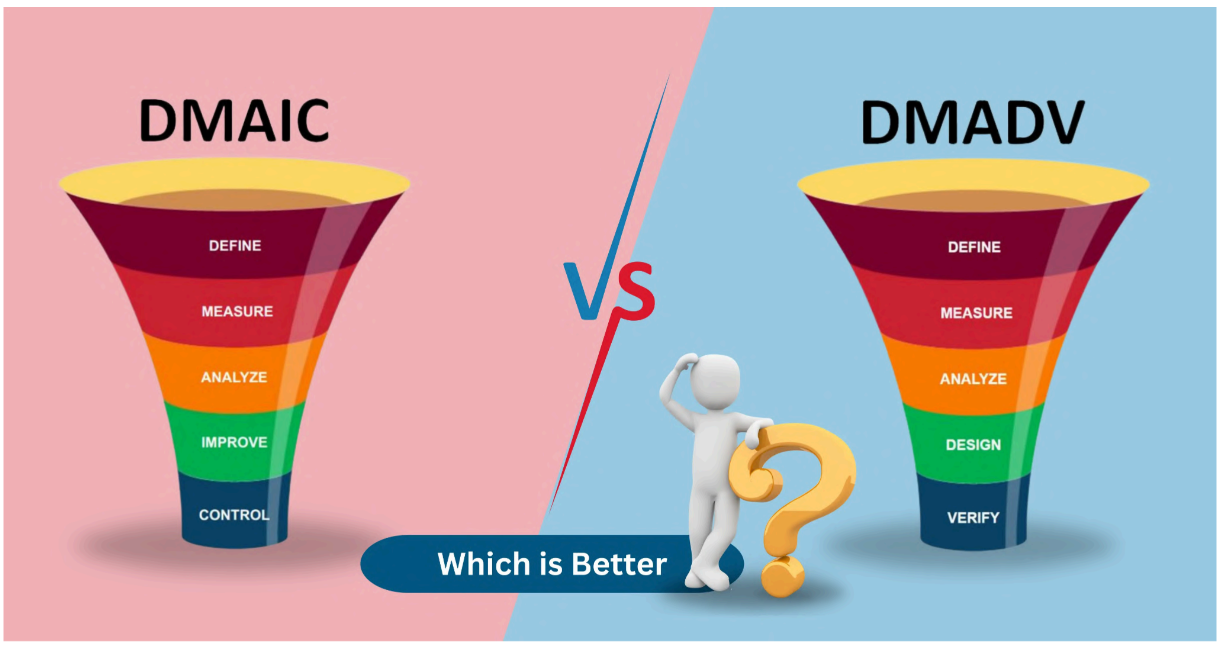
DEFECTS PER MILLION OPPORTUNITES (DPMO)

In process improvement efforts, defects per million opportunities or DPMO (or nonconformities per million opportunities (NPMO)) is a measure of process performance.

$$DPMO = \frac{Number\ of\ defects}{Number\ of\ units * Number\ of\ opportunities} \times 1{,}000{,}000$$

IMPLEMENTING SIX SIGMA

Six Sigma projects follow two project methodologies inspired by Deming's Plan-Do Check-Act Cycle. These methodologies, composed of five phases each, bear the acronyms DMAIC and DMADV.



• **DMAIC:**

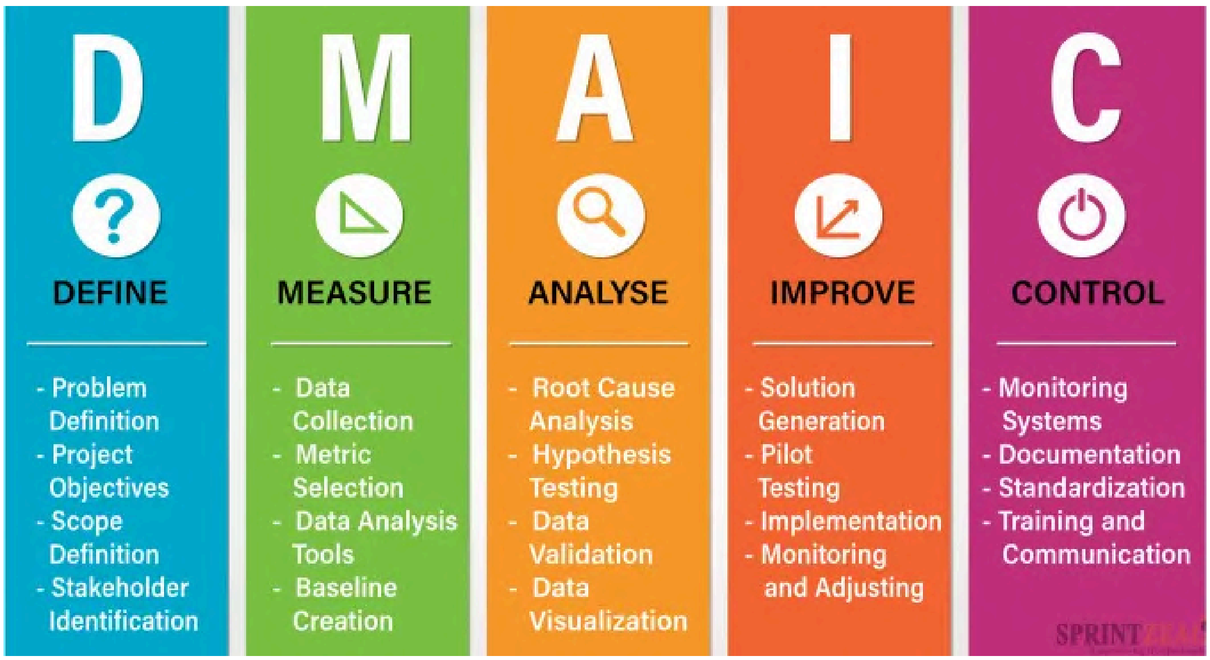
refers to a data-driven quality strategy for improving processes. This methodology is used to improve an existing business process.

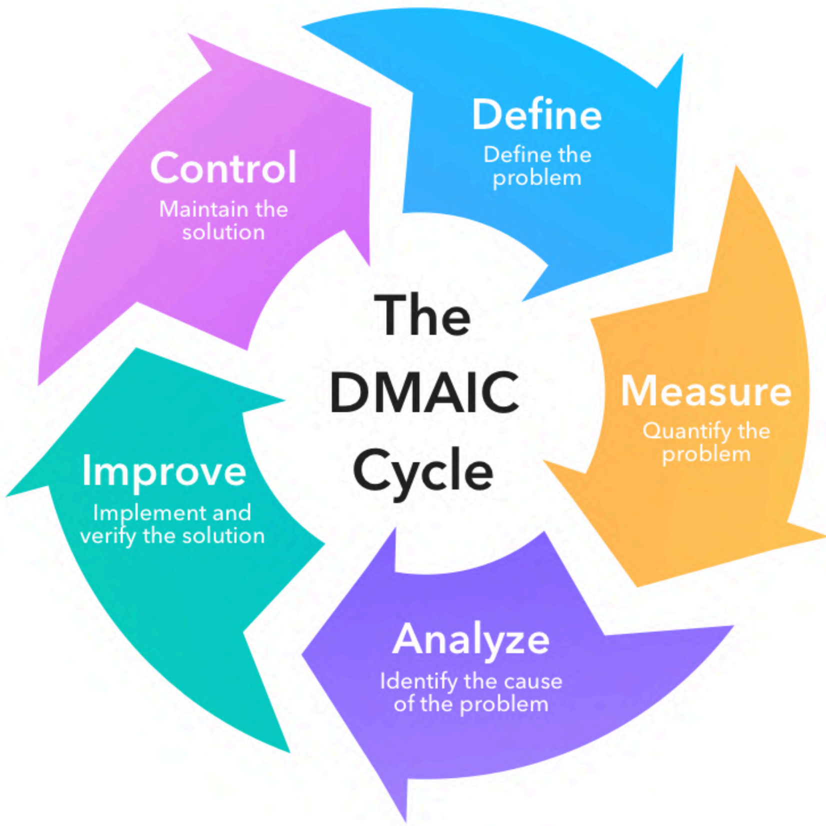
• **DMADV**:

refers to a data-driven quality strategy for designing products & processes. This methodology is used to create new product designs or process designs in such a way that it results in a more predictable, mature and defect free performance.

DMAIC METHODOLOGY

In the literature of Six Sigma, DMAIC model is most widely discussed and used model. DMAIC is a linear framework of quality improvement defined in five stages namely, define, measure, analyze, improvement, and control. The DMAIC model aims to improve, optimize, or stabilize an existing process by detecting and removing the defects or inefficiencies in the process, specifically the output defects.





Define the system, the voice of the customer and their requirements, and the project goals, specifically. We define the goals of the improvement activity. At the top level, the goals will be strategic objectives of the organization such as a higher ROI or market share. At the operations level, goals might be to increase the throughput of the production department. At the project level, the goals might be to reduce the defect level and increase throughput.

Measure key aspects of the current process and collect relevant data; calculate the 'as-is' Process Capability. We measure the existing system. Establish valid and reliable metrics to help monitor progress towards the goal(s) defined in the previous step. Begin by determining the current baseline. Use exploratory and descriptive data analysis to help you understand the data.

Analyze the data to investigate and verify cause-and-effect relationships. Determine what the relationships are and attempt to ensure that all factors have been considered. Seek out root cause of the defect under investigation. We analyze the system to identify the ways to eliminate the gap between the current performance of the system or process and the desired goal. Apply statistical tools to guide the analysis.

Improve or optimize the current process based upon data analysis using techniques such as design of experiments, poka yoke or mistake proofing, and standard work to create a new, future state process. Set up pilot runs to establish process capability. We improve the system. Be creative in finding new ways to do things better, cheaper or faster. Use project management and other planning and management tools to implement the new approach. Use statistical methods to validate the improvement.

Control the future state process to ensure that any deviations from the target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, visual workplaces, and continuously monitor the process. We control the new system. Institutionalize the improved system by modifying compensation and incentive systems, policies, procedures, MRP, budgets, operating instructions and other management systems**.**

DMADV METHODOLOGY

- **Define** design goals that are consistent with customer demands and the enterprise strategy
- **Measure** and identify CTQs (characteristics that are Critical To Quality), Measure product capabilities, production process capability, and measure risks.
- **Analyze** to develop and design alternatives.
- **Design** an improved alternative, best suited per analysis in the previous step.
- **Verify** the design, set up pilot runs, implement the production process and hand it over to the process owner(s)

Analytical Hierarchical Process (AHP)

The AHP approach, developed by Saaty (1980), is one of the more extensively used MCDM methods. The AHP has been applied to a wide variety of decisions and the human judgment process. The approach is used to construct an evaluation model and has criterion weights. It integrates different measures into a single overall score for ranking decision alternatives. Applying it usually results in simplifying a multiple criterion problem by decomposing it into a multilevel hierarchical structure. The AHP process is useful for systematically evaluating qualitative criteria.

1. <u>Why AHP</u>:-

The AHP has been applied to a variety of business decisions and processes requiring high degrees of subjective judgment setting up a problem as a hierarchy is an efficient and intuitive way of dealing with complexity and identifying the relevant components of the problem. The AHP is flexible in allowing decision-makers to structure a hierarchy to fit individual needs and preferences. In addition, used in a group setting, using AHP to structure a problem may help to isolate areas of disagreement so that more attention can be focused on them in order to achieve consensus.

2. <u>Matrix formulation</u>:-

Given a pair wise comparison, the analysis involves three tasks:

i) Developing a comparison matrix at each level of the hierarchy starting from the second level and working down.

ii) Computing the relative weights for each element of the hierarchy.

Iii Estimating the consistency ratio to check the consistency of the judgment.

Elements in each level are compared in pairs with respect to their importance to an element in the next higher level.

Starting at the top of the hierarchy and working down, the pair wise comparisons at a given level can be reduced to a number of square matrices. In AHP, Saaty (1980) recommended a scale of relative importance (given in the table below) from 1 to 9 for making subjective pair wise comparisons.

Scale of Relative Importance

Scale	Numerical rating	Reciprocal
Equal importance	1	1
Equal to moderate importance	2	1/2
Moderate importance	3	1/3
Moderate to strong importance	4	1/4
Strong importance	5	1/5
Strong to very strong importance	6	1/6
Very strong importance	7	1/7
Very strong to the extreme importance	8	1/8
Extreme importance	9	1/9

NOTE- The preferences of the individual should correspond to the following prerequisites:

- Reciprocity: if A is 3 times more important than B, then B is 1/3 times more important than A.
- Transitivity: if A>B and B>C then A>C.
- Consistency: resulting from reciprocity and transitivity.

After all, pairwise comparison matrices are formed, the vector of weights, $w = [w_1, w_2,$ ……..,

$w_n]$, is computed on the basis of Saaty's eigenvector procedure.

The computation of the weights involves two steps:

First, the pair wise comparison matrix, $A = [a_{ij}]_{nxn}$, is normalized by equation, and then the weights are computed by equation.

Normalization Equation: $a_{ij} = a_{ij}/\sum a_{ij}$, for all j = 1, 2, …., n.

Weight Calculation: $w_i = \sum a_{ij}/n$, for all i = 1, 2, ..., n.

Satty (1980) showed that there is a relationship between the vector weights w, and the pairwise comparison matrix A, as shown in equation.

$Aw = \lambda_{max}.w$

The λ_{max} value is an important validating parameter in AHP and is used as a reference index to screen information by calculating the consistency ratio (CR) of the estimated vector.

3. Consistency Check for Pairwise Comparison Matrix:-

To calculate the CR, the consistency index (CI) for each matrix of order n can be obtained from equation:

$CI = (\lambda_{max} - n)/(n-1)$

CR can be calculated by using the equation:

$CR = CI/RI$

where RI is the random consistency index obtained from a randomly generated pairwise comparison matrix. Table 2 shows the value of the RI from matrices of order 1 to 10 as suggested by Saaty (1980).

Number of Matrix (n)	Random Index / RI (inconsistency)
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

If CR < 0.1, then the comparisons are acceptable i.e. the matrix is consistent. If CR > 0.1, then the values of the ratio are indicative of inconsistent judgments. In such cases, one should reconsider and revise the original values in the pairwise comparison matrix A.

About company:

C. L. GUPTA EXPORTS LTD.

C. L. GUPTA EXPORTS LTD.

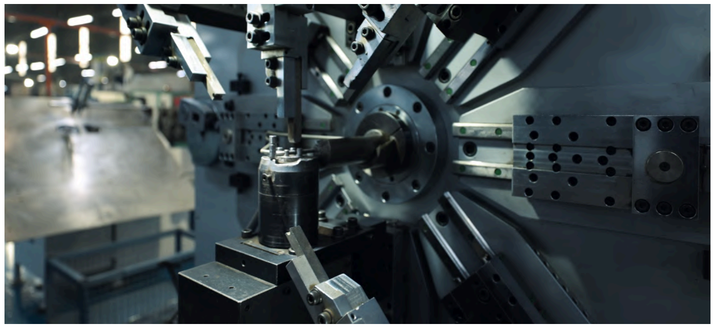
Company Profile

C. L. Gupta Exports Ltd. is a private enterprise in India, headquartered near Moradabad (18 Km. Stone, Delhi Road, Vill. Jivai, 244221), Uttar Pradesh. It operates in the Export and Manufacturing industry. The company was established in 1965. Through consistent performance, C.L. Gupta Exports Ltd. has received various awards for being a top exporter in the craft.

Company's Work and Services

CL Gupta Exports Ltd. has a manufacturing facility spread across approximately 55 acres of land, with vertically integrated production facility of materials such as Wood, Metal, Glass, Stone and Ceramic. The company deals in manufacturing and export of handicrafts.

- **Metal:** With an experience of over 65 years in manufacturing metal products, they possess expansive knowledge in the field. From die casting to sheet, wire and pipe fabrication, they use industry-leading methods and equipment to achieve top quality and finishes in their products. They work with various metals like aluminium, steel, brass, and copper.



- **Wood:** From indigenous to imported woods and veneers, they are the experts in the industry, employing people and equipment to produce state-of-the-art wood furniture and accessories across all categories of Home. With their 100% in-house manufacturing facility, they make the best quality products in the industry. In addition to being PEFC & FSC certified manufacturers, they employ sustainable processes that recycle and reuse manufacturing waste.

- **Glass:** C.L. Gupta Exports Ltd preserve the 200-year-old craft of mouth blown glass. They employ the most skilled artisans to manufacture their glass products in their in-house glass furnace.

- **Marble:** Specializing in Banswara Marble, they manufacture various tabletops and tapered stoneware products. The in-house processed marble is cut into unique profiles to cater to their versatile multi-material product range.

Company's Values

- **Customer Focus:** We know that our customer comes first. With that mentality, we give our best to understand their needs. We persevere in maintaining our strong customer relationships through professional standards, mutual respect and industrial knowledge.

- **Excellence:** With over 60 years of experience, we have built a strong passion for our products. We understand that every product is unique, and therefore, we employ the best techniques, people and ideas to cater to meet customers' expectations.We know that our customer comes first. With that mentality, we give our best to understand their needs. We persevere in maintaining our strong customer relationships through professional standards, mutual respect and industrial knowledge.

- **Versatility:** With our range of multi-material products, we are experts in the craft. We bring together a diverse group of individuals that develop ingenious solutions in wood, metal, glass, ceramic and marble decorative, lighting and furniture products.

- **Community:** At C.L. Gupta Exports Ltd, we believe that the people and the environment are the core components of a healthy and prosperous society. We take sustainable initiatives to respect our environment and provide training to our employees.

- **Team Work:** We believe that success is the by-product of a team that learns together, respects each other and works towards a common goal. At the company, we provide an inclusive environment that allows individuals to be creative and innovative.

Awards

Through consistent performance, C.L. Gupta Exports Ltd. has received various awards for being a top exporter in the craft.

- EPCH (Export Promotion Council for Handicrafts) Top Export Award for years 2012-13, 2015-16, 2016-2017, 2017-2018, 2018-19

- Certificate of Merit for the year 1996-97 by Carpet Export Promotion Council
- Certificate of Merit for the year 1997-98 by Ministry of Commerce
- Top State Export Award for the years 1996-2001 by Government of U.P
- Top Exports Award for the years 1996-98 by Export Promotion Council

Certification

Some Products

Other details regarding C. L. GUPTA EXPORTS LTD.

Address	C. L. Gupta Export Ltd. 18 Km. Stone, Delhi Road, Vill. Jivai, near Moradabad, Uttar Pradesh 244221
TEL	91 591-2477000
Website	https://clgupta.com/
Activity	Manufacturer and Exporter of Handicraft items in Metal (Aluminium, Brass, Copper, and Iron), Wood, Glass and Marble
Company Subcategory	Private
Age of company	Around 60 years (Since 1965)
Company status	Active
Class of company	Private

Problem Definition

C. L. Gupta Exports Ltd. is a private enterprise which operates in the Export and Manufacturing industry. The company has a manufacturing facility with vertically integrated production facility of materials such as **Wood, Metal, Glass, Stone and Ceramic**. The company deals in **manufacturing and export of handicrafts**. With an experience of over 65 years in manufacturing metal products, they possess expansive knowledge in the field. From die casting to sheet, wire and pipe fabrication, they use industry-leading methods and equipment to achieve top quality and finishes in their products. They work with various metals like aluminium, steel, brass, and copper. and these type of handicraft items which are produced here are having major defects of improper polishing, cracks, denting, etc. so that's why we are focusing on improving the process control of manufacturing the candle stand.

The ever increasing competition from the global market, the company always wants to put into practice the concept of **Total Quality** and to adopt **Zero Defects** policy, especially when it comes to a product that is **critical to life**.

Since obtaining a high quality of 100% non-defective product is impossible just by inspection, numerous statistical and quantifiable ways have been introduced to reduce the overall number of defects as well as to continue improving the benchmarks obtained.

This project presents an application of Quality Management principles for **manufacturing of Aluminium Candle Stands**, which is concluded through an action plan for improving product quality level and implementing the suggestions provided. In this study, quality management tools are used to establish specific inspection methods to detect the defect type which causes maximum rejection and to prevent their appearance in product. Also, Quality checking is always a continuous improvement methodology wherein defects are eliminated after every inspection resulting in lesser number of rejections and hence improving quality level

Scope of Study

The demand for higher value at reduced price is increasing on the consumer front. As a result, manufacturers are increasingly adopting quality improvement techniques to improve productivity and quality, reduce waste and thereby providing higher value at moderate cost. The data driven Six Sigma quality improvement methodology provides a framework to identify, eliminate and control the causes of variation in an operational process. Improvement using the Six Sigma technique can increase the quality of the product and reduce the number of defective items for the particular product. **C. L. Gupta Exports Ltd.** want the sigma level of their product nearly **equal or greater than 4.0.**

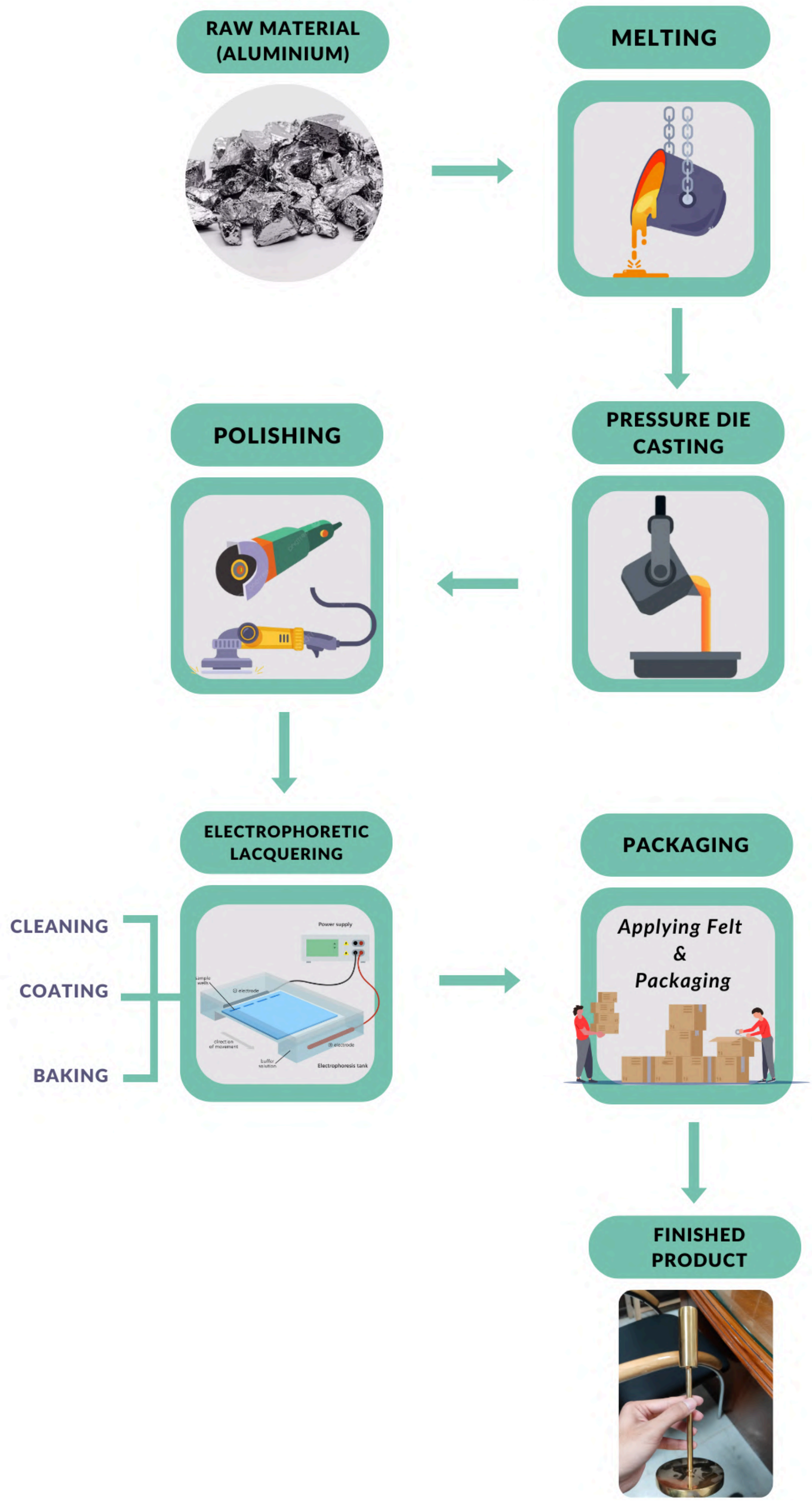
This project mainly focused on six sigma quality philosophy and other related philosophy that would be implemented in these studies in order to identify the current problem or rejection criteria facing by the company. The “**Six Sigma**” DMAIC Model is used because, it provides a step-by-step quality improvement methodology that uses statistical methods to quantify variation.

The integration of **AHP and Pareto Charts** will help the company identify their CTQ **(critical to quality)** defects and analyze on them is done.

In this case, the company loses a huge amount of money which must be nipped. Apart from these, a total quality check is important for a company so as to maintain its goodwill as well as reputation in the industry. Keeping this in mind, the study will only prove to be beneficial if the process of quality checking is done on a continuous basis.

Continuous Quality Improvement involves setting the standards and then continually improving those standards. Hence, after implementing the corrective measures improvement data was calculated and based on which new standards are being set up for the company.

