Roll no. - 21291761036

Project report

on

"PROCESS QUALITY MANAGEMENT"

undertaken at

JAY AAY ALLOYS Pvt. Ltd.

submitted by

SAHIL NASA

as an

Assignment

To

Department of Operational Research

Faculty of Mathematical Sciences

New Academic Block

University of Delhi

Delhi – 110007

Table of Contents

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 OR

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.

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 ensured 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.

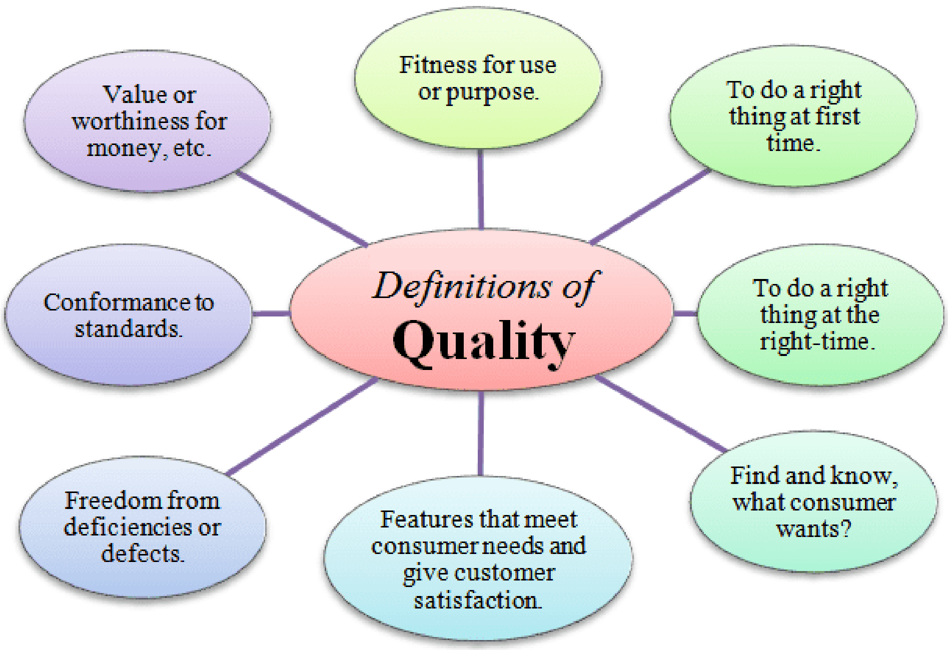
"Quality is not an art, it is a habit."

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



Customer driven definition of Quality

- **<u>Value for price paid</u>**: Quality is defined in terms of the utility of the product or service for the price paid.
- **<u>Support services</u>**: Quality is defined in terms of the support provided after the product or service is purchased.
- **<u>Psychological criteria</u>**: A way of defining quality that focuses on judgemental evaluations of what constitutes product or service excellence.

<u>Garvin's Approaches to Defining Quality</u>

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". M01_TOTAL-QUALITY-M03_SE_XXXX_CH01.indd 4 11/10/2016 2:24:12 PM Quality Concepts 5 philosophical debate. 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. **The 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.