Process Flow Chart



DMAIC (Solution Methodology)

We will use **DMAIC (Define – Measure – Analyze – Improve – Control)** Six Sigma Model to solve the problem.

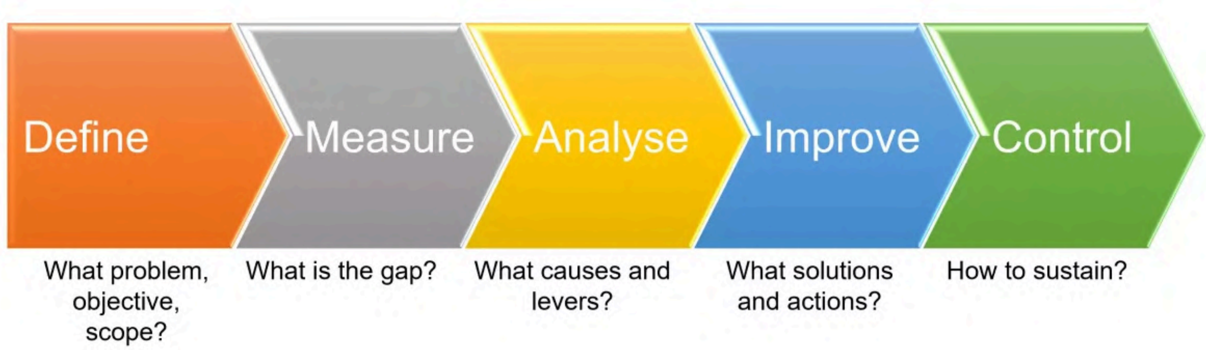
Define phase of the DMAIC model helps in understanding and documenting the problem. In this project, SIPOC diagram have been used in the define phase. **SIPOC** diagram documents complete information about the process and their related inputs and outputs.

During the **Measure** phase, based on problem definition key defects are prioritized and the baseline process performance is measured. AHP, check sheet data, p-chart, pareto charts and process sigma level have been used in this study to prioritize and measure the process performance. Data collection is done using check sheet, p-chart for fraction defective has been used to check whether the process is under control or not and baseline sigma level is calculated.

Analyze phase of DMAIC model is aimed at identifying the causes and root causes of the key defects. Cause C&E diagram, Inter-relationship Diagrams (IRD), Current Reality Tree (CRT) and Cause and Effect Matrix (C&E Matrix) method have been used to identify the important causes and root causes of the vital defects in the process.

The **improve** phase follows the analyze stage wherein the improvement efforts are established and implemented to address the root cause of the problem. Aim is to evaluate the potential solutions of the identified root causes.

In the **control** phase of the Six Sigma DMAIC model, the process is monitor and controls the improvement efforts to sustain the process sigma level.



Stage 1

DEFINE

Stage 1 comprises two primary processes: Melting and Pressure Die Casting. This stage is fundamental for transforming raw aluminium into the desired form for further shaping and refinement.

Melting:

- **Raw Material Preparation:** The process begins with preparing the raw aluminum, typically in the form of ingots, scraps, or recycled aluminum. These materials are carefully selected and cleaned to remove any impurities or contaminants that could affect the final product quality.

- **Melting Furnace:** The cleaned aluminum is placed into a melting furnace. The furnace is heated to approximately 660°C (1220°F), the melting point of aluminum. Modern furnaces are equipped with temperature control systems to ensure a consistent and controlled melting environment.

Pressure Die Casting:

- **Die Preparation:** While the aluminum is melting, the die (mold) is prepared. The die is preheated and coated with a release agent to facilitate the easy removal of the cast part and to prolong the die's life by reducing thermal shock.

- **Injection of Molten Aluminum:** Once the aluminum is fully melted and properly conditioned, it is transported to the die casting machine. The machine injects the molten aluminum into the die under high pressure, typically ranging from 1,500 to 25,000 psi (pounds per square inch). This high-pressure injection ensures that the molten metal fills all the intricate details and cavities of the die, resulting in precise and accurate parts.

- **Solidification and Cooling:** After the molten aluminum has been injected into the die, it begins to cool and solidify rapidly. The high thermal conductivity of aluminum helps in quick solidification, which is essential for maintaining the dimensional accuracy and surface finish of the cast part.

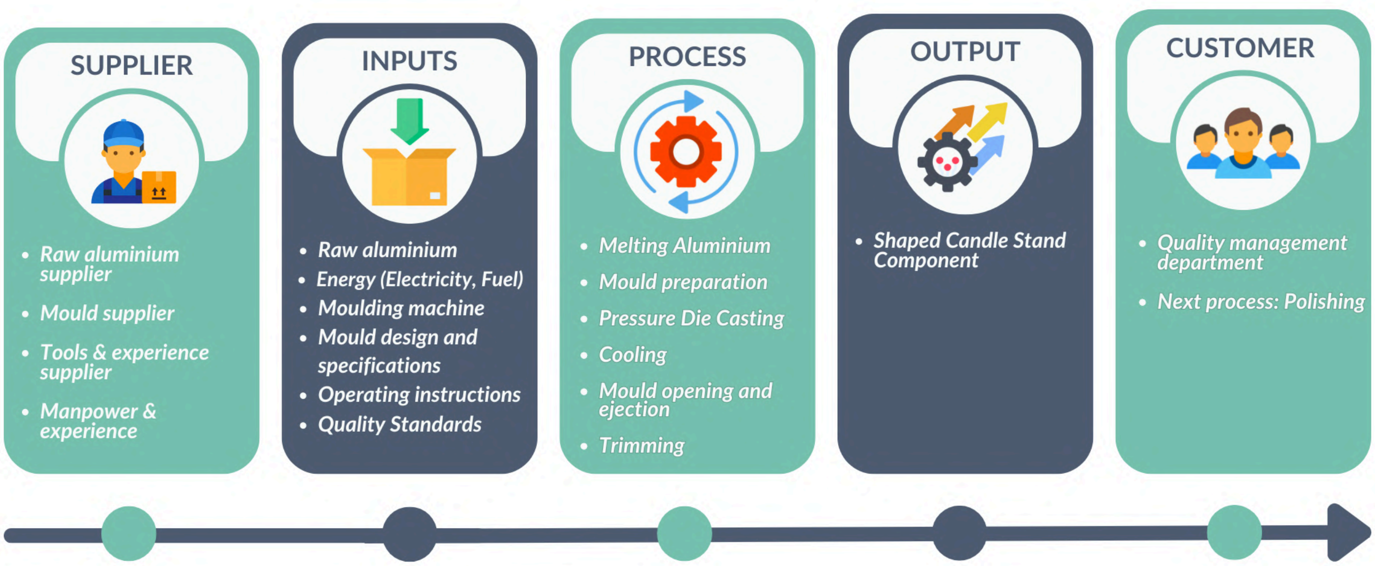
- **Ejection:** Once the aluminum has solidified, the die opens, and the cast part (aluminum candle stand) is ejected. Automated ejector pins or mechanisms are often used to push the part out of the die without causing any damage.

- **Trimming and Deburring:** After ejection, the cast aluminum candle stands may have excess material, such as flash or sprues, which need to be removed. This is done through trimming and deburring processes to ensure smooth edges and surfaces.

- **Surface Finishing:** The cast parts are then prepared for further finishing processes, such as polishing, to achieve the desired aesthetic and functional qualities. This preparation might include cleaning, sanding, or other surface treatments.

This stage is further explained by the help of SIPOC diagram:

SIPOC Diagram



The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem.

Defects Identified in Stage 1

1. **Non Filling:** This defect occurs when the molten metal fails to completely fill the entire cavity of the die during the casting process. This results in incomplete or partially formed castings, which can compromise the quality and functionality of the final product. This defect can arise due to various factors such as insufficient injection pressure, improper gating or runner design, air entrapment within the die cavity, temperature variations, inadequate die venting, or premature solidification of the molten metal. These issues can hinder the flow of molten metal into all areas of the cavity, leading to voids, porosity, or surface irregularities in the casting.

Non Filling Defect

2. **Pin Holes (“खासर”):** These are tiny voids or holes that occur on the surface or inside the casting. These defects can vary in size and frequency, ranging from small pin-sized holes to larger voids, and they can significantly affect the appearance, structural integrity, and functionality of the final product. Pinholes are typically caused by gas entrapment within the molten metal during the casting process. When the molten metal is injected into the die cavity under high pressure, gases present in the metal or released from other sources (such as moisture or lubricants) may become trapped within the casting. As the metal solidifies, these trapped gases form voids or bubbles, resulting in pinholes on the surface or inside the casting.

Pin Holes Defect

3. **Cold Shot:** A cold shot defect occurs in pressure die casting when there is incomplete fusion between the molten metal and the previously solidified material in the die cavity. This results in discontinuities or surface irregularities in the final casting, often appearing as protrusions or inclusions of solidified metal. Factors contributing to cold shot defects include improper injection parameters, such as inconsistent injection speed or pressure, poor die design, variations in metal temperature, and metal cleanliness issues.

Cold Shot Defect

4. **Dent:** A dent defect occurs in pressure die casting when depressions or concave areas appear on the surface of the casting. These dents can vary in size and depth and can compromise the appearance and functionality of the final product. Factors contributing to dent defects include poor die design, improper injection parameters, surface imperfections on the die, and variations in metal temperature.

Dent Defect

5. **Crack:** This defect occurs in pressure die casting when there is a fracture or separation in the casting material, resulting in a visible crack on the surface or within the structure of the casting. These cracks can compromise the integrity, functionality, and appearance of the final product. Factors contributing to crack defects include temperature variations within the molten metal or between the molten metal and the die, improper injection parameters, poor die design, metal cleanliness issues, and quenching effects during cooling.

Crack Defect

Project Charter

A project charter is a foundational document that outlines the scope, objectives, and parameters of a project. It defines the problem to be addressed and aligns the project with organizational goals. The charter establishes the project team, their roles, responsibilities, and authority levels. It sets a clear timeline for project completion, with milestones and deadlines. Additionally, it outlines the desired outputs and deliverables, ensuring alignment with business demands and customer requirements. The charter fosters effective collaboration and communication among team members. It serves as a roadmap for project initiation, execution, and evaluation. Overall, the project charter ensures clarity, accountability, and alignment throughout the project lifecycle.

PROJECT DESCRIPTION
Defect reduction in stage 1 which involves melting, mould preparation, pressure die casting cooling, mould opening and ejection, and trimming
PROJECT OBJECTIVE AND GOAL
To reduce the crack and pin hole defect in the mentioned processes of stage 1
PROJECT LOCATION
C. L. Gupta Export Ltd. 18 Km. Stone, Delhi Road, Vill. Jivai, near Moradabad, Uttar Pradesh 244221
BACKGROUND AND RATIONALE FOR PROJECT SELECTION
In the baseline process, Prioritize the defects in which Crack and Pin Holes has found to be highest priority as compared to the other defects based on the pareto chart (frequency) of the defects.
PROJECT TEAM
Quality Head Mangers from Manufacturing, Purchasing and Maintenance Quality control inspector, Research advisor and associates, and Floor operator
EXPECTED BENEFITS
Reduction in the defects due to crack and pin holes which would lead to cost benefits.
PROJECT PLAN
Application of DMAIC model of Six-Sigma
PROJECT TIMELINE
2 Months

Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the five defects identified in the defined stage is established, followed by defect prioritization with the help of pareto chart. Process specifications are followed to inspect the items with defects. The process output is sampled for 25 days and 25 data points are collected as C. L. Gupta Exports Ltd. works in 1 single shift. In total, 10642 units are observed in 25 days. To check whether process is in control or not, p-chartis plotted as number of units inspected in each day are different and we are considering the entire candle stand as a defective.

a) Check sheet for Pre-Analysis:

		Defects					
Day	Total inspected units	Non Filling	Pin holes	Cold Shot	Dent	Crack	No. of Defectives
1	417	1	15	3	5	16	37
2	440	5	23	5	3	17	36
3	432	2	10	1	4	15	39
4	413	5	20	6	1	16	33
5	428	6	15	2	2	23	35
6	413	1	20	4	5	18	42
7	434	2	10	3	1	22	31
8	424	3	21	8	2	17	34
9	426	6	5	3	3	18	40
10	433	2	27	8	4	27	43
11	437	4	15	5	3	17	41
12	425	0	19	7	1	24	30
13	436	4	5	4	2	19	45
14	440	0	17	4	5	23	34
15	418	6	15	6	3	27	40
16	413	3	15	3	2	19	35
17	432	5	30	4	0	18	45
18	419	4	10	3	3	16	42
19	413	6	21	1	2	21	36
20	419	4	16	5	5	27	45
21	419	3	14	3	3	16	33
22	423	4	29	4	2	19	45

23	434	2	16	2	4	18	32
24	426	1	26	1	2	21	39
25	428	5	20	2	3	23	34
Total	**10642**	**84**	**434**	**97**	**70**	**497**	**946**

From the above table we can see that we have total inspected 10642 units and total no. of defectives are 946. Now we will plot the p-chart.

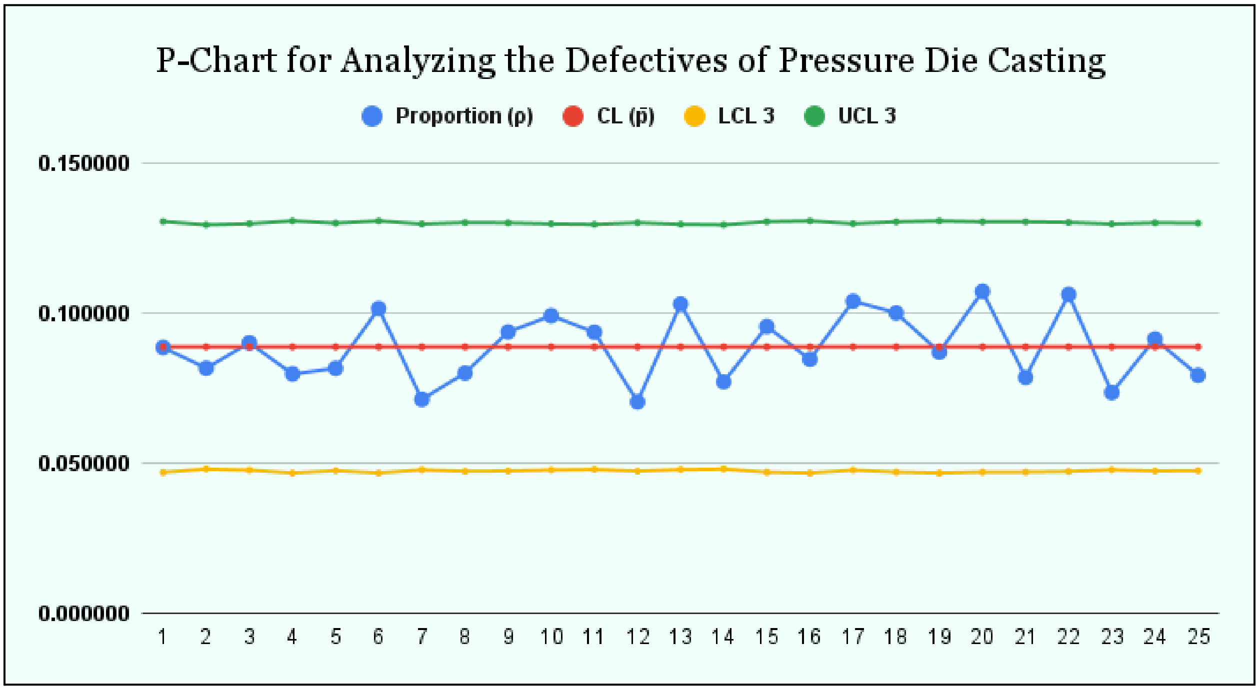
b) <u>Construction of P-chart</u>

Next, we proceed to measure our baseline quality level by making calculations for proportion, control limit, upper control limits and lower control limits (1**σ**, 2**σ** & 3**σ**) by their respective formulas which is depicted from the table given below.

Day	Total inspected units	No. of Defectives	Proportion (ρ)	CL ($\bar{p}$)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	417	37	0.088729	0.088893	0.130702	0.047084	0.116766	0.061020	0.102829	0.074957
2	440	36	0.081818	0.088893	0.129595	0.048191	0.116028	0.061759	0.102460	0.075326
3	432	39	0.090278	0.088893	0.129970	0.047816	0.116278	0.061508	0.102585	0.075201
4	413	33	0.079903	0.088893	0.130904	0.046882	0.116901	0.060886	0.102897	0.074889
5	428	35	0.081776	0.088893	0.130161	0.047625	0.116405	0.061381	0.102649	0.075137
6	413	42	0.101695	0.088893	0.130904	0.046882	0.116901	0.060886	0.102897	0.074889
7	434	31	0.071429	0.088893	0.129875	0.047911	0.116215	0.061572	0.102554	0.075232
8	424	34	0.080189	0.088893	0.130356	0.047430	0.116535	0.061251	0.102714	0.075072
9	426	40	0.093897	0.088893	0.130258	0.047528	0.116470	0.061316	0.102681	0.075105
10	433	43	0.099307	0.088893	0.129923	0.047864	0.116246	0.061540	0.102570	0.075217
11	437	41	0.093822	0.088893	0.129734	0.048052	0.116121	0.061666	0.102507	0.075279
12	425	30	0.070588	0.088893	0.130307	0.047479	0.116502	0.061284	0.102698	0.075088
13	436	45	0.103211	0.088893	0.129781	0.048005	0.116152	0.061634	0.102522	0.075264
14	440	34	0.077273	0.088893	0.129595	0.048191	0.116028	0.061759	0.102460	0.075326
15	418	40	0.095694	0.088893	0.130652	0.047134	0.116733	0.061054	0.102813	0.074973
16	413	35	0.084746	0.088893	0.130904	0.046882	0.116901	0.060886	0.102897	0.074889
17	432	45	0.104167	0.088893	0.129970	0.047816	0.116278	0.061508	0.102585	0.075201
18	419	42	0.100239	0.088893	0.130602	0.047184	0.116699	0.061087	0.102796	0.074990
19	413	36	0.087167	0.088893	0.130904	0.046882	0.116901	0.060886	0.102897	0.074889
20	419	45	0.107399	0.088893	0.130602	0.047184	0.116699	0.061087	0.102796	0.074990
21	419	33	0.078759	0.088893	0.130602	0.047184	0.116699	0.061087	0.102796	0.074990
22	423	45	0.106383	0.088893	0.130405	0.047381	0.116567	0.061219	0.102730	0.075056
23	434	32	0.073733	0.088893	0.129875	0.047911	0.116215	0.061572	0.102554	0.075232

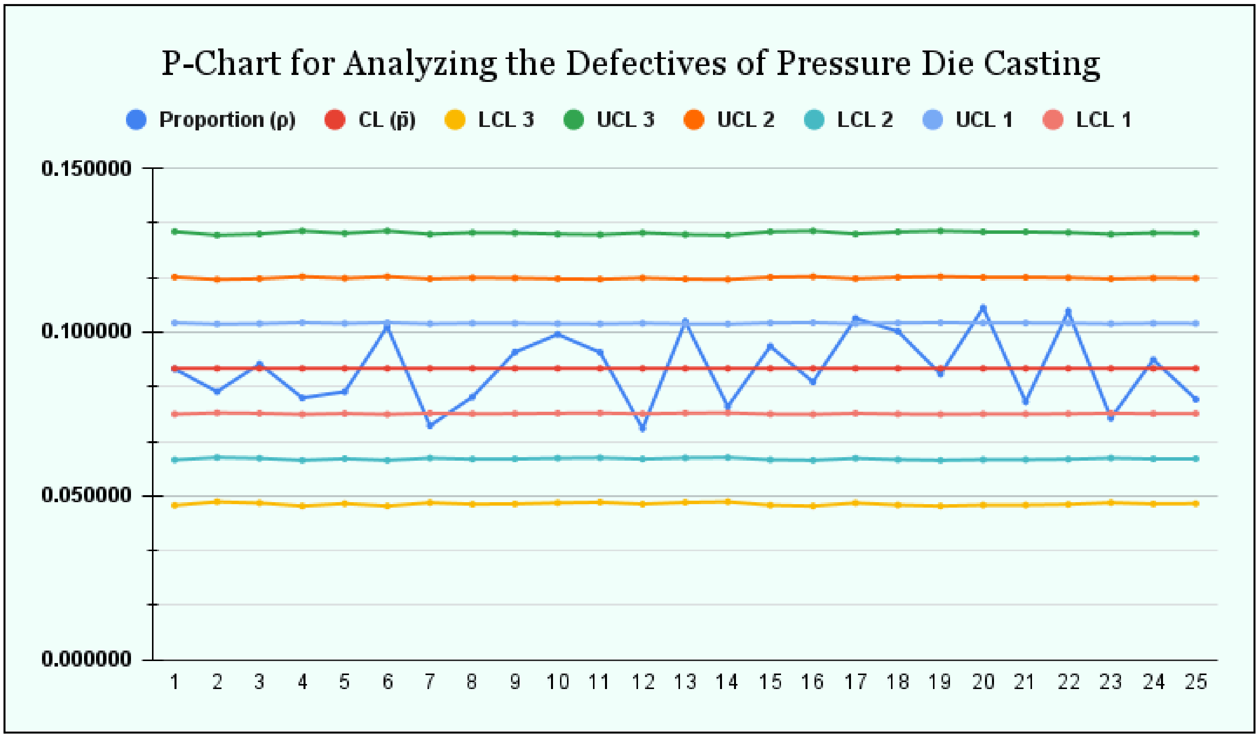
24	426	39	0.091549	0.088893	0.130258	0.047528	0.116470	0.061316	0.102681	0.075105
25	428	34	0.079439	0.088893	0.130161	0.047625	0.116405	0.061381	0.102649	0.075137
Total	**10642**	**946**	**0.09**							

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1**σ**, 2**σ** limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

P-Chart with all Control Limits (1σ, 2σ, 3σ):



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

c) Calculating the Sigma Level

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	946
Opportunities	5
Total Units	10642
Total Opportunities	53210
DPU	0.08889306521
DPO	0.01777861304
DPMO	17778.61304
Yield	98.2221387
Sigma Value	3.601954904

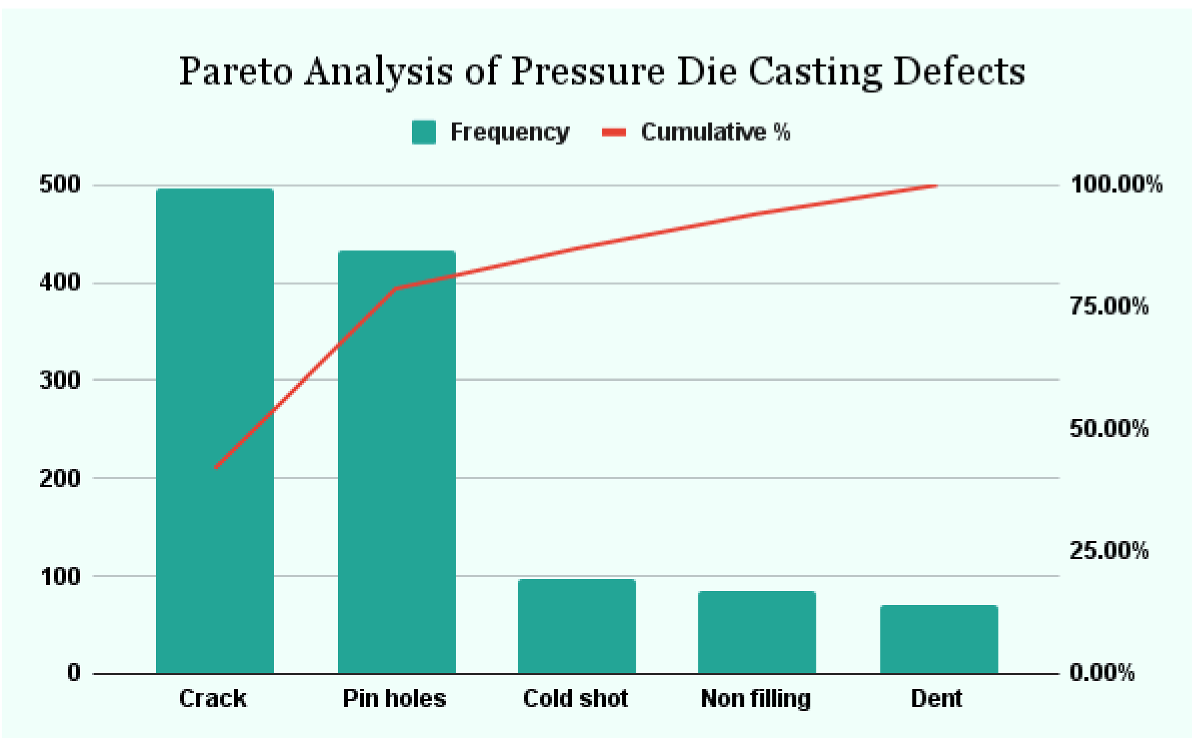
As we can see that the Sigma level for this is 3.6019 which means we can work on some defects to reduce them so that sigma level improves.

Analyse

Now first of all we see on which defects we need to work upon which we can see by the help of pareto chart which prioritize the defects on the basis of its frequency of occurrence.

Defect	Frequency	Frequency %	Cumulative %
Crack	497	42.05%	42.05%
Pin holes	434	36.72%	78.76%
Cold shot	97	8.21%	86.97%
Non filling	84	7.11%	94.08%
Dent	70	5.92%	100.00%
	1182		

a) **Pareto Chart**



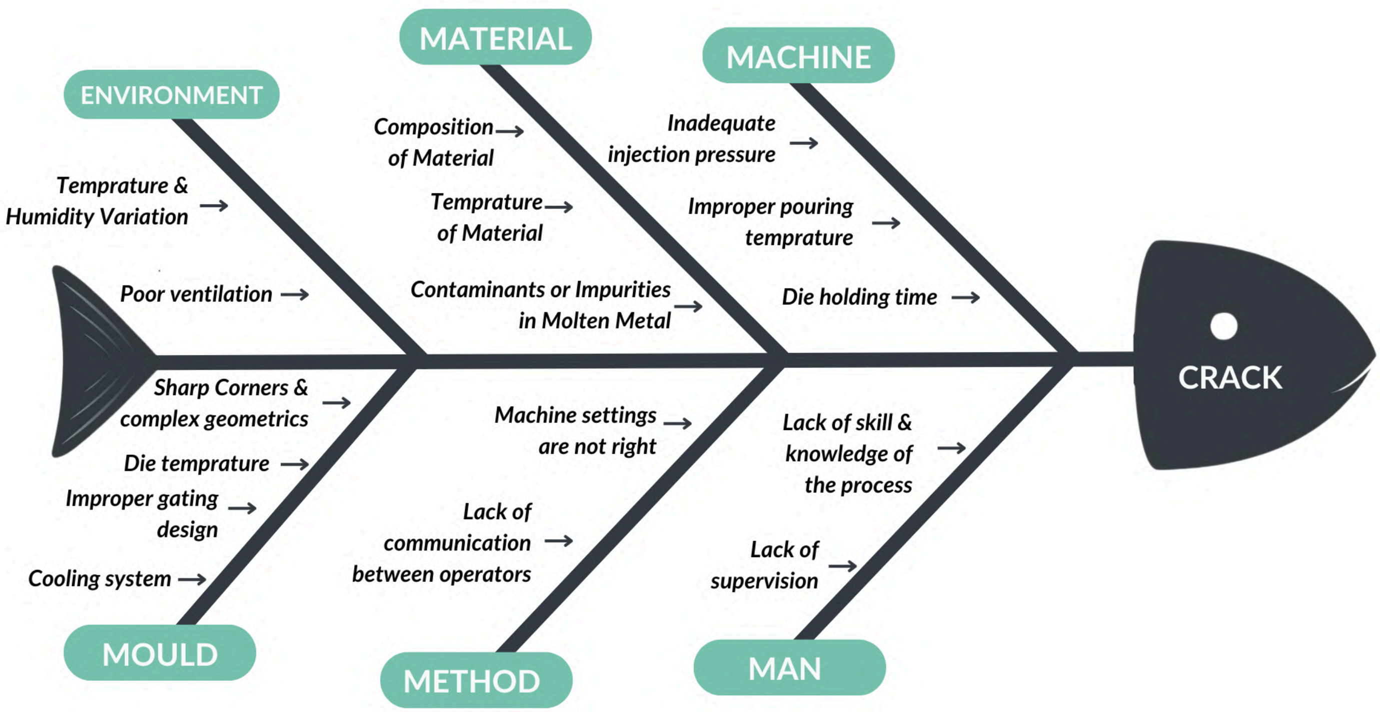
We can see from the pareto chart that elbow is forming at the defect 'Pin Holes'. Therefore, we need to work upon two defects which are **Crack** and **Pin Holes.**
So, now we will work on these two defects to improve the sigma level**.**
Cause & Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in six generic categories was prepared as show. We will be working with

one defect at a time because implementing all the corrective measures simultaneously is not practical.

b) <u>Cause and Effect Diagrams (Fishbone Diagrams)</u>

- **<u>Cause and Effect Diagram for Crack</u>**

Fishbone diagram of Crack categorize the causes into 6 categories as shown below.



As the causes of Crack are independent of each other therefore we can directly suggest some improvement measures to the company in order to improve the sigma level.

Root Causes:

- Improper gating system
- Inadequate injection pressure
- Temprature & humidity variation

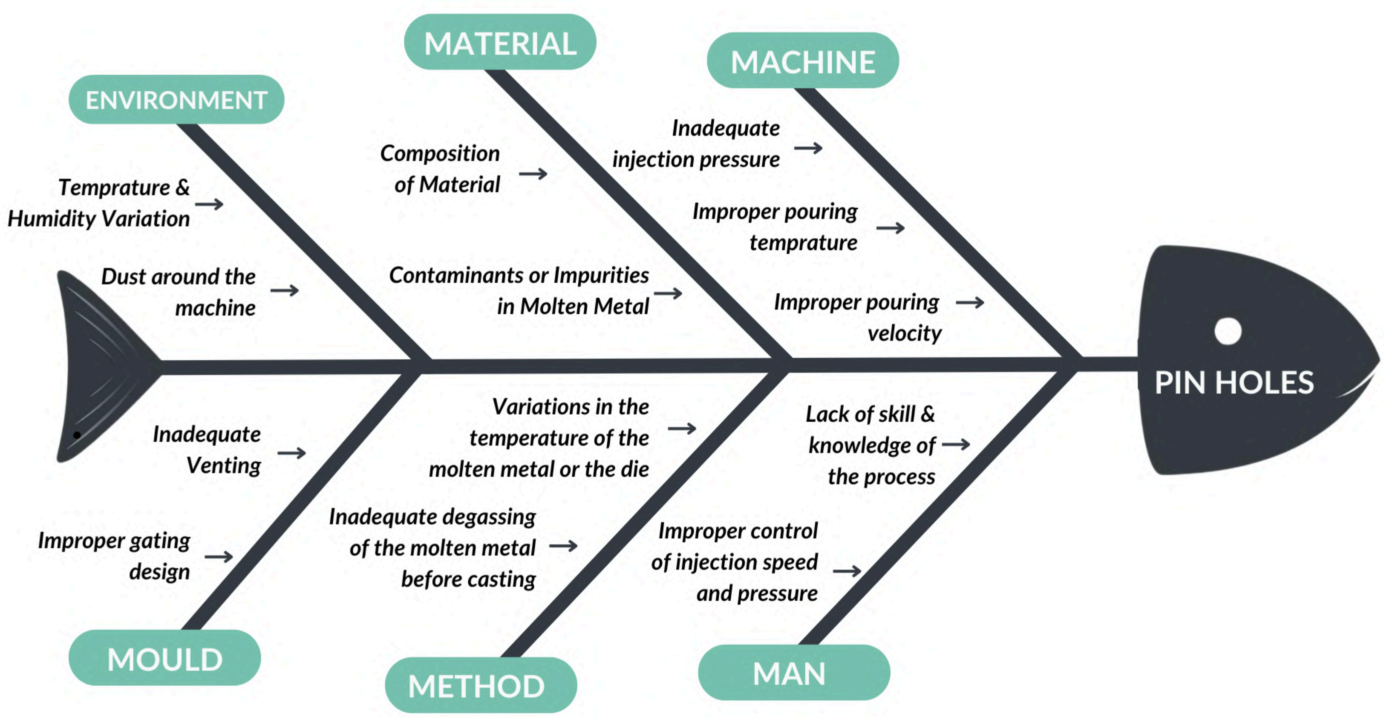
Corrective measures to reduce Crack defect:

- Ensure consistent injection pressure and velocity to prevent excessive mechanical stress on the casting.

- Adjust dwell time to allow for proper filling of the die cavity without inducing excessive thermal stress.
- Redesign dies to include adequate fillets and radii at sharp corners and edges to minimize stress concentration.
- Avoid complex geometries that may lead to uneven metal flow and cooling.
- Monitor and maintain uniform metal temperature throughout the casting process to minimize thermal gradients and associated stress.
- Implement proper cooling systems in the die to ensure controlled solidification and minimize thermal shock.
- Implement effective metal cleaning and degassing procedures to remove impurities and gases from the molten metal.
- Use high-quality aluminum alloys with low levels of impurities to reduce the risk of crack formation.
- Enhance die venting to allow for the escape of trapped gases during the casting process, reducing the likelihood of internal defects.
- Conduct thorough inspections of castings for crack defects using non-destructive testing methods such as visual inspection, dye penetrant testing, or radiographic testing.

- **<u>Cause and Effect Diagram for Pin Holes (“खासर”)</u>**

  Fishbone diagram of Pin Holes (“खासर”) categorize the causes into 6 categories as shown below.



Root Causes:

- Inadequate venting
- Composition of material
- Improper pouring temprature

Corrective measures to reduce Pin Holes (“खासर”) defect:

- Ensure proper melting temperature and duration to achieve complete alloy homogenization and degassing.
- Ensure proper vent design and placement to facilitate gas evacuation without compromising casting integrity.
- Maintain consistent injection pressure and velocity to promote smooth metal flow and minimize gas entrapment.
- Adjust injection parameters based on the size and complexity of the casting to ensure complete cavity filling without inducing excessive turbulence.
- Optimize gating and runner systems to promote even metal distribution and minimize turbulence during injection.
- Implement proper cooling systems in the die to ensure controlled solidification and minimize the formation of shrinkage voids.
- Use efficient melting equipment and techniques to minimize exposure to atmospheric contaminants.

After suggesting the corrective measure company will work on them to improve the sigma level as on all the defects we cannot work simultaneously so first we improve the defects of Crack and then of Pin Holes.

IMPROVEMENT

a) Improvement of Crack:

The above suggestions were provided to the company and they further implemented these changes according to their company terms and conditions. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process.

After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure.

The process output is sampled for 12 days and 12 data points are collected as C. L. Gupta Exports works in 1 shift. The sampling data were recorded using check sheets and the data is collected during this shift.

Check sheet for improving Crack

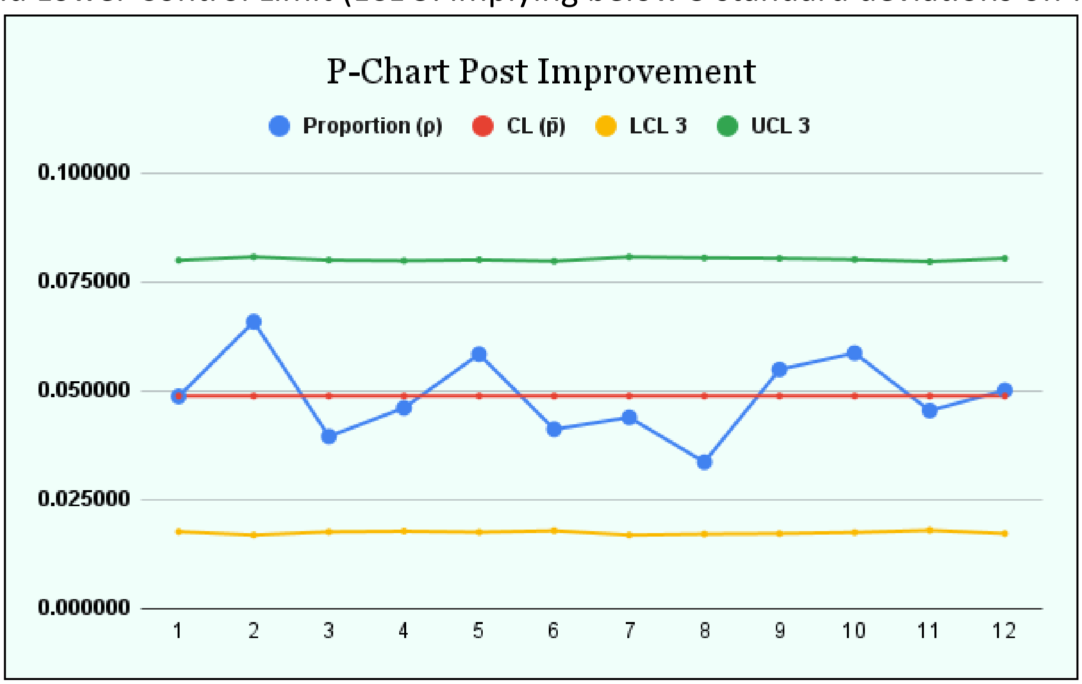
		Defects					
Day	Total inspected units	Non Filling	Pin holes	Cold Shot	Dent	Crack	No. of Defectives
1	431	1	11	3	5	6	21
2	410	5	19	5	3	5	27
3	430	2	9	1	4	6	17
4	434	5	17	6	1	11	20
5	428	6	15	2	2	11	25
6	437	1	17	4	5	5	18
7	410	2	10	3	1	6	18
8	416	3	16	8	2	6	14
9	419	6	9	3	3	8	23
10	426	2	17	8	4	11	25
11	440	4	12	5	3	7	20
12	419	0	14	7	1	6	21
Total	**5100**	**37**	**166**	**55**	**34**	**88**	**249**

From the above check sheet we can see that the no. of occurrence of defect Crack is reduced. There will also be decrease in some other defects as correcting one will also have impact on others. Now we will draw the P-chart to check whether the process is still in control or not.

Construction of P-chart

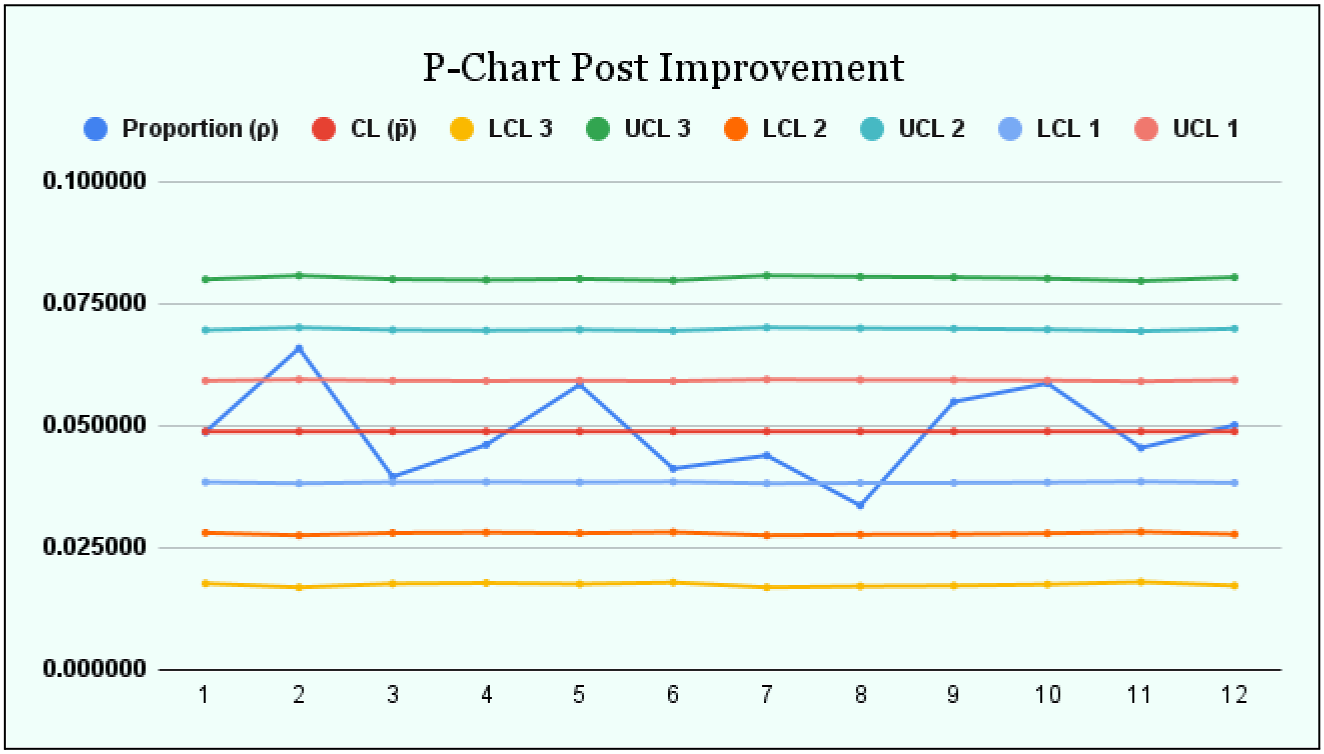
Day	Total inspected units	No. of Defectives	Proportion (ρ)	CL (p̄)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	431	21	0.048724	0.048824	0.079964	0.017683	0.069584	0.028063	0.059204	0.038443
2	410	27	0.065854	0.048824	0.080752	0.016895	0.070109	0.027538	0.059466	0.038181
3	430	17	0.039535	0.048824	0.080000	0.017647	0.069608	0.028039	0.059216	0.038431
4	434	20	0.046083	0.048824	0.079856	0.017791	0.069512	0.028135	0.059168	0.038479
5	428	25	0.058411	0.048824	0.080073	0.017574	0.069657	0.027990	0.059240	0.038407
6	437	18	0.041190	0.048824	0.079750	0.017897	0.069441	0.028206	0.059132	0.038515
7	410	18	0.043902	0.048824	0.080752	0.016895	0.070109	0.027538	0.059466	0.038181
8	416	14	0.033654	0.048824	0.080521	0.017126	0.069955	0.027692	0.059389	0.038258
9	419	23	0.054893	0.048824	0.080407	0.017240	0.069879	0.027768	0.059351	0.038296
10	426	25	0.058685	0.048824	0.080146	0.017501	0.069705	0.027942	0.059264	0.038383
11	440	20	0.045455	0.048824	0.079644	0.018003	0.069371	0.028277	0.059097	0.038550
12	419	21	0.050119	0.048824	0.080407	0.017240	0.069879	0.027768	0.059351	0.038296
Total	**5100**	**249**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1σ, 2σ limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

P-Chart with all Control Limits (1σ, 2σ, 3σ):



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

Calculating the Sigma Level

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	249
Opportunities	5
Total Units	5100
Total Opportunities	25500
DPU	0.04882352941
DPO	0.009764705882
DPMO	9764.705882
Yield	99.02352941
Sigma Value	3.835268249

As we can see that the Sigma level for this is 3.8352 which means working on Crack defect sigma level has improved from 3.6019 to 3.8352.

Now we work on other defect which is Pin Holes to see whether we can further be able to improve the sigma level or not.

b) Improvement of Pin Holes:

The above suggestions were provided to the company and they further implemented these changes according to their company terms and conditions. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process.

After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure.

The process output is sampled for 12 days and 12 data points are collected as C. L. Gupta Exports works in 1 shift. The sampling data were recorded using check sheets and the data is collected during this shift.

Check sheet for improving Pin Holes

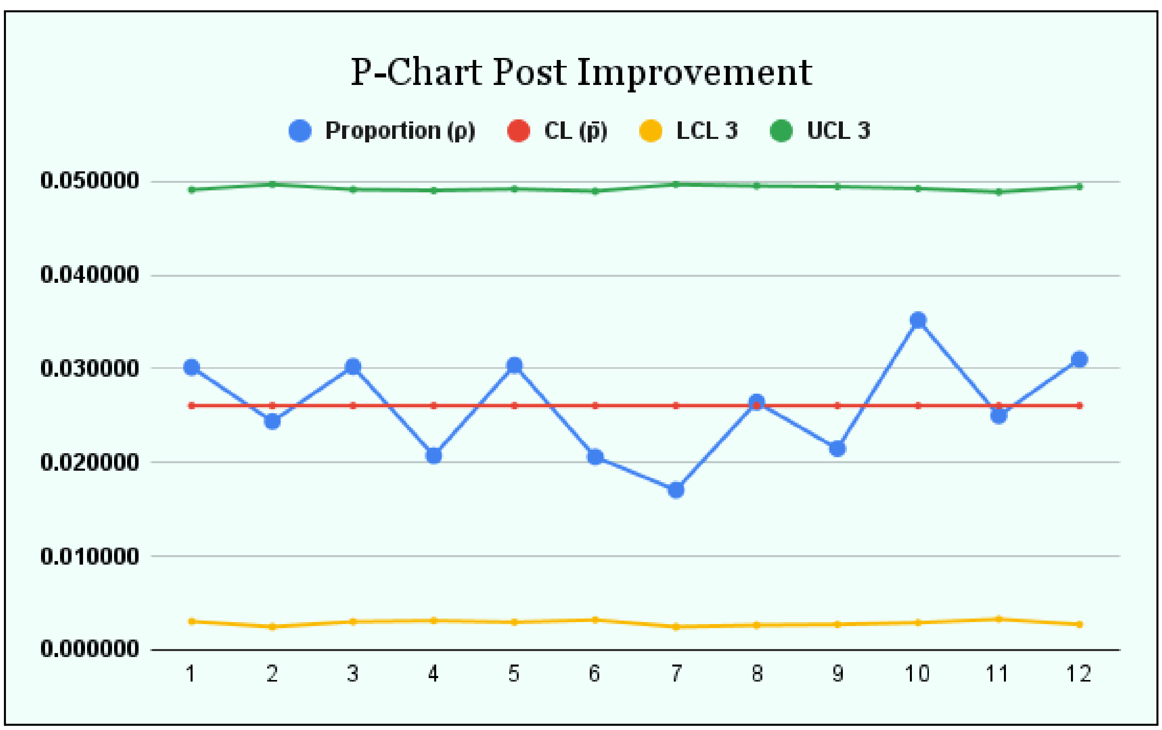
		Defects					
Day	Total inspected units	Non Filling	Pin holes	Cold Shot	Dent	Crack	No. of Defectives
1	431	2	4	2	3	3	13
2	410	2	8	2	2	5	10
3	430	2	4	0	4	5	13
4	434	1	5	5	4	3	9
5	428	2	9	4	4	6	13
6	437	1	6	1	1	4	9
7	410	2	8	3	1	5	7
8	416	1	5	1	0	2	11
9	419	0	7	2	3	6	9
10	426	1	9	4	1	8	15
11	440	2	5	2	3	7	11
12	419	3	6	1	4	8	13
Total	**5100**	**19**	**76**	**27**	**30**	**62**	**133**

From the above check sheet we can see that the no. of occurrence of defect Pin Holes is reduced. There will also be decrease in some other defects as correcting one will also have impact on others. Now we will draw the P-chart to check whether the process is still in control or not.

Construction of P-chart

Day	Total inspected units	No. of Defectives	Proportion (ρ)	CL (p̄)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	431	13	0.030162	0.026078	0.049108	0.003049	0.041431	0.010725	0.033755	0.018402
2	410	10	0.024390	0.026078	0.049690	0.002466	0.041820	0.010337	0.033949	0.018208
3	430	13	0.030233	0.026078	0.049135	0.003022	0.041449	0.010708	0.033764	0.018393
4	434	9	0.020737	0.026078	0.049028	0.003129	0.041378	0.010779	0.033728	0.018428
5	428	13	0.030374	0.026078	0.049189	0.002968	0.041485	0.010672	0.033782	0.018375
6	437	9	0.020595	0.026078	0.048949	0.003208	0.041326	0.010831	0.033702	0.018455
7	410	7	0.017073	0.026078	0.049690	0.002466	0.041820	0.010337	0.033949	0.018208
8	416	11	0.026442	0.026078	0.049519	0.002637	0.041706	0.010451	0.033892	0.018265
9	419	9	0.021480	0.026078	0.049435	0.002721	0.041650	0.010507	0.033864	0.018293
10	426	15	0.035211	0.026078	0.049243	0.002914	0.041521	0.010636	0.033800	0.018357
11	440	11	0.025000	0.026078	0.048871	0.003286	0.041274	0.010883	0.033676	0.018481
12	419	13	0.031026	0.026078	0.049435	0.002721	0.041650	0.010507	0.033864	0.018293
Total	**5100**	**133**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



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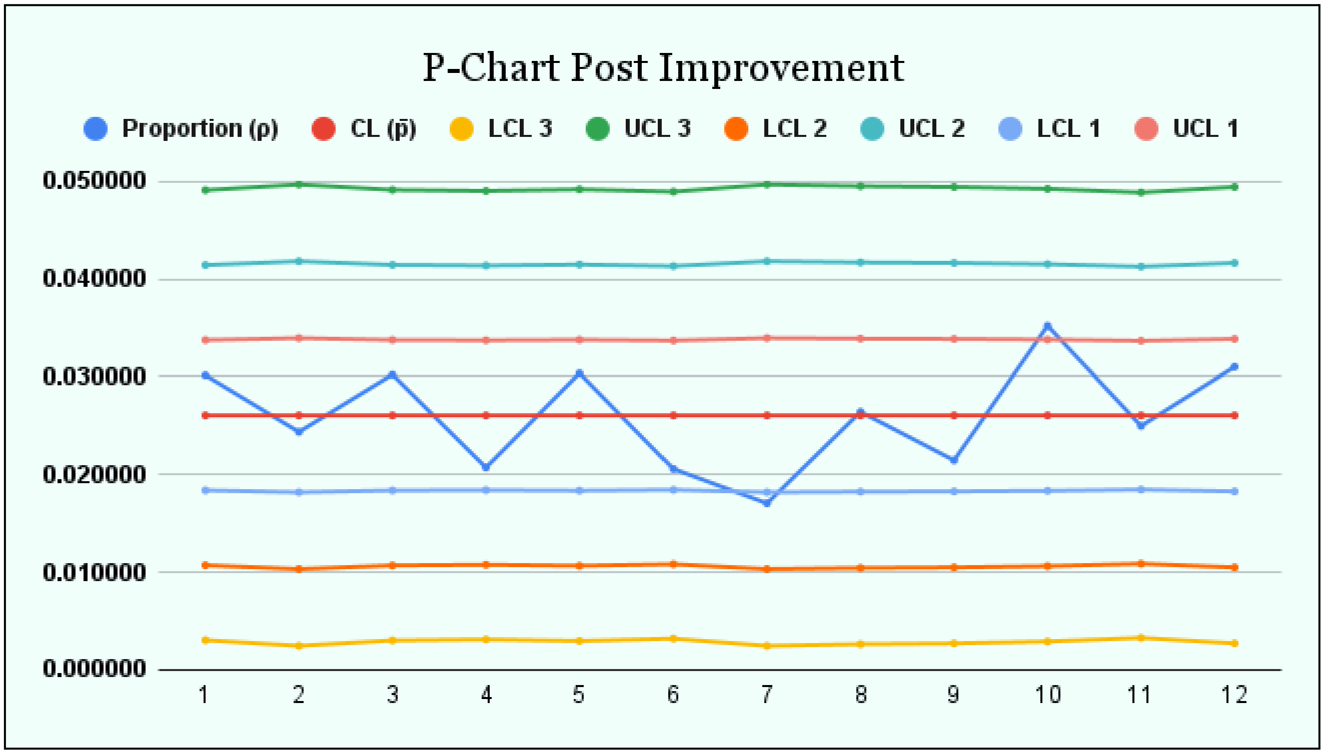

From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

<u>Calculating the Sigma Level</u>

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

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- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

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Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
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19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
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43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
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65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	133
Opportunities	5
Total Units	5100
Total Opportunities	25500
DPU	0.02607843137
DPO	0.00521568627 5
DPMO	5215.686275
Yield	99.47843137
Sigma Value	4.061191882

An implementation of the suggestions was done to the process and studied for a period of 12 days. The sigma level showed an improvement from **3.8352 to 4.0611** and the defects arising due to **Crack** and **Pin Holes** were decreased; this may be a more optimistic picture in the reality. Thus, in control the process with improvements is maintained and standardized.

STAGE 2

DEFINE

Stage 2 comprises of surface preparation, grinding, Intermediate Polishing, Final Polishing, Cleaning.

The polishing process is a critical step in the manufacturing of aluminum candle stands, enhancing both the aesthetic appeal and surface quality of the product. This process involves several stages to ensure a smooth, shiny, and defect-free finish on the aluminum surface. The aluminum candle stands are thoroughly inspected for any surface defects or irregularities that need to be addressed before polishing.

Surface Preparation:
Any visible defects, such as burrs, scratches, or rough spots, are removed using abrasive tools or sandpaper. This step ensures that the surface is smooth and ready for polishing.

Grinding:
The candle stands are subjected to a grinding process using coarse abrasive wheels or belts to remove any remaining imperfections and achieve a uniform surface.

Intermediate Polishing:
After grinding, the stands undergo intermediate polishing using finer abrasives. This stage gradually refines the surface, reducing the appearance of any grinding marks and enhancing the smoothness.

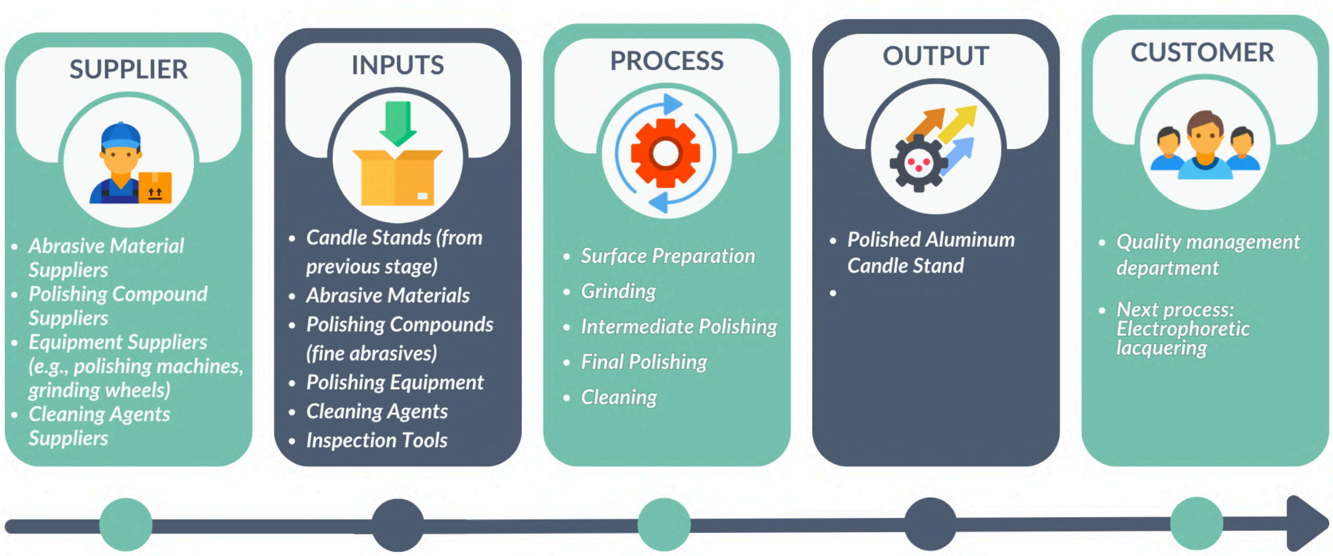
Final Polishing:
In the final stage, the aluminum candle stands are polished using fine abrasive compounds and soft polishing wheels. This step brings out the desired shine and smoothness, giving the stands a reflective, high-quality finish.

Cleaning:
Once polishing is complete, the stands are cleaned to remove any residual abrasive materials or polishing compounds. This can involve ultrasonic cleaning or manual wiping with cleaning agents.

This stage is further explained by the help of SIPOC diagram:

SIPOC Diagram

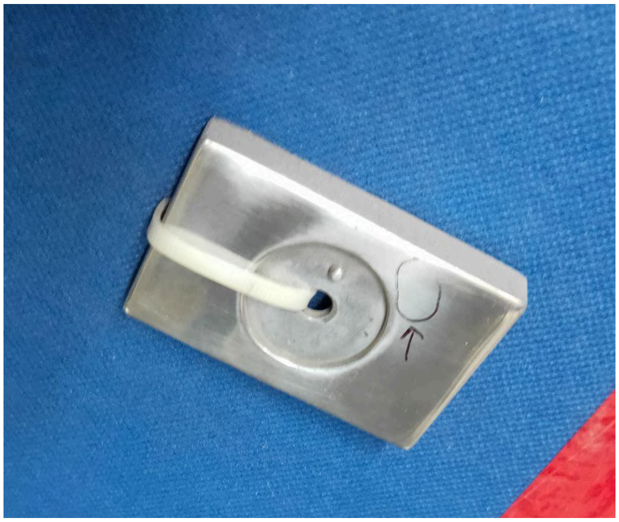
The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem



Defects in the various process of Stage 2 which are identified by the company are:

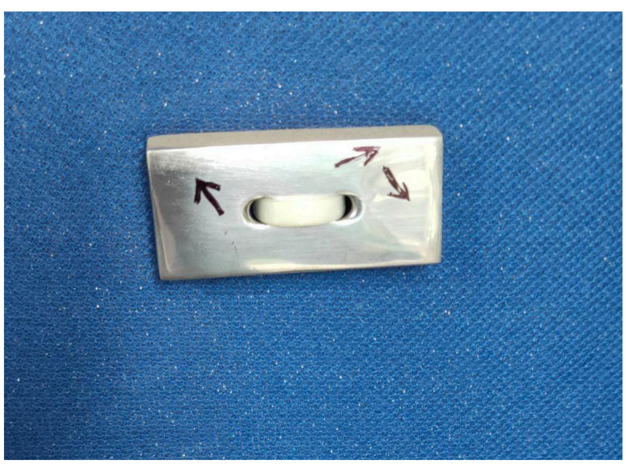
1. **Tool Marks**
   Tool marks defect in the polishing process occurs when abrasive tools, grinding wheels, or polishing equipment leave visible scratches, lines, or grooves on the surface of the aluminum candle stand. These defects can significantly affect the aesthetic quality and smoothness of the final product. Tool marks are often caused by improper handling of polishing tools, excessive pressure, or the use of worn-out or inappropriate abrasive materials. To prevent tool marks, it is essential to use the

correct polishing techniques, maintain equipment properly, and regularly replace or clean abrasive tools. Detecting and addressing tool marks during the intermediate and final inspection stages ensures a high-quality, polished finish.



Tool Marks Defect

2. **Scratches**
   Scratches defect in the polishing process occurs when unwanted lines or marks are left on the surface of the aluminum candle stand. These defects can result from improper handling of the workpiece, using inappropriate or worn-out abrasive materials, or applying excessive pressure during polishing. Scratches can detract from the visual appeal and smoothness of the final product. To prevent scratches, it is crucial to use the correct abrasive materials, maintain clean and well-functioning polishing equipment, and apply consistent and moderate pressure. Detecting and addressing scratches during the intermediate and final inspection stages ensures a flawless, high-quality polished finish.

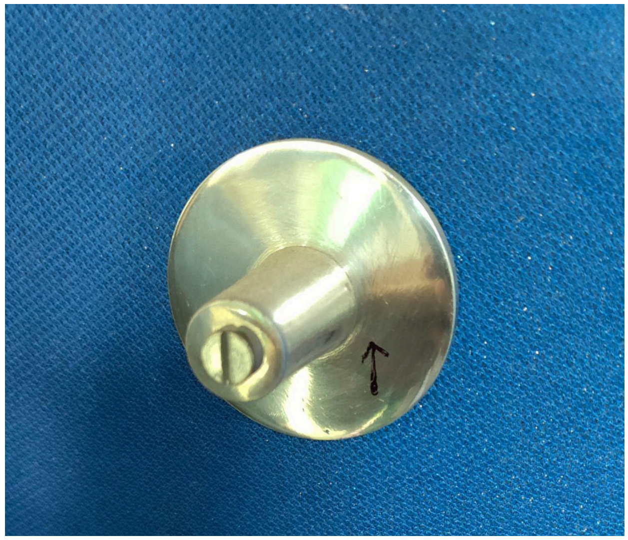


Scratches Defect

3. **Buff Marks**
   Buff marks defect in the polishing process occurs when the surface of the aluminum candle stand displays uneven or hazy areas after buffing. These defects are typically caused by improper buffing techniques, such as using contaminated or overloaded buffing wheels, applying uneven pressure, or insufficient cleaning between polishing stages. Buff marks can detract from the uniformity and shine of the final product. To prevent buff marks, it is essential to use clean and properly maintained buffing wheels, apply consistent and moderate pressure, and ensure thorough cleaning between polishing stages. Identifying and addressing buff marks during the final inspection helps achieve a smooth, reflective, and high-quality polished finish.

Buff Marks Defect

4. **Lancer Marks**
   Lancer marks defect in the polishing process occurs when linear or patterned marks are left on the surface of the aluminum candle stand by polishing tools or abrasive materials. These marks are often caused by incorrect use of polishing lancers, improper alignment of tools, or the use of worn or inappropriate abrasive materials. Lancer marks can negatively impact the surface finish and overall appearance of the product. To prevent lancer marks, it is important to use the correct polishing techniques, ensure proper alignment and maintenance of tools, and regularly replace or clean abrasive materials. Detecting and addressing lancer marks during the intermediate and final inspection stages ensures a high-quality, smooth, and visually appealing finish.

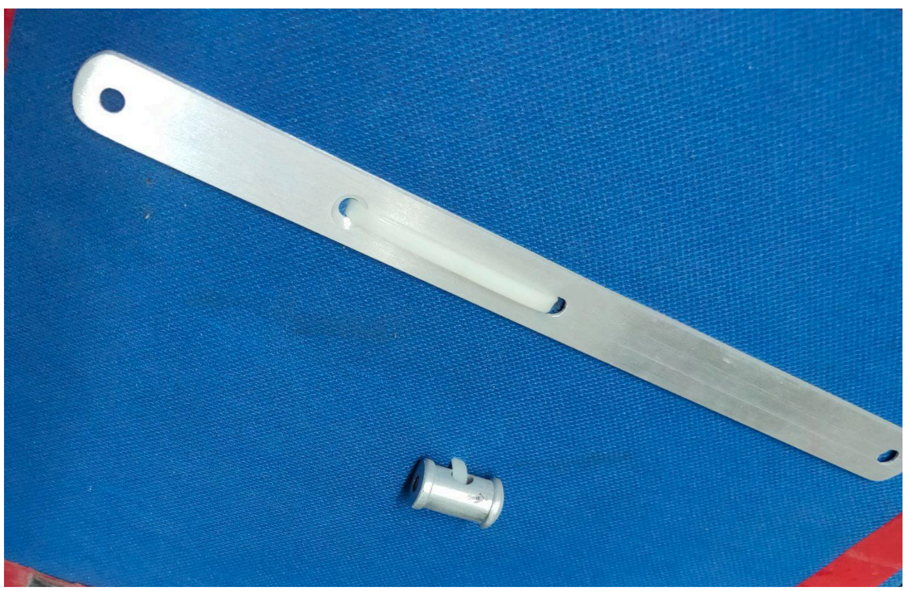


Lancer Mark Defect

5. **Blackness**
   Blackness defect in the polishing process occurs when dark spots or discoloration appear on the surface of the aluminum candle stand. This defect can be caused by several factors, including the use of contaminated polishing compounds, excessive heat generation during polishing, improper cleaning of the workpiece, or residual oils and greases from previous manufacturing stages. Blackness can significantly detract from the aesthetic quality and uniformity of the finished product. To prevent blackness, it is crucial to use clean and appropriate polishing compounds, control heat generation during the process, and thoroughly clean the workpiece before and after polishing. Identifying and addressing blackness during the final inspection ensures a bright, clean, and high-quality polished finish.

Blackness Defect

6. **Improper Polishing**
   Improper polishing defect in the polishing process occurs when the surface of the aluminum candle stand does not achieve the desired smoothness, shine, or uniformity. This defect can result from using incorrect abrasive materials, inadequate or excessive polishing pressure, insufficient polishing time, or improper technique. Improper polishing can lead to a variety of surface imperfections, including uneven texture, residual scratches, and inadequate shine. To prevent improper polishing, it is essential to use the right polishing compounds and tools, apply consistent and appropriate pressure, and follow standardized polishing procedures. Thorough training of personnel and regular equipment maintenance also contribute to achieving a high-quality polished finish. Identifying and correcting improper polishing during intermediate and final inspections ensures the product meets quality standards and customer expectations.



Improper Polishing Defect

7. **Improper Texture**
   Improper texture defect in the polishing process occurs when the surface of the aluminum candle stand exhibits an inconsistent or undesired texture. This can be caused by using the wrong grade of abrasive materials, uneven application of pressure, or insufficient polishing time. Additionally, worn-out polishing tools or incorrect polishing techniques can contribute to this defect. Improper texture affects the aesthetic quality and feel of the final product, making it less visually appealing and potentially uncomfortable to handle. To prevent improper texture, it is crucial to use

the correct abrasive materials and tools, maintain consistent and appropriate pressure, and follow standardized polishing procedures. Regular inspections during the polishing process help identify and rectify texture issues, ensuring a smooth, uniform, and high-quality finish.

Improper Texture Defect

Project Charter

A project charter is a foundational document that outlines the scope, objectives, and parameters of a project. It defines the problem to be addressed and aligns the project with organizational goals. The charter establishes the project team, their roles, responsibilities, and authority levels. It sets a clear timeline for project completion, with milestones and deadlines. Additionally, it outlines the desired outputs and deliverables, ensuring alignment with business demands and customer requirements. The charter fosters effective collaboration and communication among team members. It serves as a roadmap for project initiation, execution, and evaluation. Overall, the project charter ensures clarity, accountability, and alignment throughout the project lifecycle.

PROJECT DESCRIPTION
Defect reduction in stage 2 which involves surface preparation, grinding, Intermediate Polishing, Final Polishing, Cleaning.
PROJECT OBJECTIVE AND GOAL
To reduce defects like Tool Marks & Scractes in the mentioned processes of stage 1
PROJECT LOCATION
C. L. Gupta Export Ltd. 18 Km. Stone, Delhi Road, Vill. Jivai, near Moradabad, Uttar Pradesh 244221
BACKGROUND AND RATIONALE FOR PROJECT SELECTION
In the baseline process, Prioritize the defects in which Tool Marks, Scratches has found to be highest priority as compared to the other defects based on the pareto chart (frequency) of the defects.
PROJECT TEAM
Quality Head Mangers from Manufacturing, Purchasing and Maintenance Quality control inspector, Research advisor and associates, and Floor operator
EXPECTED BENEFITS
Reduction in the defects due to tool marks which would lead to cost benefits.
PROJECT PLAN
Application of DMAIC model of Six-Sigma
PROJECT TIMELINE
2 Months

Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the five defects identified in the defined stage is established, followed by defect prioritization with the help of pareto chart. Process specifications are followed to inspect the items with defects. The process output is sampled for 25 days and 25 data points are collected as C. L. Gupta Exports Ltd. works in 1 single shift. In total, 10642 units are observed in 25 days. To check whether process is in control or not, p-chartis plotted as number of units inspected in each day are different and we are considering the entire candle stand as a defective.

a) Check sheet for Pre-Analysis:

		Defects							
Day	Total inspected units	Tool marks	Scratches	Buff marks	Lancer marks	Blackness	Improper polishing	Improper Texture	Defectives
1	440	23	17	4	7	5	18	1	61
2	434	18	27	3	6	5	12	2	55
3	414	28	13	9	2	2	19	1	59
4	440	13	22	2	7	1	21	0	51
5	425	32	18	5	3	3	7	3	56
6	435	17	28	1	9	1	8	2	43
7	433	23	15	2	8	2	16	4	56
8	424	9	27	5	4	1	29	2	50
9	433	29	11	3	5	4	17	2	47
10	415	14	28	1	6	1	12	1	51
11	437	27	19	4	9	3	14	1	64
12	425	8	14	3	4	1	17	1	53
13	433	31	9	1	5	4	10	5	58
14	422	16	17	8	4	3	12	0	54
15	422	27	22	9	2	8	14	0	50
16	410	16	29	7	6	4	11	2	63
17	437	21	14	1	3	5	15	1	61
18	422	14	10	3	9	2	18	1	63
19	430	34	16	2	10	7	28	4	59
20	438	11	21	5	8	5	29	3	63
21	434	25	32	2	3	6	31	5	69
22	419	16	18	4	10	5	18	2	45

23	425	30	20	6	7	4	10	1	51
24	413	11	16	5	9	3	22	3	59
25	432	25	20	1	5	2	15	1	65
Total	**10692**	**518**	**483**	**96**	**151**	**87**	**423**	**48**	**1406**

From the above table we can see that we have total inspected 10692 units and total no. of defectives are 1406. Now we will plot the p-chart.

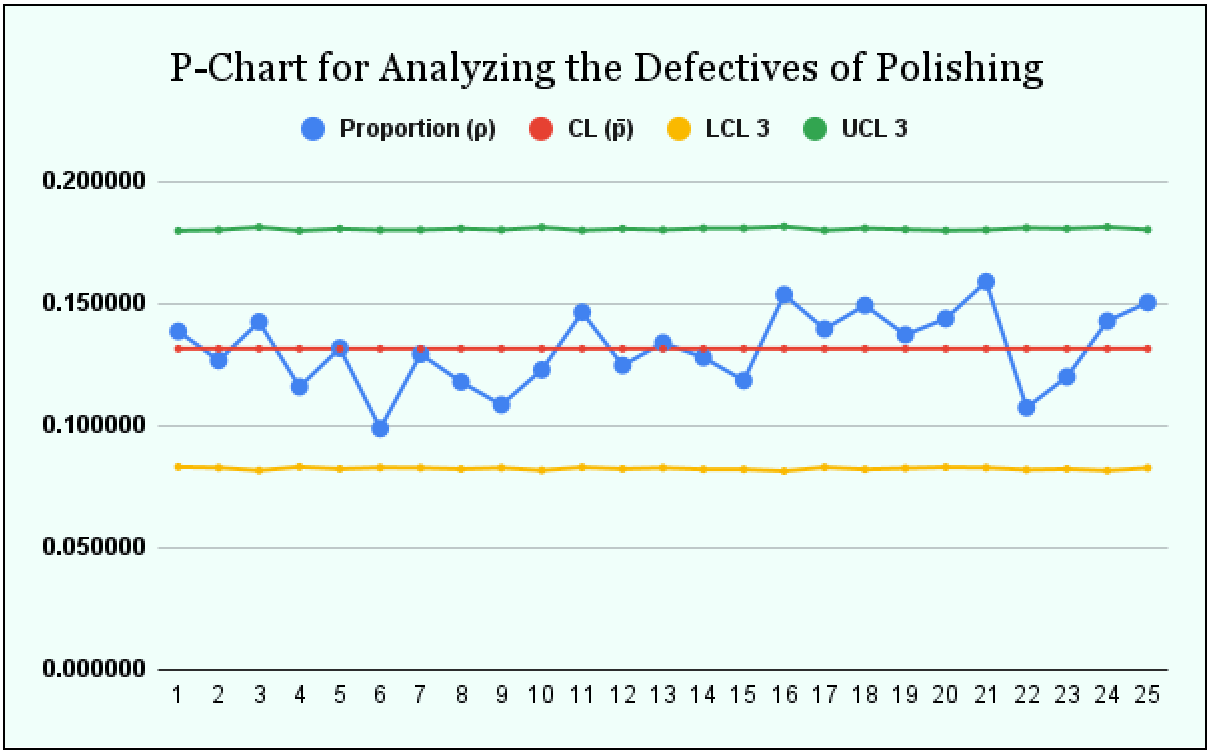
b) <u>Construction of P-chart</u>

Next, we proceed to measure our baseline quality level by making calculations for proportion, control limit, upper control limits and lower control limits (1σ, 2σ & 3σ) by their respective formulas which is depicted from the table given below.

Day	Total inspected units	Defectives	Proportion (ρ)	CL ($\bar{p}$)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	440	61	0.138636	0.131500	0.179833	0.083167	0.163722	0.099278	0.147611	0.115389
2	434	55	0.126728	0.131500	0.180166	0.082834	0.163944	0.099056	0.147722	0.115278
3	414	59	0.142512	0.131500	0.181328	0.081673	0.164719	0.098282	0.148109	0.114891
4	440	51	0.115909	0.131500	0.179833	0.083167	0.163722	0.099278	0.147611	0.115389
5	425	56	0.131765	0.131500	0.180679	0.082322	0.164286	0.098715	0.147893	0.115107
6	435	43	0.098851	0.131500	0.180110	0.082890	0.163907	0.099094	0.147703	0.115297
7	433	56	0.129330	0.131500	0.180222	0.082778	0.163982	0.099019	0.147741	0.115260
8	424	50	0.117925	0.131500	0.180737	0.082264	0.164324	0.098676	0.147912	0.115088
9	433	47	0.108545	0.131500	0.180222	0.082778	0.163982	0.099019	0.147741	0.115260
10	415	51	0.122892	0.131500	0.181268	0.081733	0.164678	0.098322	0.148089	0.114911
11	437	64	0.146453	0.131500	0.179999	0.083002	0.163833	0.099168	0.147666	0.115334
12	425	53	0.124706	0.131500	0.180679	0.082322	0.164286	0.098715	0.147893	0.115107
13	433	58	0.133949	0.131500	0.180222	0.082778	0.163982	0.099019	0.147741	0.115260
14	422	54	0.127962	0.131500	0.180853	0.082147	0.164402	0.098598	0.147951	0.115049
15	422	50	0.118483	0.131500	0.180853	0.082147	0.164402	0.098598	0.147951	0.115049
16	410	63	0.153659	0.131500	0.181570	0.081430	0.164880	0.098120	0.148190	0.114810
17	437	61	0.139588	0.131500	0.179999	0.083002	0.163833	0.099168	0.147666	0.115334
18	422	63	0.149289	0.131500	0.180853	0.082147	0.164402	0.098598	0.147951	0.115049
19	430	59	0.137209	0.131500	0.180392	0.082608	0.164095	0.098906	0.147797	0.115203
20	438	63	0.143836	0.131500	0.179943	0.083057	0.163796	0.099205	0.147648	0.115352
21	434	69	0.158986	0.131500	0.180166	0.082834	0.163944	0.099056	0.147722	0.115278
22	419	45	0.107399	0.131500	0.181029	0.081971	0.164520	0.098481	0.148010	0.114990

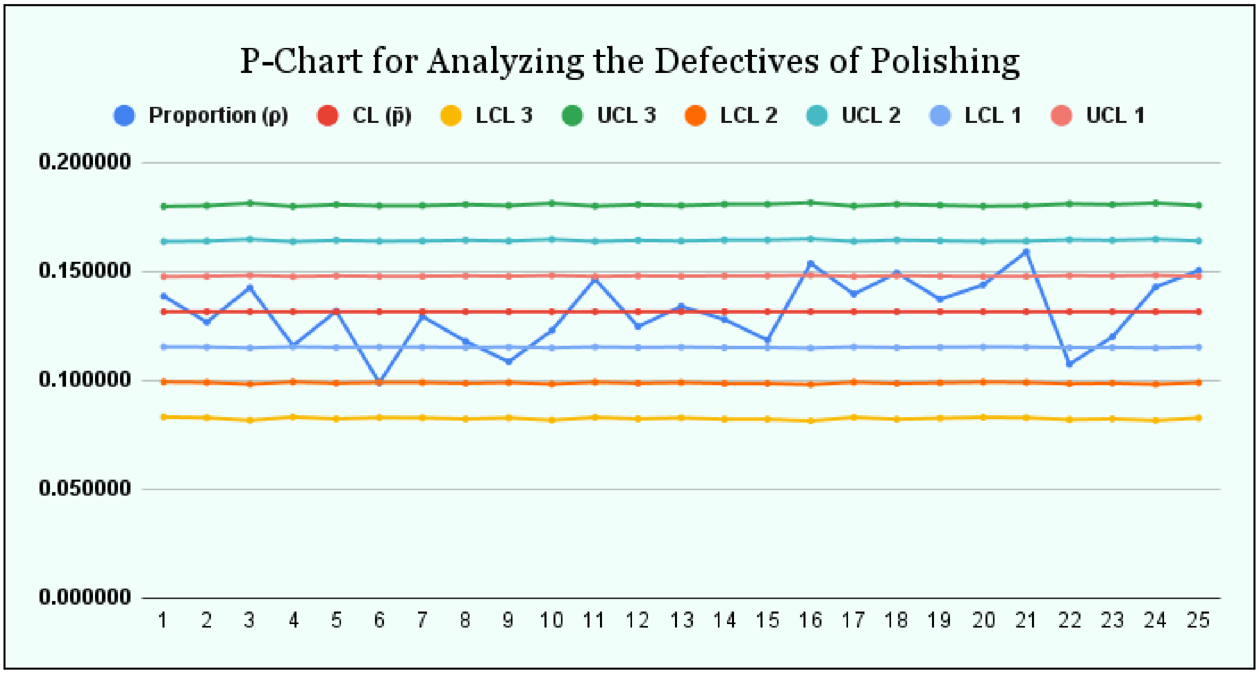
23	425	51	0.120000	0.131500	0.180679	0.082322	0.164286	0.098715	0.147893	0.115107
24	413	59	0.142857	0.131500	0.181388	0.081612	0.164759	0.098242	0.148129	0.114871
25	432	65	0.150463	0.131500	0.180279	0.082722	0.164019	0.098981	0.147760	0.115241
Total	**10692**	**1406**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1σ, 2σ limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

P-Chart with all Control Limits (1σ, 2σ, 3σ):



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

c) Calculating the Sigma Level

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	1406
Opportunities	7
Total Units	10692
Total Opportunities	74844
DPU	0.1315001871
DPO	0.01878574101
DPMO	18785.74101
Yield	98.1214259
Sigma Value	3.579499299

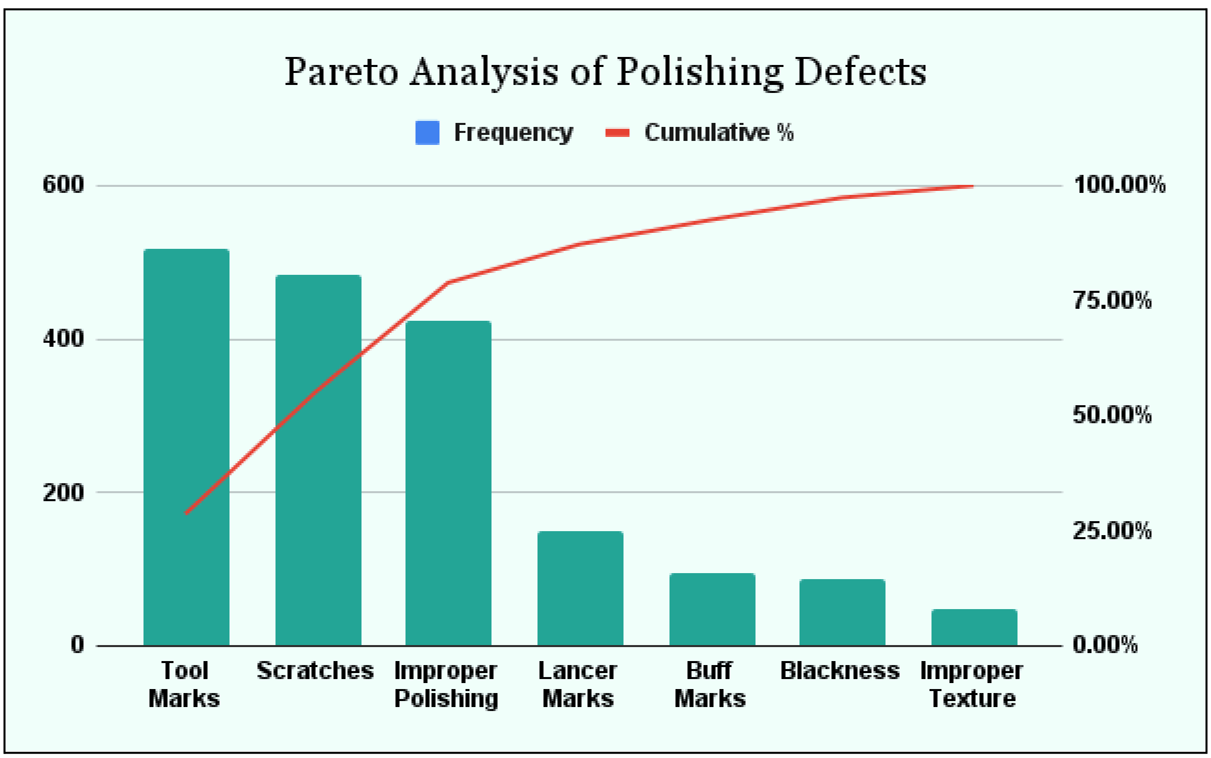
As we can see that the Sigma level for this is 3.5794 which means we can work on some defects to reduce them so that sigma level improves.

Analyse

Now first of all we see on which defects we need to work upon which we can see by the help of pareto chart which prioritize the defects on the basis of its frequency of occurrence.

Defect Type	Frequency	Frequency %	Cumulative %
Tool Marks	518	28.68%	28.68%
Scratches	483	26.74%	55.43%
Improper Polishing	423	23.42%	78.85%
Lancer Marks	151	8.36%	87.21%
Buff Marks	96	5.32%	92.52%
Blackness	87	4.82%	97.34%
Improper Texture	48	2.66%	100.00%
Total	**1806**		

a) Pareto Chart



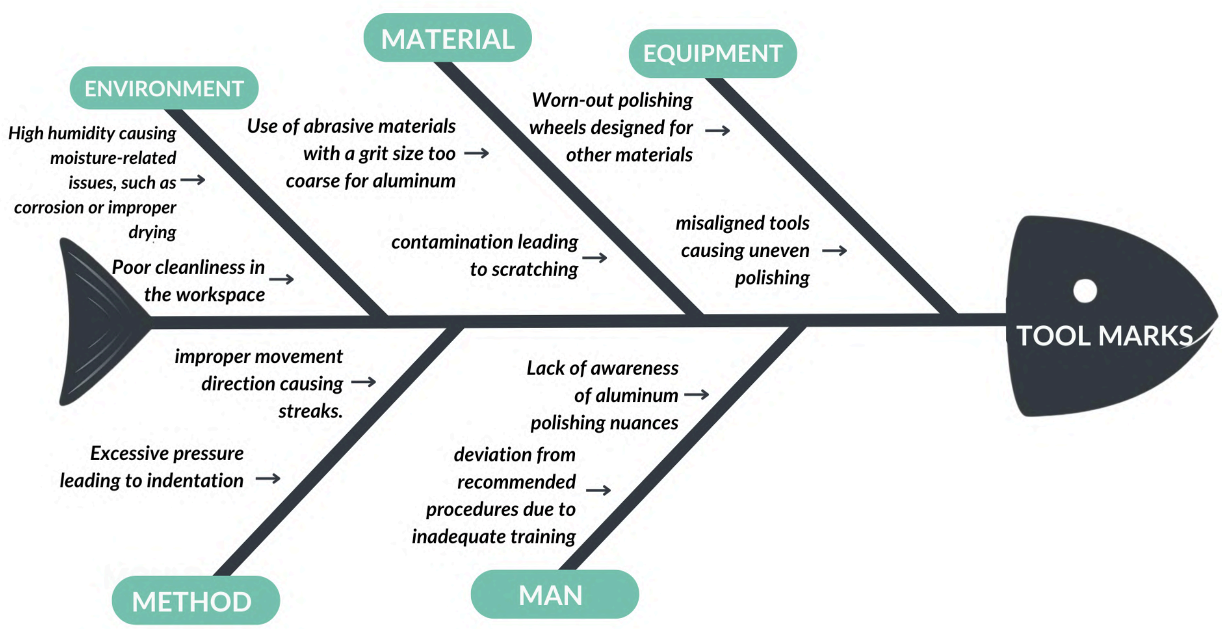
We can see from the pareto chart that elbow is forming at the defect 'Improper Polishing'. Therefore, we need to work upon three defects which are **Tool Marks**, **Scratches** & **Improper Polishing .**
So, now we will work on these three defects to improve the sigma level**.**

Cause & Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in six generic categories was prepared as show. We will be working with one defect at a time because implementing all the corrective measures simultaneously is not practical.

b) Cause and Effect Diagrams (Fishbone Diagrams)

- **Cause and Effect Diagram for Tool Marks**

Fishbone diagram of Tool Marks categorize the causes into 5 categories as shown below.



Root Causes:

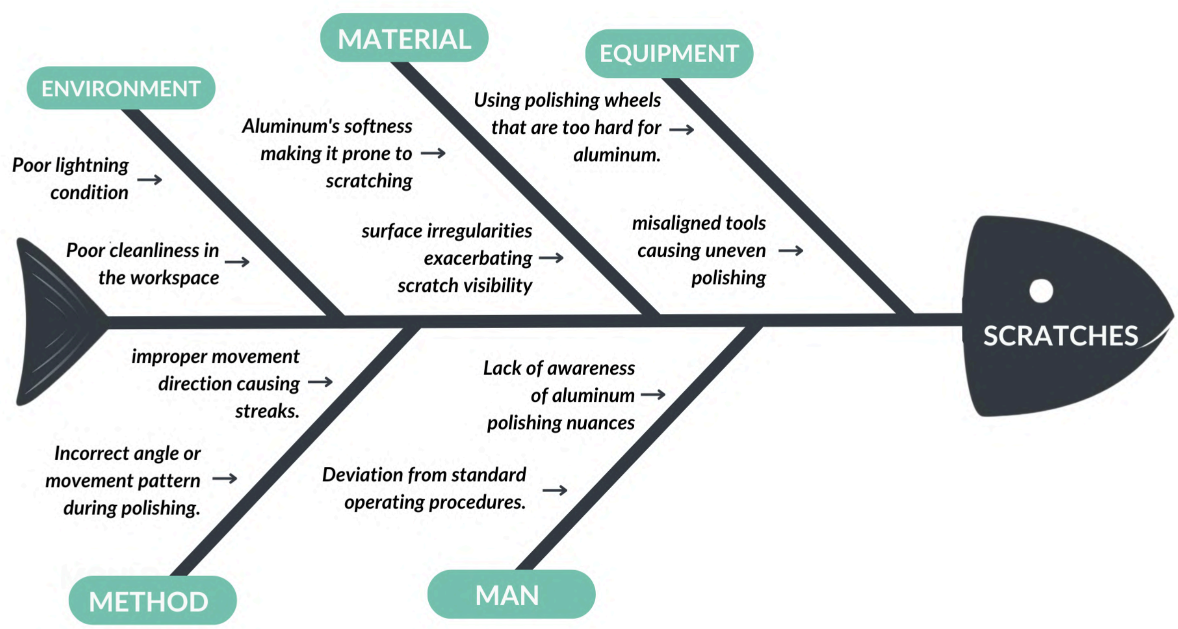
- Worn-out polishing tools causing uneven surface contact.
- Excessive pressure applied during the polishing process.
- Contaminated abrasive materials scratching the aluminum surface.

Corrective measures to reduce Tool Marks defect:

- Implement a regular maintenance and replacement schedule for polishing tools to ensure they are in good condition.
- Provide training for operators on proper polishing techniques, emphasizing the importance of applying consistent and appropriate pressure.
- Establish strict procedures for storing and handling abrasive materials to keep them clean and free from contaminants.
- Standardize the polishing speed settings on all equipment and ensure operators adhere to these guidelines to achieve a uniform finish.
- Conduct regular calibration and alignment checks for polishing equipment to ensure tools are correctly positioned and functioning properly.

- **<u>Cause and Effect Diagram for Sratches</u>**

Fishbone diagram of Scratches categorize the causes into 5 categories as shown below.



Root Causes:

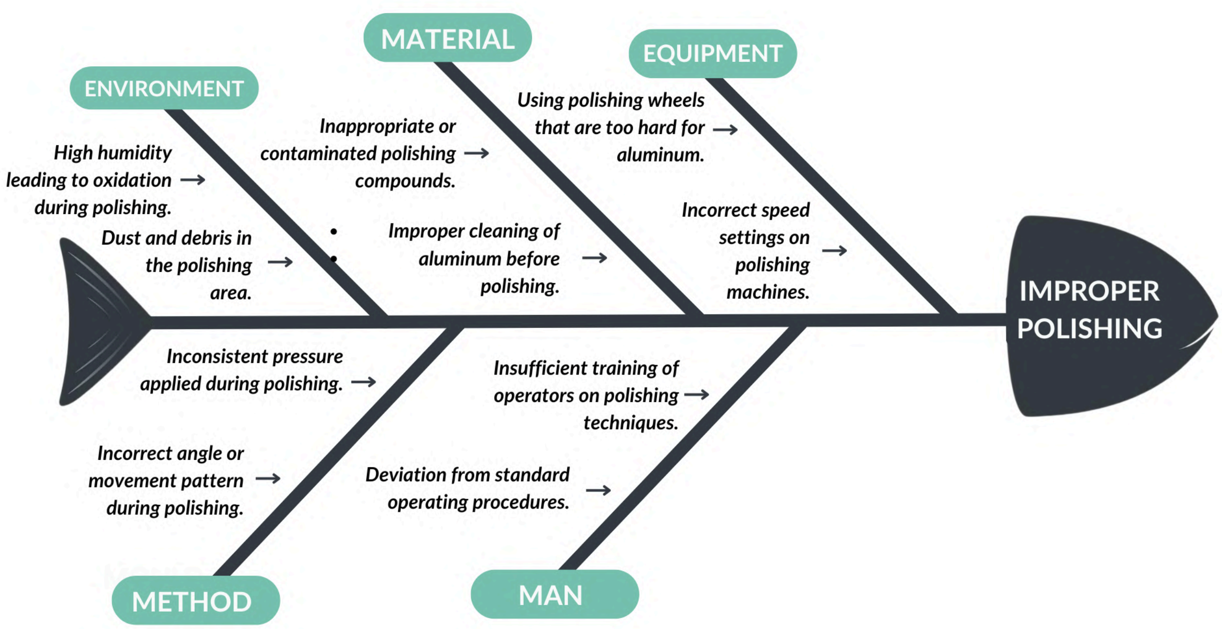
- Use of abrasive materials with incorrect grit size.
- Presence of contaminants on the aluminum surface or polishing tools.
- Inadequate cleaning between polishing steps

Corrective measures to reduce Scratches defect:

- Ensure the selection of appropriate grit sizes for each polishing stage, starting with coarser grits and progressing to finer grits as needed.
- Implement strict cleaning protocols for the aluminum workpieces and polishing tools to remove any dust, dirt, or debris before polishing begins.
- Establish thorough cleaning procedures between each polishing step to remove residual abrasive particles and prevent cross-contamination
- Store abrasive materials in a clean, dry environment to prevent contamination and ensure they remain in optimal condition for polishing.

- **<u>Cause and Effect Diagram for Improper Polishing</u>**

Fishbone diagram of Improper polishing categorize the causes into 5 categories as shown below.



Root Causes:

- Inconsistent pressure application during polishing.
- Improper polishing technique results in inconsistent surface texture.
- Use of inappropriate polishing compounds or abrasives

Corrective measures to reduce Improper polishing defect:

- Provide training to operators on maintaining consistent pressure during polishing to ensure uniformity in the surface finish.
- Evaluate and select polishing compounds and abrasives specifically designed for aluminum surfaces to ensure effective polishing without causing damage.
- Regularly inspect and maintain polishing equipment to ensure optimal performance and consistency in the polishing process.
- Implement stringent quality control checks throughout the polishing process to detect and rectify any inconsistencies in the surface finish promptly.

IMPROVEMENT

a) Improvement of Tool Marks:

The above suggestions were provided to the company and they further implemented these changes according to their company terms and conditions. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process.

After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure.

The process output is sampled for 12 days and 12 data points are collected as C. L. Gupta Exports works in 1 shift. The sampling data were recorded using check sheets and the data is collected during this shift.

Check sheet for improving Tool Marks

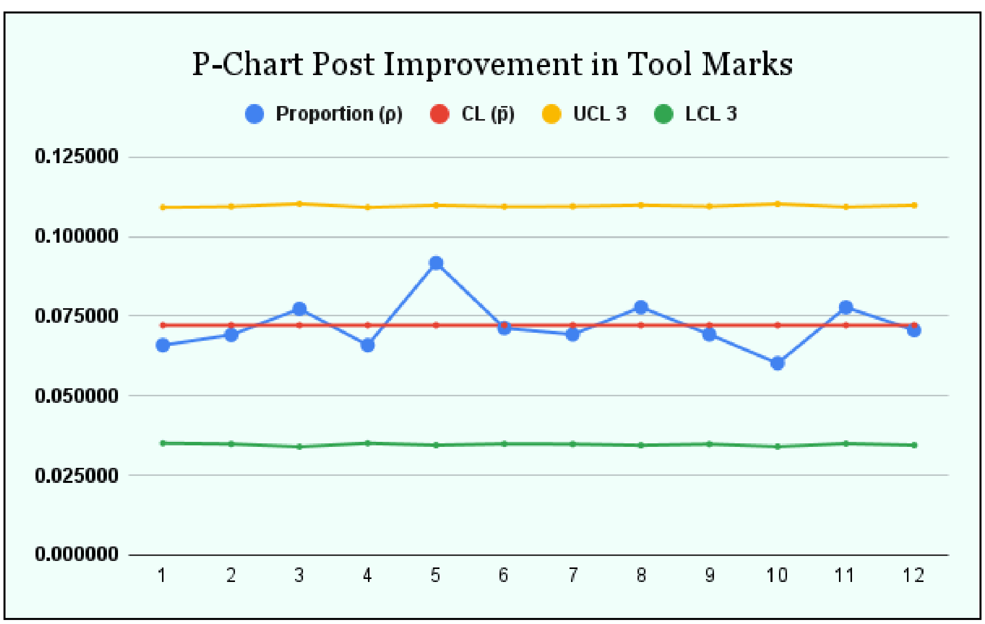
		Defects							
Day	Total inspected units	Tool marks	Scratches	Buff marks	Lancer marks	Blackness	Improper polishing	Improper Texture	Defectives
1	440	13	14	1	4	3	15	0	29
2	434	10	13	3	4	3	12	2	30
3	414	11	13	1	5	0	19	2	32
4	440	5	24	0	6	0	20	0	29
5	425	6	18	3	6	5	9	1	39
6	435	12	17	0	0	0	8	1	31
7	433	10	19	4	1	4	16	1	30
8	424	5	14	0	5	0	22	0	33
9	433	15	21	2	2	2	16	1	30
10	415	13	10	3	4	1	12	2	25
11	437	11	25	1	6	0	14	0	34
12	425	8	23	1	2	5	13	1	30
Total	**5155**	**119**	**211**	**19**	**45**	**23**	**176**	**11**	**372**

From the above check sheet we can see that the no. of occurrence of defect Tool Marks is reduced. There will also be decrease in some other defects as correcting one will also have impact on others. Now we will draw the P-chart to check whether the process is still in control or not.

<u>Construction of P-chart</u>

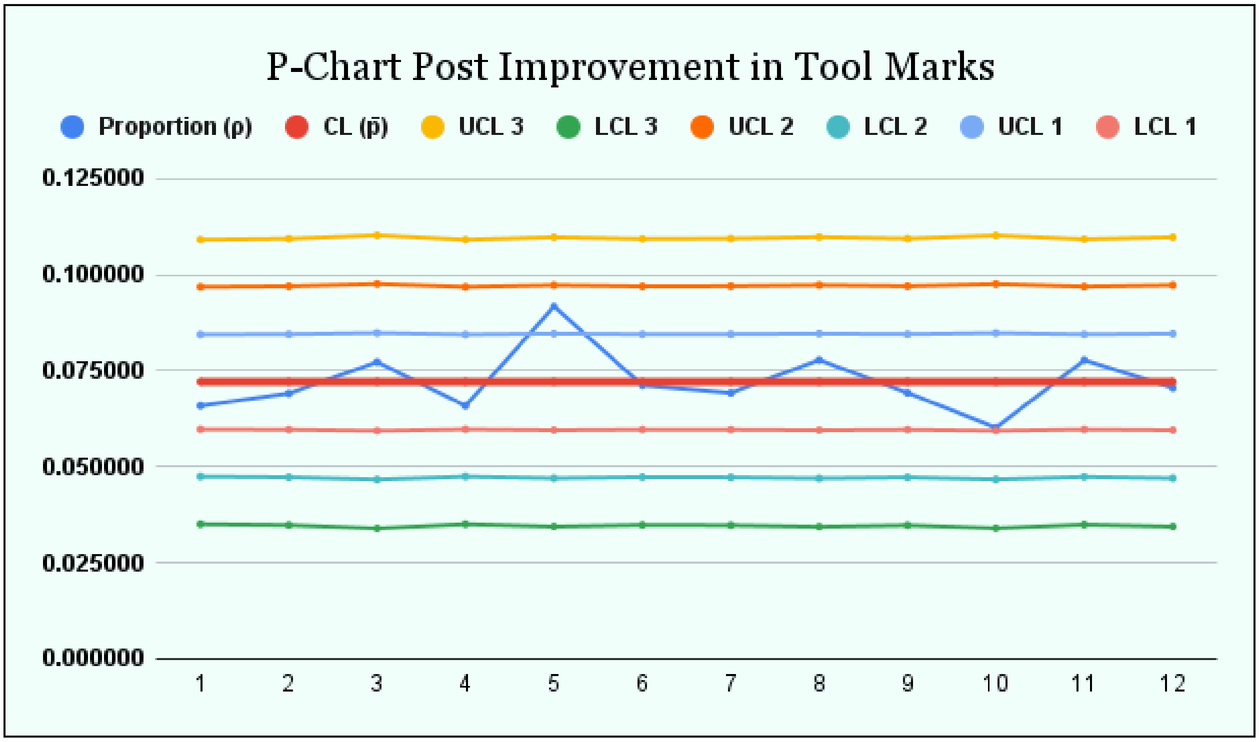
Day	Total inspected units	Defectives	Proportion (ρ)	CL (p̄)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	440	29	0.065909	0.072163	0.109170	0.035156	0.096835	0.047491	0.084499	0.059827
2	434	30	0.069124	0.072163	0.109425	0.034901	0.097004	0.047321	0.084584	0.059742
3	414	32	0.077295	0.072163	0.110315	0.034011	0.097597	0.046728	0.084880	0.059446
4	440	29	0.065909	0.072163	0.109170	0.035156	0.096835	0.047491	0.084499	0.059827
5	425	39	0.091765	0.072163	0.109818	0.034508	0.097266	0.047060	0.084715	0.059611
6	435	31	0.071264	0.072163	0.109382	0.034944	0.096976	0.047350	0.084569	0.059756
7	433	30	0.069284	0.072163	0.109468	0.034858	0.097033	0.047293	0.084598	0.059728
8	424	33	0.077830	0.072163	0.109862	0.034464	0.097296	0.047030	0.084729	0.059597
9	433	30	0.069284	0.072163	0.109468	0.034858	0.097033	0.047293	0.084598	0.059728
10	415	25	0.060241	0.072163	0.110269	0.034057	0.097567	0.046759	0.084865	0.059461
11	437	34	0.077803	0.072163	0.109297	0.035029	0.096919	0.047407	0.084541	0.059785
12	425	30	0.070588	0.072163	0.109818	0.034508	0.097266	0.047060	0.084715	0.059611
Total	**5155**	**372**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1**σ**, 2**σ** limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

P-Chart with all Control Limits (1σ, 2σ, 3σ):



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

<u>Calculating the Sigma Level</u>

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100

- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	372
Opportunities	7
Total Units	5155
Total Opportunities	36085
DPU	0.07216294859
DPO	0.01030899266
DPMO	10308.99266
Yield	98.96910073
Sigma Value	3.814907674

As we can see that the Sigma level for this is 3.8149 which means working on Tool Marks defect sigma level has improved from 3.6019 to 3.8149.

Now we work on other two defectsto see whether we can further be able to improve the sigma level or not.

b) Improvement of Scratches:

The above suggestions were provided to the company and they further implemented these changes according to their company terms and conditions. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process.

After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure.

The process output is sampled for 12 days and 12 data points are collected as C. L. Gupta Exports works in 1 shift. The sampling data were recorded using check sheets and the data is collected during this shift.

Check sheet for improving Scratches

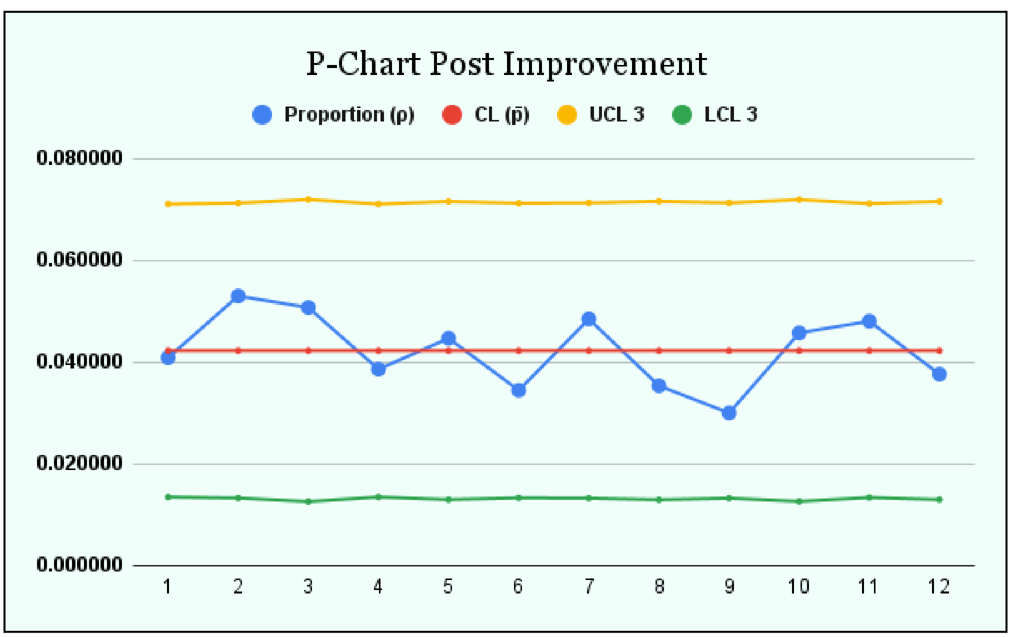
		Defects							
Day	Total inspected units	Tool marks	Scratches	Buff marks	Lancer marks	Blackness	Improper polishing	Improper Texture	Defectives
1	440	10	14	1	4	0	14	0	18
2	434	9	9	3	4	3	10	1	23
3	414	11	9	1	5	0	17	0	21
4	440	5	10	0	6	0	19	0	17
5	425	6	13	3	6	5	9	1	19
6	435	8	10	0	0	0	8	1	15
7	433	9	14	4	1	2	16	1	21
8	424	5	9	0	5	0	18	0	15
9	433	12	11	2	2	2	16	1	13
10	415	11	9	3	4	1	12	2	19
11	437	11	10	1	6	0	14	0	21
12	425	8	13	1	2	5	13	1	16
Total	**5155**	**105**	**131**	**19**	**45**	**18**	**166**	**8**	**218**

From the above check sheet we can see that the no. of occurrence of defect Scratches is reduced. There will also be decrease in some other defects as correcting one will also have impact on others. Now we will draw the P-chart to check whether the process is still in control or not.

Construction of P-chart

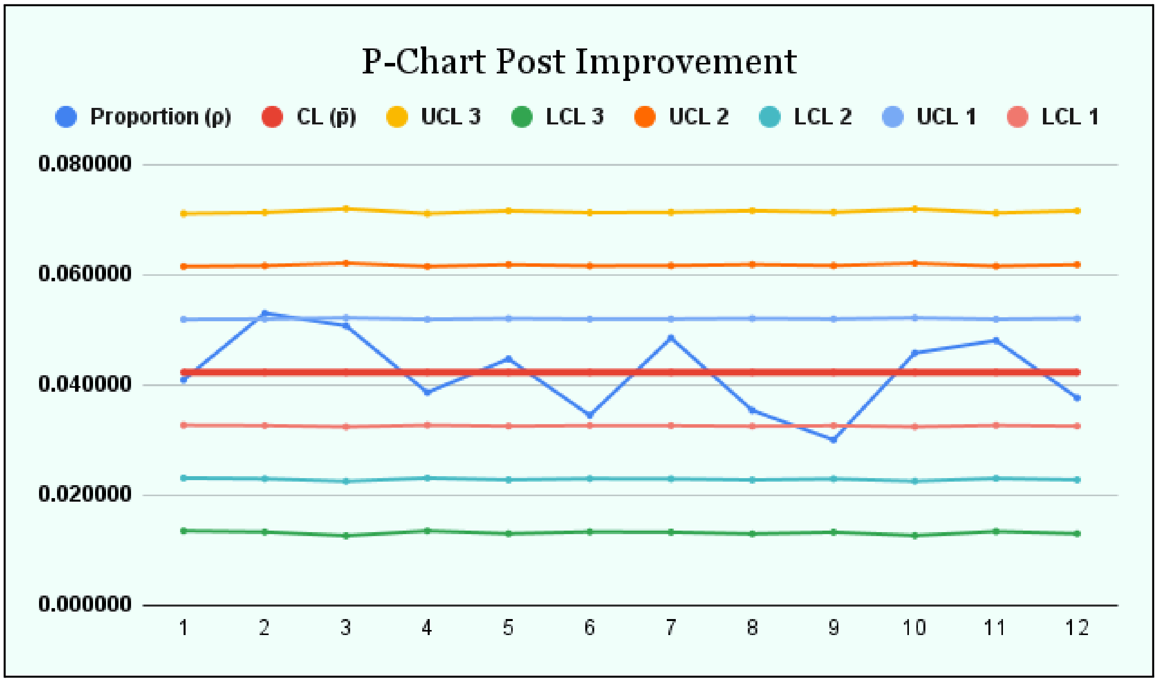
Day	Total inspected units	Defectives	Proportion (ρ)	CL (p̄)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	440	18	0.040909	0.042289	0.071071	0.013507	0.061477	0.023101	0.051883	0.032695
2	434	23	0.052995	0.042289	0.071270	0.013308	0.061609	0.022969	0.051949	0.032629
3	414	21	0.050725	0.042289	0.071961	0.012617	0.062071	0.022507	0.052180	0.032398
4	440	17	0.038636	0.042289	0.071071	0.013507	0.061477	0.023101	0.051883	0.032695
5	425	19	0.044706	0.042289	0.071575	0.013003	0.061813	0.022765	0.052051	0.032527
6	435	15	0.034483	0.042289	0.071236	0.013342	0.061587	0.022991	0.051938	0.032640
7	433	21	0.048499	0.042289	0.071303	0.013275	0.061632	0.022946	0.051960	0.032618
8	424	15	0.035377	0.042289	0.071609	0.012969	0.061836	0.022742	0.052062	0.032516
9	433	13	0.030023	0.042289	0.071303	0.013275	0.061632	0.022946	0.051960	0.032618
10	415	19	0.045783	0.042289	0.071926	0.012652	0.062047	0.022531	0.052168	0.032410
11	437	21	0.048055	0.042289	0.071170	0.013408	0.061543	0.023035	0.051916	0.032662
12	425	16	0.037647	0.042289	0.071575	0.013003	0.061813	0.022765	0.052051	0.032527
Total	**5155**	**218**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1σ, 2σ limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

P-Chart with all Control Limits (1σ, 2σ, 3σ):



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

<u>Calculating the Sigma Level</u>

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	218
Opportunities	7
Total Units	5155
Total Opportunities	36085
DPU	0.04228903977
DPO	0.006041291395
DPMO	6041.291395
Yield	99.39587086
Sigma Value	4.00972321

As we can see that the Sigma level for this is 4.0097 which means working on Scratches defect sigma level has improved from 3.8149 to 4.0097.
Now we work on the last defect to see whether we can further be able to improve the sigma level or not.

c) Improvement of Improper Polishing:

The above suggestions were provided to the company and they further implemented these changes according to their company terms and conditions. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process.

After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure.

The process output is sampled for 12 days and 12 data points are collected as C. L. Gupta Exports works in 1 shift. The sampling data were recorded using check sheets and the data is collected during this shift.

Check sheet for improving Improper Polishing

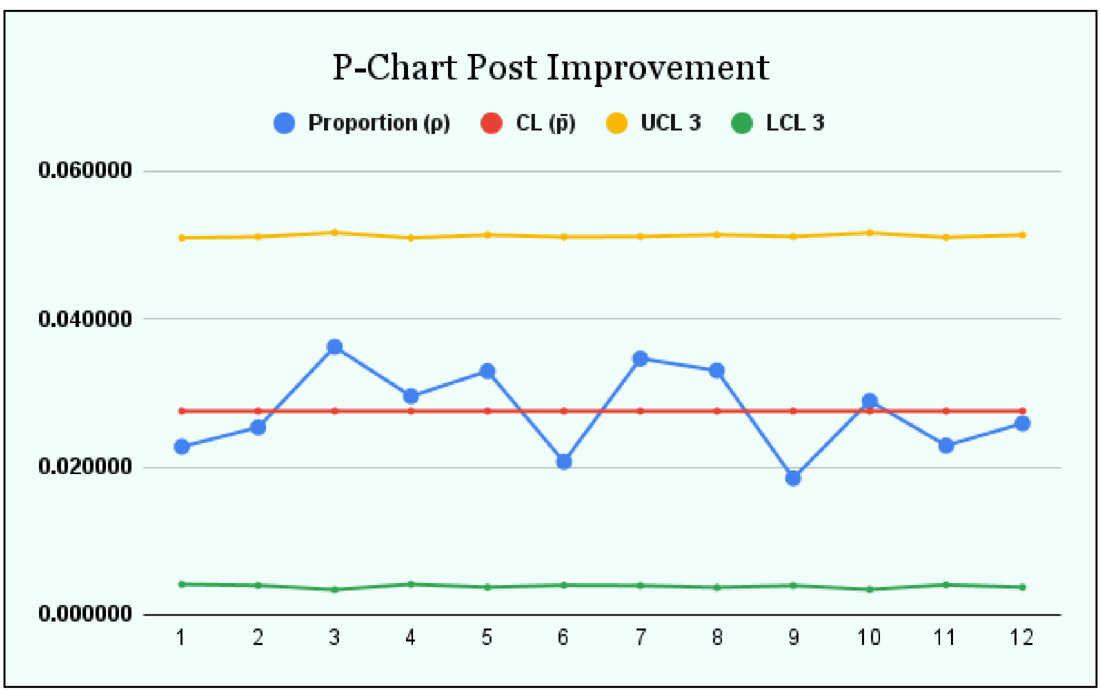
		Defects							
Day	Total inspected units	Tool marks	Scratches	Buff marks	Lancer marks	Blackness	Improper polishing	Improper Texture	Defectives
1	440	5	6	1	3	0	5	0	10
2	434	7	10	3	1	3	6	1	11
3	414	8	7	1	2	0	11	0	15
4	440	6	6	0	4	0	8	0	13
5	425	5	10	3	3	5	11	1	14
6	435	7	5	0	0	0	11	1	9
7	433	5	7	4	1	2	9	1	15
8	424	5	7	0	5	0	11	0	14
9	433	5	5	2	2	2	7	1	8
10	415	6	10	3	4	1	10	2	12
11	437	8	8	1	5	0	11	0	10
12	425	5	10	1	0	1	10	1	11
Total	**5155**	**72**	**91**	**19**	**30**	**14**	**110**	**8**	**142**

From the above check sheet we can see that the no. of occurrence of defect Improper Polishing is reduced. There will also be decrease in some other defects as correcting one will also have impact on others. Now we will draw the P-chart to check whether the process is still in control or not.

Construction of P-chart

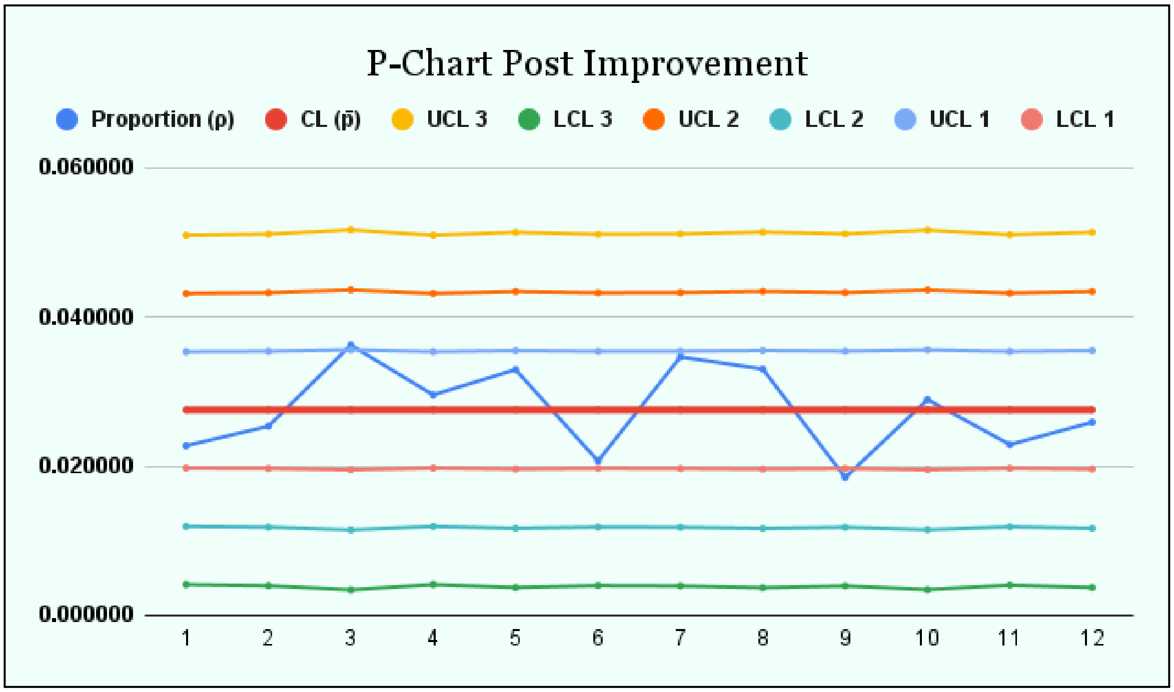
Day	Total inspected units	Defectives	Proportion (ρ)	CL (p̄)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	440	10	0.022727	0.027546	0.050954	0.004138	0.043151	0.011941	0.035349	0.019743
2	434	11	0.025346	0.027546	0.051115	0.003977	0.043259	0.011833	0.035402	0.019690
3	414	15	0.036232	0.027546	0.051678	0.003415	0.043634	0.011458	0.035590	0.019502
4	440	13	0.029545	0.027546	0.050954	0.004138	0.043151	0.011941	0.035349	0.019743
5	425	14	0.032941	0.027546	0.051363	0.003729	0.043424	0.011668	0.035485	0.019607
6	435	9	0.020690	0.027546	0.051088	0.004004	0.043241	0.011851	0.035393	0.019699
7	433	15	0.034642	0.027546	0.051142	0.003950	0.043277	0.011815	0.035411	0.019681
8	424	14	0.033019	0.027546	0.051391	0.003701	0.043443	0.011649	0.035495	0.019598
9	433	8	0.018476	0.027546	0.051142	0.003950	0.043277	0.011815	0.035411	0.019681
10	415	12	0.028916	0.027546	0.051649	0.003444	0.043614	0.011478	0.035580	0.019512
11	437	10	0.022883	0.027546	0.051034	0.004058	0.043205	0.011887	0.035375	0.019717
12	425	11	0.025882	0.027546	0.051363	0.003729	0.043424	0.011668	0.035485	0.019607
Total	**5155**	**142**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1**σ**, 2**σ** limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

*P-Chart with all Control Limits (1**σ**, 2**σ**, 3**σ**):*



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

<u>Calculating the Sigma Level</u>

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100

- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	142
Opportunities	7
Total Units	5155
Total Opportunities	36085
DPU	0.02754607177
DPO	0.003935153111
DPMO	3935.153111
Yield	99.60648469
Sigma Value	4.157583627

An implementation of the suggestions was done to the process and studied for a period of 12 days. The sigma level showed an improvement from 3.6019 to 4.1575 and the defects arising due to **Tool Marks, Scratches,** and **Improper Polishing** were decreased; this may be a more optimistic picture in the reality. Thus, in control the process with improvements is maintained and standardized.

Stage 3

DEFINE

Stage 3 comprises of Cleaning, Electrophoretic lacquering, Coating, Baking.

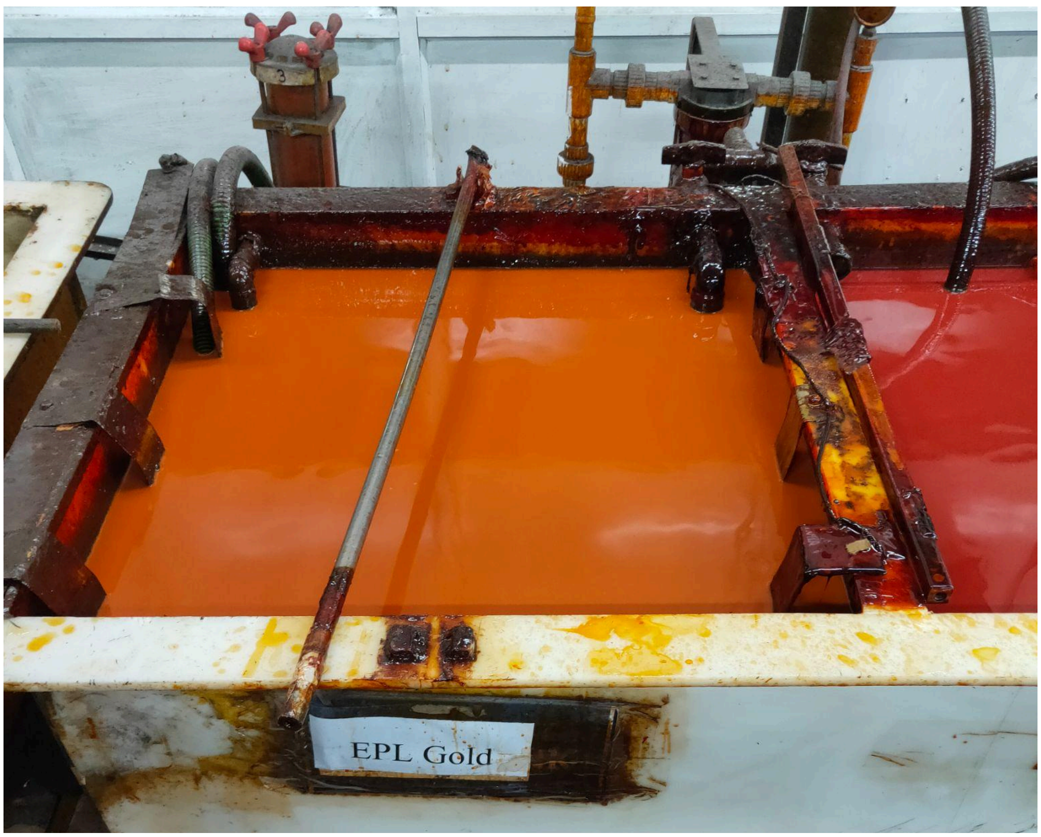
Electrophoretic lacquering, also known as e-coating, is a process used to apply a protective and decorative coating to metal surfaces. This process involves the deposition of paint particles onto a substrate using an electrical current.
In the electrophoretic lacquering process, aluminum candle stands are submerged in a bath containing a water-based paint or lacquer solution. An electrical current is applied, causing the paint particles to migrate towards and uniformly coat the aluminum surfaces. This process ensures an even, durable, and corrosion-resistant finish. After coating, the items are rinsed and cured in an oven to achieve the final hardened finish.

Preparation:

- **Cleaning and Degreasing:** The aluminum candle stands must be thoroughly cleaned to remove any dirt, grease, or contaminants that could affect the adhesion of the lacquer. This is typically done using a combination of alkaline or acidic cleaners and water rinses.

- **Surface Conditioning:** After cleaning, the surface may undergo conditioning or etching to ensure proper adhesion of the lacquer. This could involve using a chemical conditioner or a mild acid etch.

- **Bath Preparation:** The e-coating bath is prepared with a water-based paint or lacquer solution. The concentration and composition of the bath must be carefully controlled to ensure consistent coating quality.



Immersion:

- **Submersion:** The clean and conditioned aluminum candle stands are submerged into the e-coating bath. The parts must be fully immersed to ensure complete coverage.

- **Fixture Setup:** Candle stands are often mounted on fixtures to ensure they are held in the correct position and orientation during the coating process.

Electrodeposition:

- **Application of Electrical Current:** An electrical current is applied to the bath, with the aluminum candle stands acting as the cathode (negative electrode) and the tank walls or other structures acting as the anode (positive electrode). The electrical current causes the paint particles to migrate towards and deposit onto the surface of the aluminum.

- **Coating Formation:** The paint particles form a uniform, adherent coating on the aluminum surfaces. The thickness of the coating can be controlled by adjusting the voltage and time of the electrodeposition process.

Rinsing:

- **Post-Coating Rinse:** After the electrodeposition step, the coated aluminum candle stands are removed from the bath and rinsed with deionized water. This step removes any excess paint or lacquer that did not adhere to the surface, ensuring a smooth and even coating.

- **Quality Check:** The rinsing process is crucial for preventing defects such as drips, runs, or uneven coating thickness.

Curing:

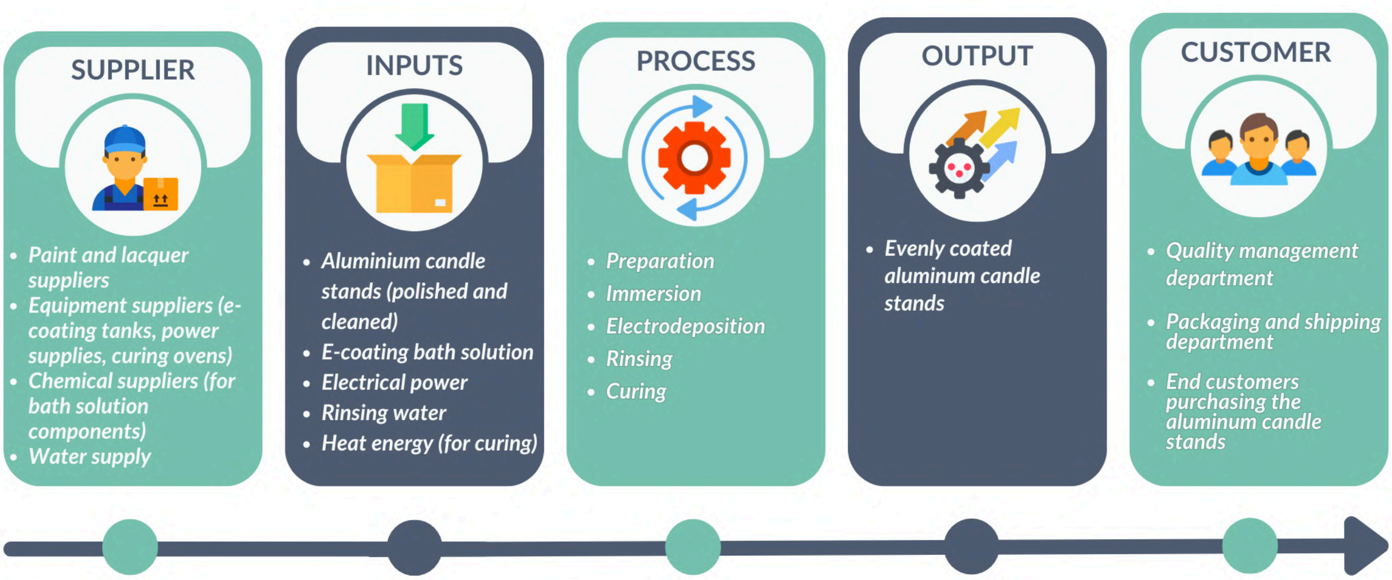
- **Oven Curing:** The rinsed aluminum candle stands are placed in a curing oven. The temperature and duration of the curing process depend on the specific lacquer used but generally involve heating the items to a temperature between 150-200°C (300-390°F) for a specified period.

- **Hardening the Coating:** During curing, the lacquer hardens and bonds firmly to the aluminum surface, forming a durable and protective layer.

This stage 3 is further explained by the help of SIPOC diagram:

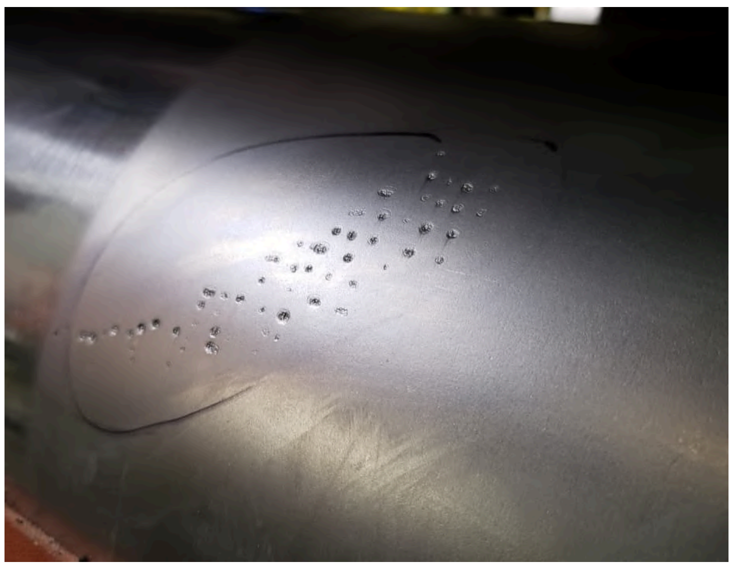
SIPOC Diagram

The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem



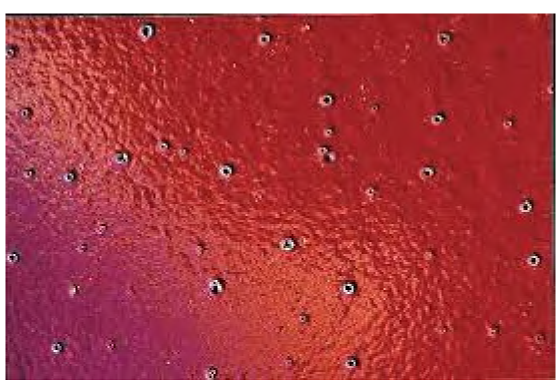
Defects in the various process of Stage 3 which are identified by the company are:

1. **Cratering**
   Cratering is a common defect in the electrophoretic lacquering (e-coating) process, characterized by small, round depressions or "craters" in the coating surface. These craters often have a central point where the defect initiates and spread outwards, creating a visually unappealing and potentially weak area in the coating.



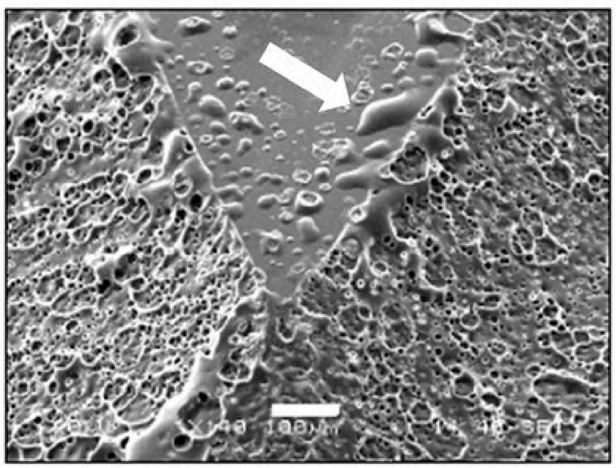
Cratering Defect

2. **Rupturing**
   Rupturing is a defect in the electrophoretic lacquering (e-coating) process where the coating film cracks or breaks, leading to exposed areas on the aluminum surface. This defect compromises the protective and aesthetic qualities of the coating.



Rupturing Defect

3. **Roughness**
   Roughness is a defect in the electrophoretic lacquering (e-coating) process characterized by a textured or uneven surface finish on the coated aluminum parts. This defect affects both the visual appeal and the functional performance of the coating. Roughness in the electrophoretic lacquering process refers to the presence of an irregular, coarse, or gritty surface texture on the finished coating. This defect can manifest as small bumps, granules, or an overall uneven finish that deviates from the desired smooth and glossy appearance.



Roughness Defect

4. **Gloss/Colour Variation:**
   Gloss/Colour Variation is a defect in the electrophoretic lacquering (e-coating) process characterized by inconsistent gloss levels or color differences on the coated surface. This defect can affect both the appearance and perceived quality of the final product.

Gloss/Colour Variation Defect

Project Charter

A project charter is a foundational document that outlines the scope, objectives, and parameters of a project. It defines the problem to be addressed and aligns the project with organizational goals. The charter establishes the project team, their roles, responsibilities, and authority levels. It sets a clear timeline for project completion, with milestones and deadlines. Additionally, it outlines the desired outputs and deliverables, ensuring alignment with business demands and customer requirements. The charter fosters effective collaboration and communication among team members. It serves as a roadmap for project initiation, execution, and evaluation. Overall, the project charter ensures clarity, accountability, and alignment throughout the project lifecycle.

PROJECT DESCRIPTION
Defect reduction in stage 3 which involves cleaning, electrophoretic lacquering, curing.
PROJECT OBJECTIVE AND GOAL
To reduce defects like cratering & gloss/colour variation in the mentioned processes of stage 3
PROJECT LOCATION
C. L. Gupta Export Ltd. 18 Km. Stone, Delhi Road, Vill. Jivai, near Moradabad, Uttar Pradesh 244221
BACKGROUND AND RATIONALE FOR PROJECT SELECTION
In the baseline process, Prioritize the defects in which cratering & gloss/colour variation has found to be highest priority as compared to the other defects based on the pareto chart (frequency) of the defects.
PROJECT TEAM
Quality Head Mangers from Manufacturing, Purchasing and Maintenance Quality control inspector, Research advisor and associates, and Floor operator
EXPECTED BENEFITS
Reduction in the defects due to cratering which would lead to cost benefits.
PROJECT PLAN
Application of DMAIC model of Six-Sigma
PROJECT TIMELINE
2 Months

Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the five defects identified in the defined stage is established, followed by defect prioritization with the help of pareto chart. Process specifications are followed to inspect the items with defects. The process output is sampled for 25 days and 25 data points are collected as C. L. Gupta Exports Ltd. works in 1 single shift. In total, 10642 units are observed in 25 days. To check whether process is in control or not, p-chartis plotted as number of units inspected in each day are different and we are considering the entire candle stand as a defective.

a) **Check sheet for Pre-Analysis:**

		Defects				
Day	Total Inspected Units	Cratering	Gloss/Colour Variation	Roughness	Rupturing	Defectives
1	414	14	18	11	6	38
2	423	19	16	11	5	37
3	419	19	13	10	9	40
4	423	10	13	11	7	40
5	411	14	12	9	10	47
6	424	18	17	10	8	43
7	422	13	11	10	5	40
8	435	16	18	9	9	31
9	414	19	16	11	10	36
10	433	18	15	11	10	45
11	425	15	15	12	7	40
12	415	16	14	10	7	35
13	425	18	15	13	7	38
14	426	13	15	11	10	36
15	425	21	16	12	5	30
16	425	16	12	12	10	35
17	426	15	17	12	10	33
18	440	17	18	12	6	40
19	420	20	12	13	5	35
20	418	18	15	12	10	49
21	433	17	14	11	6	45
22	419	12	13	10	10	35

23	440	17	16	11	8	40
24	420	13	13	12	7	35
25	426	11	13	12	6	46
Total	**10601**	**399**	**367**	**278**	**193**	**969**

From the above table we can see that we have total inspected 10601 units and total no. of defectives are 969. Now we will plot the p-chart.

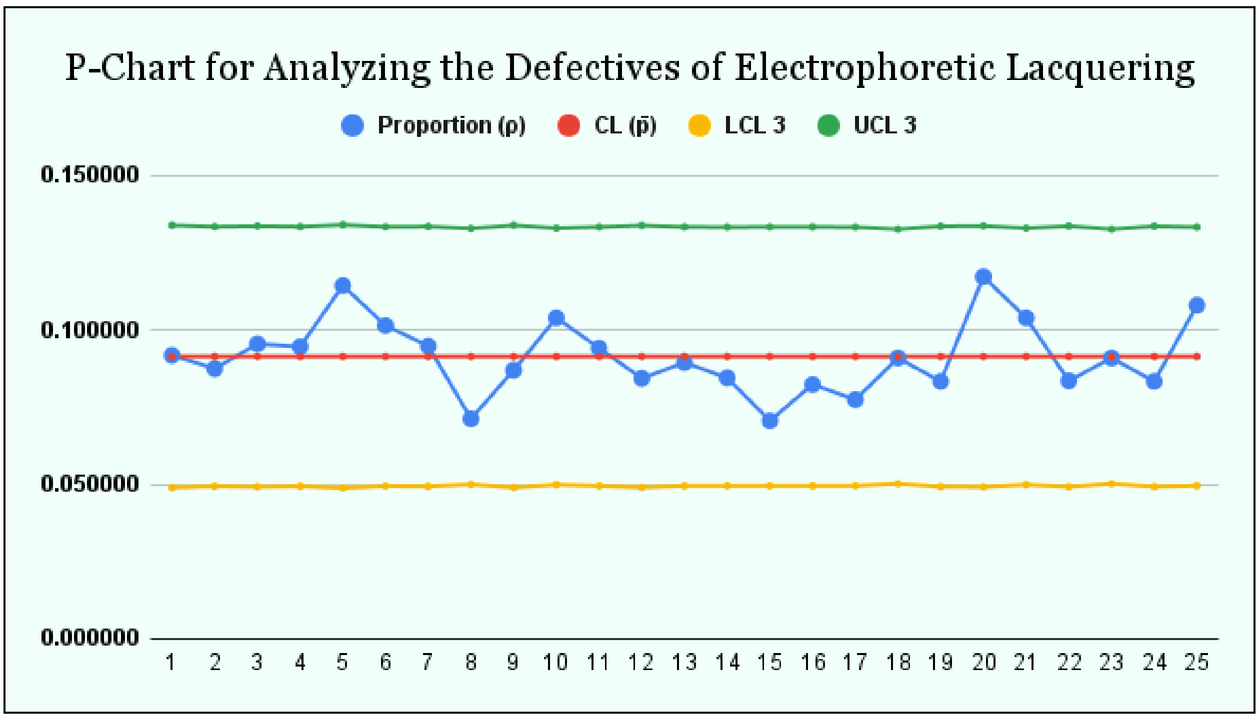
b) <u>Construction of P-chart</u>

Next, we proceed to measure our baseline quality level by making calculations for proportion, control limit, upper control limits and lower control limits (1σ, 2σ & 3σ) by their respective formulas which is depicted from the table given below.

Day	Total Inspected Units	Defectives	Proportion (ρ)	CL ($\bar{p}$)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	414	38	0.091787	0.107981	0.153741	0.062222	0.138488	0.077475	0.123234	0.092728
2	423	37	0.087470	0.107981	0.153251	0.062711	0.138161	0.077801	0.123071	0.092891
3	419	40	0.095465	0.107981	0.153467	0.062495	0.138305	0.077657	0.123143	0.092819
4	423	40	0.094563	0.107981	0.153251	0.062711	0.138161	0.077801	0.123071	0.092891
5	411	47	0.114355	0.107981	0.153908	0.062055	0.138599	0.077364	0.123290	0.092672
6	424	43	0.101415	0.107981	0.153198	0.062764	0.138126	0.077837	0.123053	0.092909
7	422	40	0.094787	0.107981	0.153305	0.062657	0.138197	0.077765	0.123089	0.092873
8	435	31	0.071264	0.107981	0.152623	0.063340	0.137742	0.078220	0.122862	0.093101
9	414	36	0.086957	0.107981	0.153741	0.062222	0.138488	0.077475	0.123234	0.092728
10	433	45	0.103926	0.107981	0.152726	0.063237	0.137811	0.078152	0.122896	0.093066
11	425	40	0.094118	0.107981	0.153145	0.062818	0.138090	0.077872	0.123036	0.092927
12	415	35	0.084337	0.107981	0.153686	0.062277	0.138451	0.077512	0.123216	0.092746
13	425	38	0.089412	0.107981	0.153145	0.062818	0.138090	0.077872	0.123036	0.092927
14	426	36	0.084507	0.107981	0.153092	0.062871	0.138055	0.077908	0.123018	0.092944
15	425	30	0.070588	0.107981	0.153145	0.062818	0.138090	0.077872	0.123036	0.092927
16	425	35	0.082353	0.107981	0.153145	0.062818	0.138090	0.077872	0.123036	0.092927
17	426	33	0.077465	0.107981	0.153092	0.062871	0.138055	0.077908	0.123018	0.092944
18	440	40	0.090909	0.107981	0.152368	0.063594	0.137573	0.078390	0.122777	0.093186
19	420	35	0.083333	0.107981	0.153413	0.062550	0.138269	0.077694	0.123125	0.092837
20	418	49	0.117225	0.107981	0.153521	0.062441	0.138341	0.077621	0.123161	0.092801
21	433	45	0.103926	0.107981	0.152726	0.063237	0.137811	0.078152	0.122896	0.093066
22	419	35	0.083532	0.107981	0.153467	0.062495	0.138305	0.077657	0.123143	0.092819

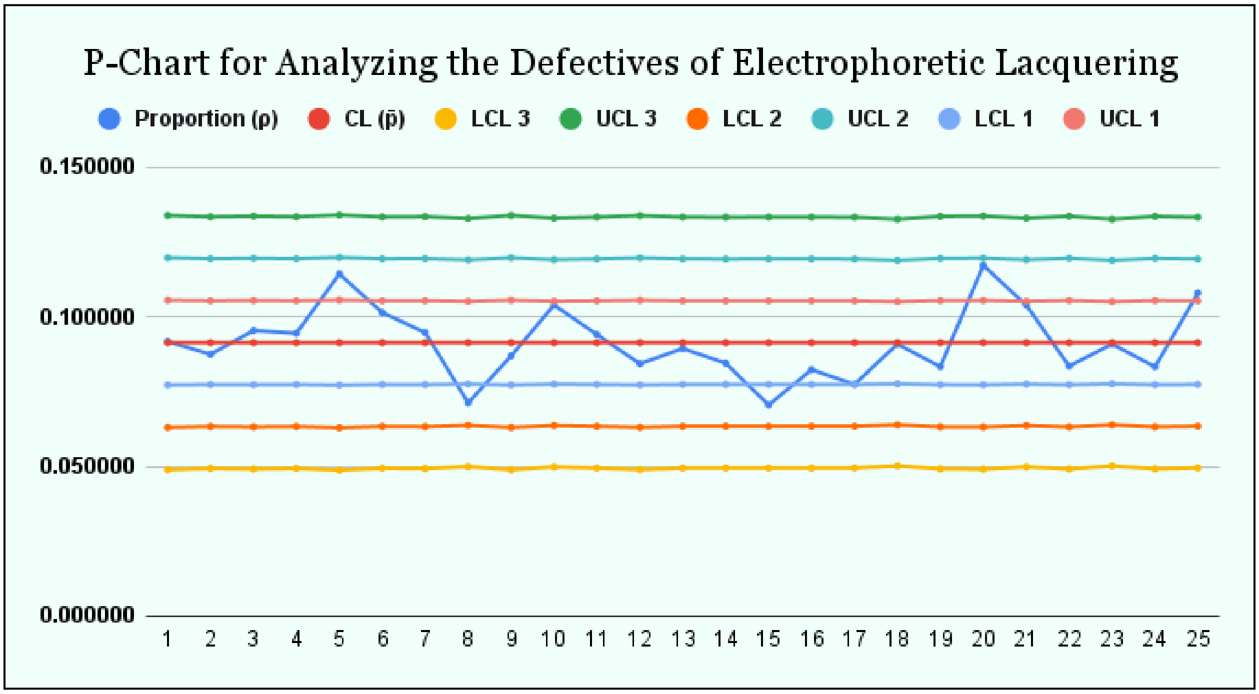
23	440	40	0.090909	0.107981	0.152368	0.063594	0.137573	0.078390	0.122777	0.093186
24	420	35	0.083333	0.107981	0.153413	0.062550	0.138269	0.077694	0.123125	0.092837
25	426	46	0.107981	0.107981	0.153092	0.062871	0.138055	0.077908	0.123018	0.092944
Total	**10601**	**969**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1**σ**, 2**σ** limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

P-Chart with all Control Limits (1σ, 2σ, 3σ):



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

c) <u>Calculating the Sigma Level</u>

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000
- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	985
Opportunities	5
Total Units	10601
Total Opportunities	53005
DPU	0.09291576266
DPO	0.01858315253
DPMO	18583.15253
Yield	98.14168475
Sigma Value	3.583932526

As we can see that the Sigma level for this is 3.5839 which means we can work on some defects to reduce them so that sigma level improves.

Analyse

a) AHP Technique

Now we wish to improve the current level of sigma. For this, we have used AHP techniques which will give information regarding which defects has to be taken care or analyzed in order to reduce the number of defectives so that we can further improve the sigma value for this process. For AHP, we have taken four criteria points which are as follows:

1. criticality to customer

2. Time requirement

3. Cost

4. No. of Defectives

After consulting from the quality team at C. L. Gupta Exports Ltd. we get to know that criticality to customer is the most important criteria followed by time requirement, cost and at last no. of defects. Now we develop the pairwise comparison matrix to prioritize the defects as suggested by the company.

i. Pairwise comparison matrix for criterion

Factors	criticality to customer	Time requirement	Cost	No. of Defectives	GM	Normalized GM	AW		
criticality to customer	1.00	3.00	5.00	4.00	2.783	0.523	2.215	**lamda-max**	4.189
Time requirement	0.33	1.00	5.00	3.00	1.495	0.281	1.172	**CI**	0.063
Cost	0.20	0.20	1.00	0.33	0.340	0.064	0.269	**CR**	0.070
No. of Defectives	0.25	0.33	3.00	1.00	0.707	0.133	0.548		
					5.325	1.000			

ii. Pairwise comparison matrix of defects on the basis of Criticality of customers

Criticality to customer	Cratering	Roughness	Cratering	Gloss/Colour Variation	GM	Normalized GM	AW		
Cratering	1.00	1.00	0.20	0.33	0.508	0.099	0.396	lamda-max	4.004
Roughness	1.00	1.00	0.20	0.33	0.508	0.099	0.396	CI	0.001
Cratering	5.00	5.00	1.00	2.00	2.659	0.518	2.076	CR	0.002
Gloss/Colour Variation	3.00	3.00	0.50	1.00	1.456	0.284	1.137		
					5.132	1.000			

iii. Pairwise comparison matrix of defects on the basis of Time Requirement

Time requirement	Cratering	Roughness	Cratering	Gloss/Colour Variation	GM	Normalized GM	AW		
Cratering	1.00	1.00	0.33	0.20	0.508	0.099	0.396	lamda-max	4.004
Roughness	1.00	1.00	0.33	0.20	0.508	0.099	0.396	CI	0.001
Cratering	3.00	3.00	1.00	0.50	1.456	0.284	1.137	CR	0.002
Gloss/Colour Variation	5.00	5.00	2.00	1.00	2.659	0.518	2.076		
					5.132	1.000			

iv. Pairwise comparison matrix of defects on the basis of Cost

Cost	Cratering	Roughness	Cratering	Gloss/Colour Variation	GM	Normalized GM	AW		
Cratering	1.00	1.00	0.20	0.14	0.411	0.068	0.276	lamda-max	4.073
Roughness	1.00	1.00	0.20	0.14	0.411	0.068	0.276	CI	0.024
Cratering	5.00	5.00	1.00	0.33	1.699	0.283	1.161	CR	0.027
Gloss/Colour Variation	7.00	7.00	3.00	1.00	3.482	0.580	2.388		
					6.003	1.000			

v. Pairwise comparison matrix of defects on the basis of No. of Defective

No. of Defectives	Cratering	Roughness	Cratering	Gloss/Colour Variation	GM	Normalized GM	AW		
Cratering	1.00	4.00	0.33	3.00	1.414	0.248	1.003	**lamda-max**	4.057
Roughness	0.25	1.00	0.14	0.50	0.366	0.064	0.260	**CI**	0.019
Cratering	3.00	7.00	1.00	6.00	3.350	0.587	2.386	**CR**	0.021
Gloss/Colour Variation	0.33	2.00	0.17	1.00	0.577	0.101	0.410		
					5.707	1.000			

v. Priority Vector

Now we have average priority vector of all the criterion and priority vector of criteria themselves. Multiplying these two matrices we get the desired priority vector for defect we need to work upon.

Final Priority	criticality to customer	Time requirement	Cost	No. of Defectives	Rating
Cratering	0.052	0.028	0.004	0.033	0.117
Roughness	0.052	0.028	0.004	0.009	0.092
Cratering	0.271	0.080	0.018	0.078	0.446
Gloss/Colour Variation	0.148	0.145	0.037	0.013	0.344
					1.000

	Rating	Rank
Cratering	0.446	1
Gloss/Colour Variation	0.344	2
Cratering	0.117	3
Roughness	0.092	4

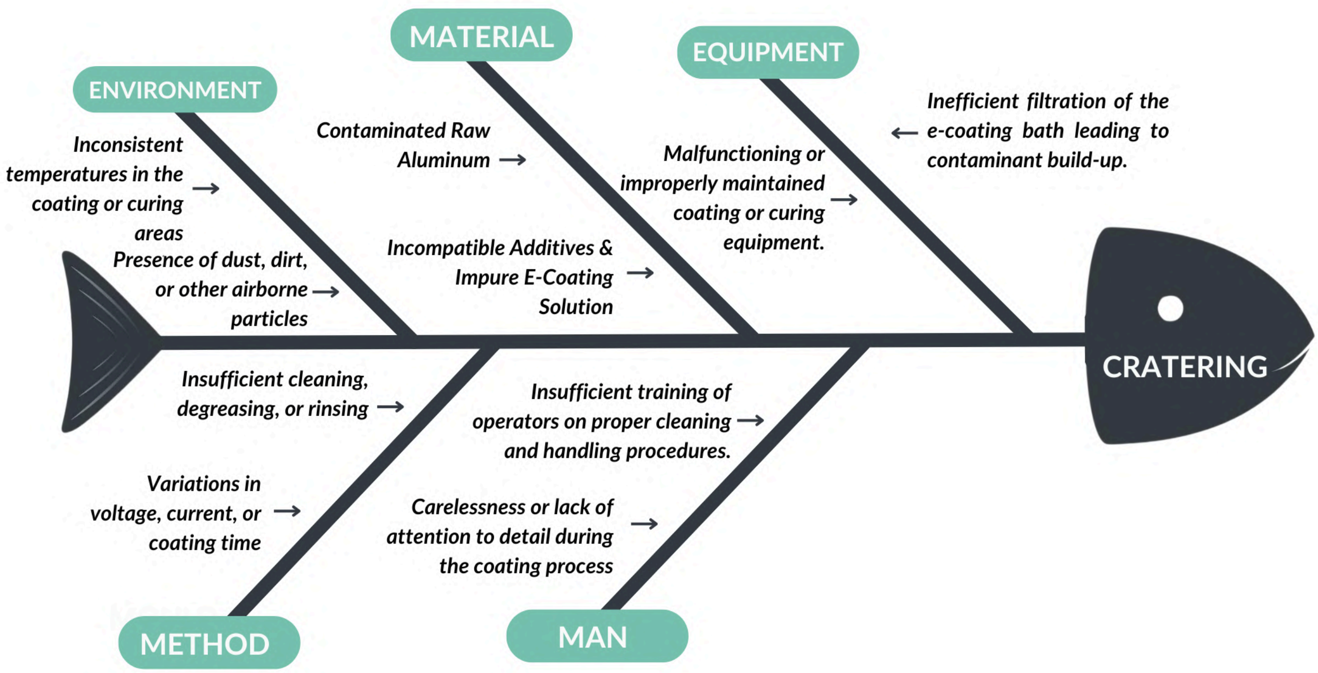
So according to AHP we need to work upon Cratering and Gloss/Colour Variation defect. We are now going to find the causes of this defect by the help of cause and effect diagram.

Cause & Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in six generic categories was prepared as show. We will be working with one defect at a time because implementing all the corrective measures simultaneously is not practical.

b) Cause and Effect Diagrams (Fishbone Diagrams)

- **Cause and Effect Diagram for Cratering**

Fishbone diagram of Cratering categorize the causes into 5 categories as shown below.



Root Causes:

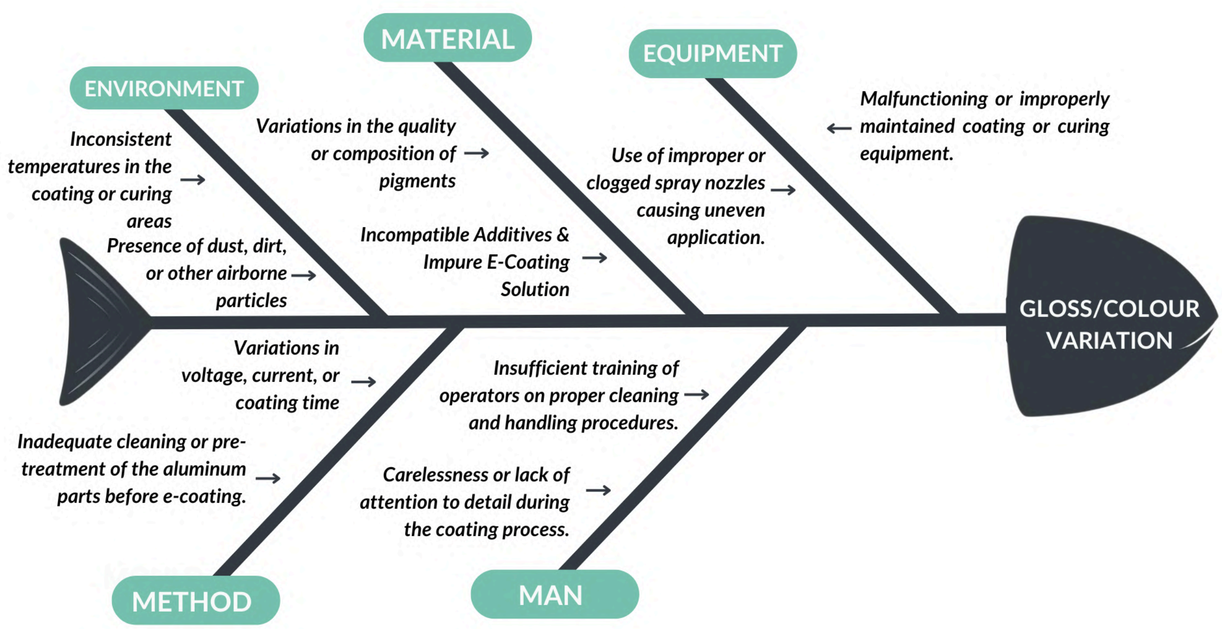
- Contaminants in the e-coating bath.
- Inadequate surface preparation of the aluminum parts.
- Improper curing temperatures or times.

Corrective measures to reduce Cratering defect:

- Implement strict filtration and cleaning protocols for the e-coating bath to remove contaminants
- Enhance surface preparation procedures to ensure thorough cleaning and degreasing of aluminum parts before coating.
- Maintain accurate and consistent curing temperatures and times by regularly calibrating curing ovens.
- Conduct regular quality checks and maintenance of the e-coating bath to ensure chemical balance and purity.
- Improve operator training to ensure adherence to proper surface preparation and coating procedures.

- **Cause and Effect Diagram for Gloss/Colour Variation**

Fishbone diagram of Gloss/Colour Variation categorize the causes into 5 categories as shown below.



Root Causes:

- Inconsistent application parameters such as voltage and current during the e-coating process.
- Improper mixing or agitation of the e-coating solution leading to uneven pigment distribution.
- Temperature fluctuations in the curing oven.

Corrective measures to reduce Gloss/Colour Variation defect:

- Ensure consistent voltage, current, and coating time during the e-coating process by regularly calibrating equipment and following established protocols.
- Implement thorough mixing and agitation practices for the e-coating solution to achieve uniform pigment dispersion and maintain solution homogeneity.
- Maintain stable and consistent temperatures in the curing oven by using calibrated temperature controls and monitoring systems to prevent fluctuations.
- Conduct regular inspections and tests of the e-coating solution, raw materials, and final products to ensure consistent color and gloss levels, identifying and addressing any variations promptly.

IMPROVEMENT

a) Improvement of Cratering:

The above suggestions were provided to the company and they further implemented these changes according to their company terms and conditions. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process.

After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure.

The process output is sampled for 12 days and 12 data points are collected as C. L. Gupta Exports works in 1 shift. The sampling data were recorded using check sheets and the data is collected during this shift.

Check sheet for improving Cratering

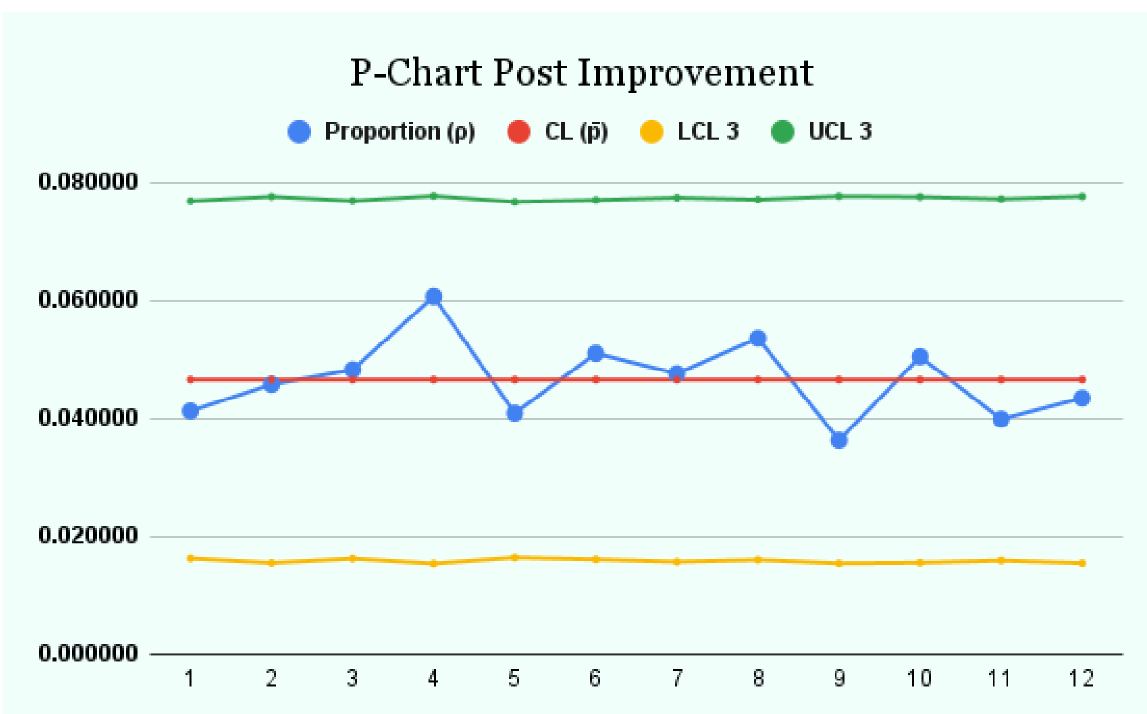
		Defects				
Day	Total Inspected Units	Cratering	Gloss/Colour Variation	Roughnes s	Rupturing	Defectives
1	436	5	14	7	3	18
2	415	11	11	10	3	19
3	435	6	12	9	4	21
4	412	10	10	8	4	25
5	440	6	13	5	4	18
6	431	12	14	10	0	22
7	420	13	10	7	3	20
8	429	5	10	6	1	23
9	413	12	10	9	3	15
10	416	11	13	5	4	21
11	426	5	14	7	1	17
12	414	11	12	9	2	18
Total	**5087**	**107**	**143**	**92**	**32**	**237**

From the above check sheet we can see that the no. of occurrence of defect Cratering is reduced. There will also be decrease in some other defects as correcting one will also have impact on others. Now we will draw the P-chart to check whether the process is still in control or not.

Construction of P-chart

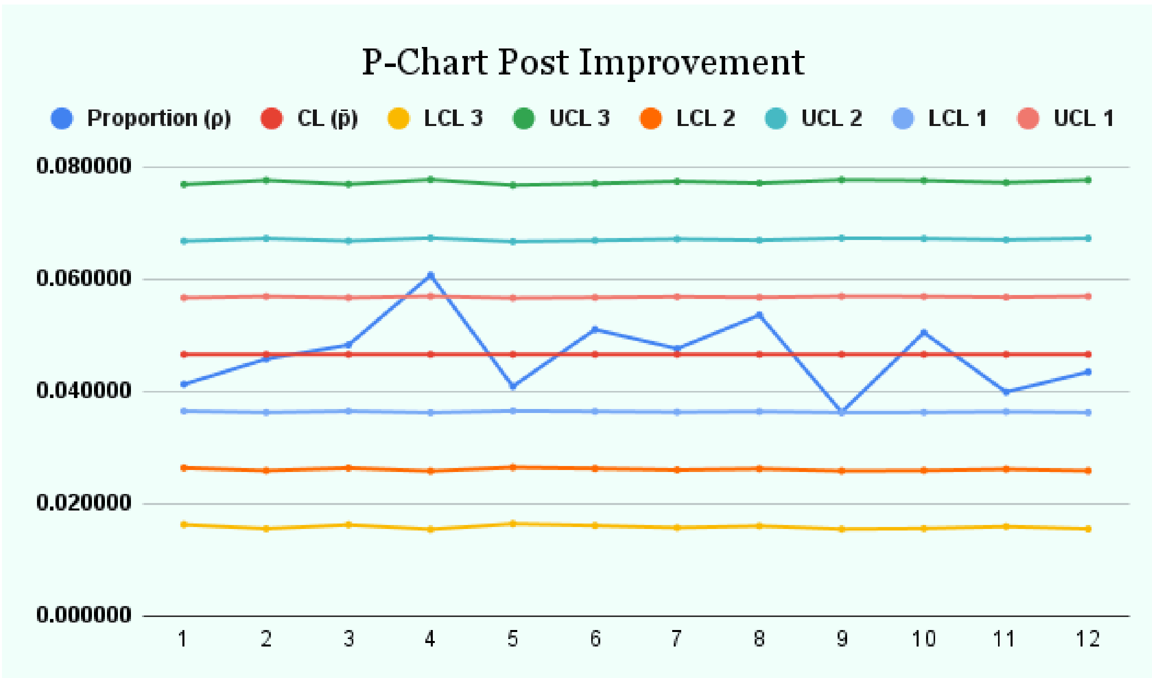
Day	Total Inspected Units	Defectives	Proportion (ρ)	CL ($\bar{p}$)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	436	18	0.041284	0.046589	0.076870	0.016309	0.066776	0.026402	0.056683	0.036496
2	415	19	0.045783	0.046589	0.077626	0.015552	0.067281	0.025898	0.056935	0.036244
3	435	21	0.048276	0.046589	0.076905	0.016274	0.066799	0.026379	0.056694	0.036484
4	412	25	0.060680	0.046589	0.077739	0.015439	0.067356	0.025823	0.056973	0.036206
5	440	18	0.040909	0.046589	0.076732	0.016447	0.066684	0.026494	0.056637	0.036542
6	431	22	0.051044	0.046589	0.077045	0.016134	0.066893	0.026286	0.056741	0.036438
7	420	20	0.047619	0.046589	0.077441	0.015738	0.067157	0.026022	0.056873	0.036305
8	429	23	0.053613	0.046589	0.077116	0.016063	0.066940	0.026238	0.056765	0.036414
9	413	15	0.036320	0.046589	0.077701	0.015477	0.067331	0.025848	0.056960	0.036219
10	416	21	0.050481	0.046589	0.077589	0.015590	0.067256	0.025923	0.056923	0.036256
11	426	17	0.039906	0.046589	0.077223	0.015956	0.067012	0.026167	0.056801	0.036378
12	414	18	0.043478	0.046589	0.077664	0.015515	0.067306	0.025873	0.056948	0.036231
Total	**5087**	**237**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



From the graph it is clear that the process is in statistical control as it is entirely within 3 standard deviations off the mean. But to check further if there is any variation due to any assignable causes, we plot 1σ, 2σ limits as well and use the Nelson Rules to rule out the possibility of variation due to an assignable cause.

P-Chart with all Control Limits (1σ, 2σ, 3σ):



From the above plot, it can be seen that none of the Nelson Rules were violated. So the variation was only caused due to chance causes.

Calculating the Sigma Level

Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

Formulae Used:

- DPU= defectives/inspected
- DPO=defectives/total opportunities
- DPMO=(defectives/total opportunities)*1000000

- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	237
Opportunities	4
Total Units	5087
Total Opportunities	20348
DPU	0.04658934539
DPO	0.01164733635
DPMO	11647.33635
Yield	98.83526637
Sigma Value	3.76856696

As we can see that the Sigma level for this is 3.7685 which means working on Crack defect sigma level has improved from 3.5839 to 3.7685.Now we work on other defect which is Gloss/Colour Variation to see whether we can further be able to improve the sigma level or not.

b) Improvement of Gloss/Colour Variation:

The above suggestions were provided to the company and they further implemented these changes according to their company terms and conditions. Sufficient time and resources were dedicated to this procedure aiming to improve the sigma level, i.e. the performance of the process.

After this, new data was recorded to monitor the improvements (if any) that were achieved by following the mentioned procedure.

The process output is sampled for 12 days and 12 data points are collected as C. L. Gupta Exports works in 1 shift. The sampling data were recorded using check sheets and the data is collected during this shift.

Check sheet for improving Gloss/Colour Variation

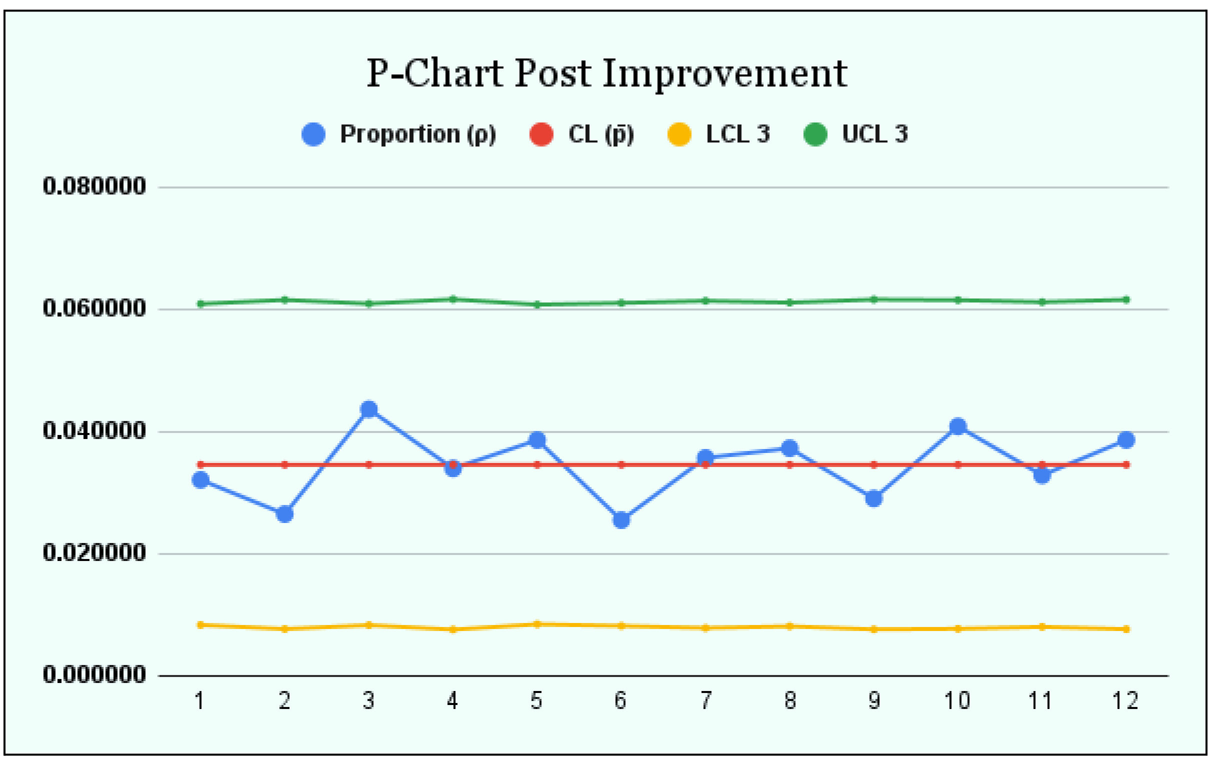
		Defects				
Day	Total Inspected Units	Cratering	Gloss/Colour Variation	Roughness	Rupturing	Defectives
1	436	9	10	3	1	14
2	415	9	9	7	2	11
3	435	7	5	4	2	19
4	412	6	9	5	1	14
5	440	8	5	5	2	17
6	431	9	6	5	0	11
7	420	4	7	5	3	15
8	429	6	6	9	3	16
9	413	8	8	4	3	12
10	416	7	9	3	0	17
11	426	5	9	5	0	14
12	414	5	10	2	3	16
Total	**5087**	**83**	**93**	**57**	**20**	**176**

From the above check sheet we can see that the no. of occurrence of defect Gloss/Colour Variation is reduced. There will also be decrease in some other defects as correcting one will also have impact on others. Now we will draw the P-chart to check whether the process is still in control or not.

Construction of P-chart

Day	Total Inspected Units	Defectives	Proportion (ρ)	CL (p̄)	UCL 3	LCL 3	UCL 2	LCL 2	UCL 1	LCL 1
1	436	14	0.032110	0.038647	0.066341	0.010954	0.057110	0.020185	0.047879	0.029416
2	415	11	0.026506	0.038647	0.067033	0.010262	0.057571	0.019724	0.048109	0.029185
3	435	19	0.043678	0.038647	0.066373	0.010922	0.057131	0.020164	0.047889	0.029406
4	412	14	0.033981	0.038647	0.067136	0.010159	0.057640	0.019655	0.048144	0.029151
5	440	17	0.038636	0.038647	0.066215	0.011080	0.057026	0.020269	0.047836	0.029458
6	431	11	0.025522	0.038647	0.066501	0.010794	0.057217	0.020078	0.047932	0.029363
7	420	15	0.035714	0.038647	0.066863	0.010431	0.057458	0.019837	0.048053	0.029242
8	429	16	0.037296	0.038647	0.066566	0.010729	0.057260	0.020035	0.047954	0.029341
9	413	12	0.029056	0.038647	0.067102	0.010193	0.057617	0.019678	0.048132	0.029163
10	416	17	0.040865	0.038647	0.066999	0.010296	0.057548	0.019746	0.048098	0.029197
11	426	14	0.032864	0.038647	0.066664	0.010631	0.057325	0.019970	0.047986	0.029308
12	414	16	0.038647	0.038647	0.067067	0.010227	0.057594	0.019701	0.048121	0.029174
Total	**5087**	**176**								

Plotting the p-chart with the Upper Control Limit (UCL 3: implying above 3 standard deviations off mean) and Lower Control Limit (LCL 3: implying below 3 standard deviations off mean).



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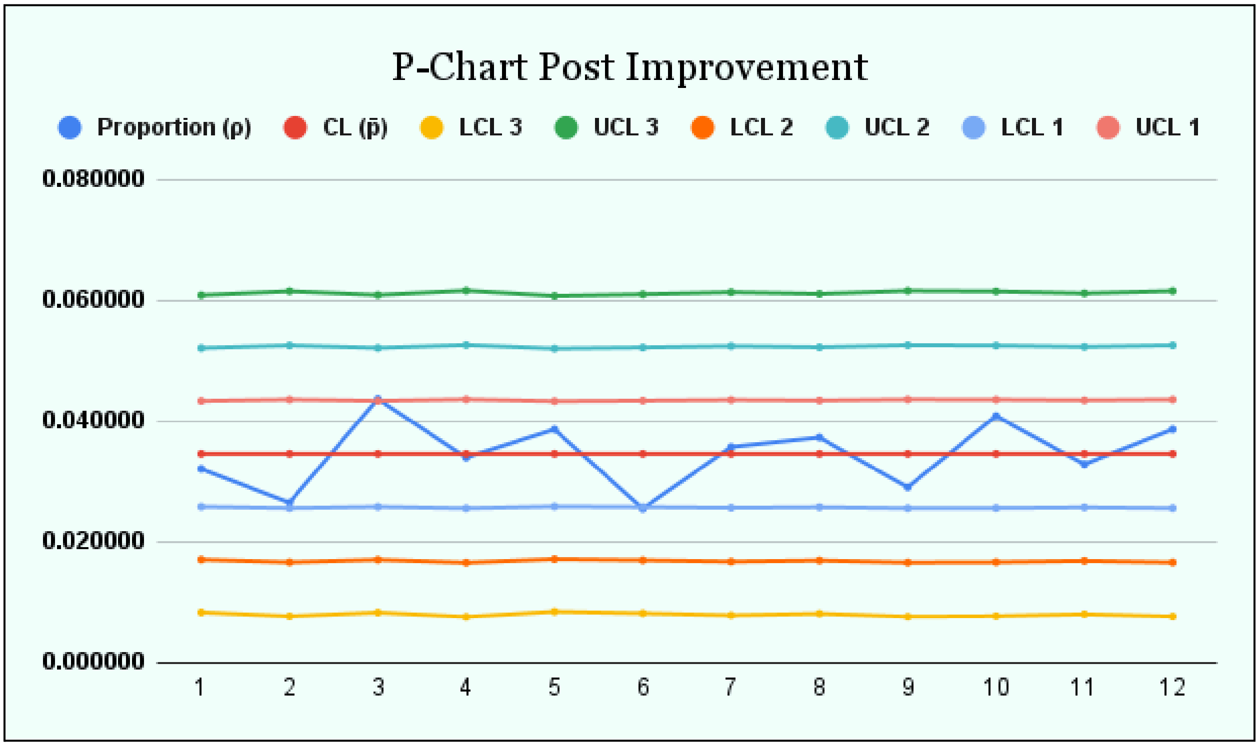
*P-Chart with all Control Limits (1**σ**, 2**σ**, 3**σ**):*



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Now we will calculate the Sigma Level. The baseline sigma level of the process is estimated with the help of DPMO (Defects per Million opportunities) where opportunities refer to the number of ways in which defect can occur. This process of Pressure Die Casting has 5 defects. Hence there are 5 ways in which defect can occur.

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- DPU= defectives/inspected
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- Yield = (1-DPO)*100
- Sigma = NORMSINV((1-DPO))+1.5 *(in Excel)*

Sigma Level is calculated using the table below (Six Sigma Conversion Table):

Six Sigma Conversion Table

Yield	DPMO	Sigma	Yield	DPMO	Sigma	Yield	DPMO	Sigma
6.6%	**934,000**	**0**	**69.2%**	**308,000**	**2**	**99.4%**	**6,210**	**4**
8.0%	920,000	0.1	72.6%	274,000	2.1	99.5%	4,660	4.1
10.0%	900,000	0.2	75.8%	242,000	2.2	99.7%	3,460	4.2
12.0%	880,000	0.3	78.8%	212,000	2.3	99.75%	2,550	4.3
14.0%	860,000	0.4	81.6%	184,000	2.4	99.81%	1,860	4.4
16.0%	840,000	0.5	84.2%	158,000	2.5	99.87%	1,350	4.5
19.0%	810,000	0.6	86.5%	135,000	2.6	99.90%	960	4.6
22.0%	780,000	0.7	88.5%	115,000	2.7	99.93%	680	4.7
25.0%	750,000	0.8	90.3%	96,800	2.8	99.95%	480	4.8
28.0%	720,000	0.9	91.9%	80,800	2.9	99.97%	330	4.9
31.0%	**690,000**	**1**	**93.3%**	**66,800**	**3**	**99.977%**	**230**	**5**
35.0%	650,000	1.1	94.5%	54,800	3.1	99.985%	150	5.1
39.0%	610,000	1.2	95.5%	44,600	3.2	99.990%	100	5.2
43.0%	570,000	1.3	96.4%	35,900	3.3	99.993%	70	5.3
46.0%	540,000	1.4	97.1%	28,700	3.4	99.996%	40	5.4
50.0%	500,000	1.5	97.7%	22,700	3.5	99.997%	30	5.5
54.0%	460,000	1.6	98.2%	17,800	3.6	99.9980%	20	5.6
58.0%	420,000	1.7	98.6%	13,900	3.7	99.9990%	10	5.7
61.8%	382,000	1.8	98.9%	10,700	3.8	99.9992%	8	5.8
65.6%	344,000	1.9	99.2%	8,190	3.9	99.9995%	5	5.9
						99.99966%	**3.4**	**6**

Defectives	176
Opportunities	4
Total Units	5087
Total Opportunities	20348
DPU	0.03459799489
DPO	0.008649498722
DPMO	8649.498722
Yield	99.13505013
Sigma Value	3.880290439

An implementation of the suggestions was done to the process and studied for a period of 12 days. The sigma level showed an improvement from 3.5839 to 3.8802 and the defects arising due to Cratering and Gloss/Colour Variation were decreased; this may be a more optimistic picture in the reality. Thus, in control the process with improvements is maintained and standardized.

Conclusion

As observed in the previous process-wise analysis, we know that the sigma level i.e. the performance level of all the processes improved significantly after implementing the suggested measures which led to the reduction of the frequencies of various defects and thus ultimately the frequencies of defectives in each process.

The results can be summarized as:

Process	σ level Pre Analysis	σ level Post Analysis
Stage 1	3.6019	4.0611
Stage 2	3.5794	4.1575
Stage 3	3.5839	3.8805
Overall	**3.5884**	**4.0330**

Also, there is significant decrease in number of defects.

Thus, there is significant improvement of process performance level and as all the manufacturing firm desire, the process is moving towards achieving even higher sigma levels. Also, these results may improve as the process settles down in long term observations.

Also, the company was aiming to achieve a sigma level greater than or equal to 4 which has been achieved here, but as mentioned, this result may get improved as the process gets standardized with due course of time.

References

a) Total Quality Management-2nd Edition Poornima M. Charantimath Publisher PEARSON

b) Statistical quality control by DOUGLAS C. MONTGOMERY

c) Research Paper by: Anshu Gupta, Pallavi Sharma, S. C. Malik, Neha Agarwal and P. C. Jha :"Productivity Improvement in the Chassis Preparation Stage of the Amplifier Production Process: A DMAIC Six Sigma Methodology" November 2016

d) Research Paper by: Anshu Gupta, Pallavi Sharma, S. C. Malik and P. C. Jha : "A DMAIC Six Sigma approach to quality improvement in the final stage of the amplifier production process"

e) An integrated DEMATEL Six Sigma hybrid framework for manufacturing process improvement Anshu Gupta1 · Pallavi Sharma2 · Akansha Jain3 · Hongbo Xue4 · S. C. Malik2 · P. C. Jha3

f) Online Search Engine www.google.com

g) Online Content Site www.wikipedia.com

h) C. L. Gupta Exports Ltd. : https://clgupta.com/home/