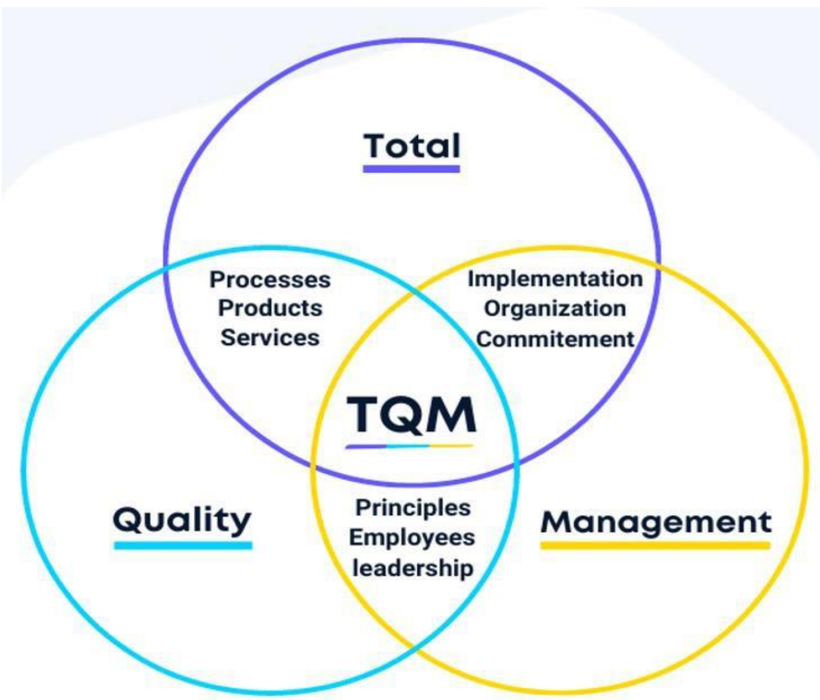
6. **Features**

(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 no

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

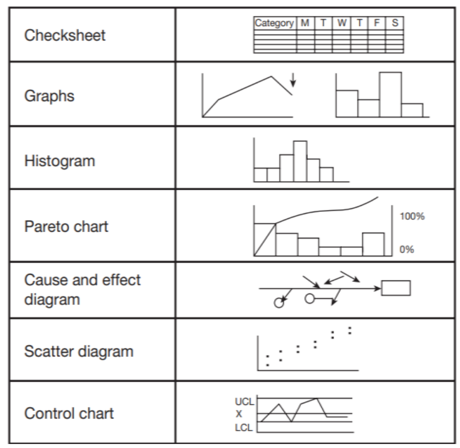
The benefits arising from the implementation of a Total Quality Management in an organization are:

• 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

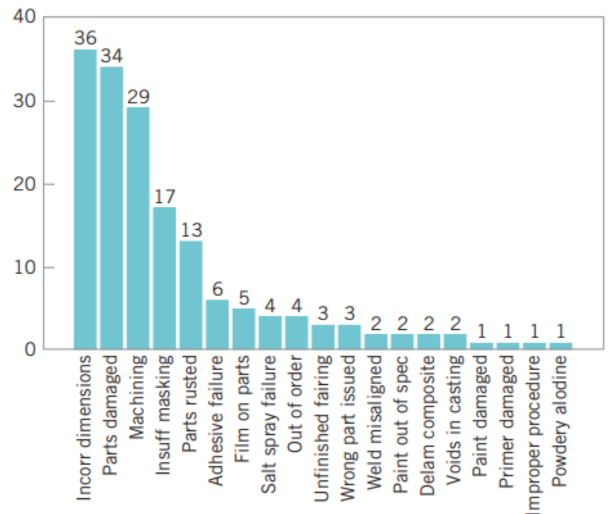
6. Control charts

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.

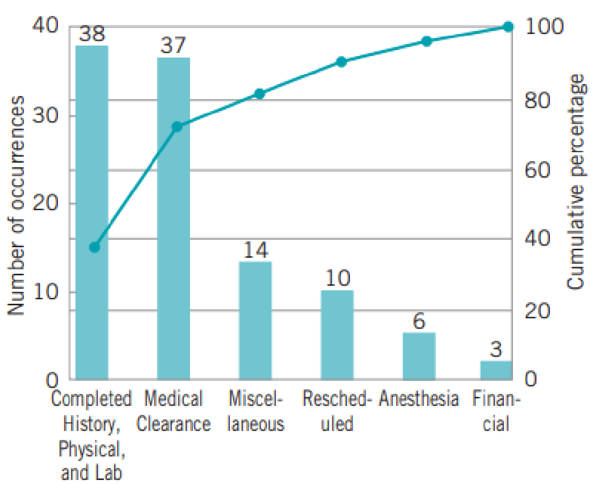
5. Add a cumulative percentage column to the table.

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.

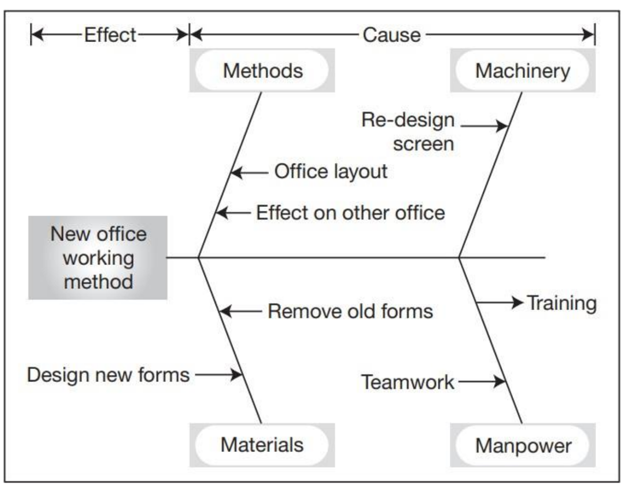
2. Identify the major cause categories and write them in the four boxes on the cause and-effect diagram. The causes may be summarized under various categories.

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.

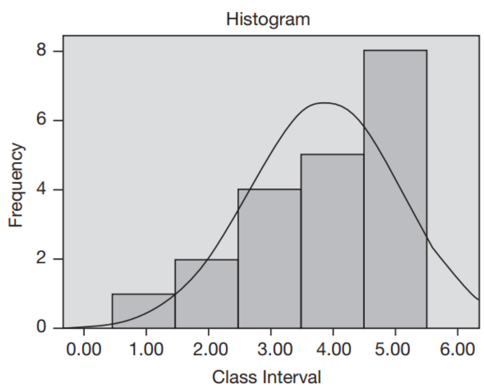
Telephone Interruptions

Reason	Day					
	Mon	Tue	Wed	Thu	Fri	Total
Wrong number	𝍸	||	|	𝍸	𝍸 ||	20
Info request	||	||	||	||	||	10
Boss	𝍸	||	𝍸 ||	|	||||	19
Total	12	6	10	8	13	49

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:

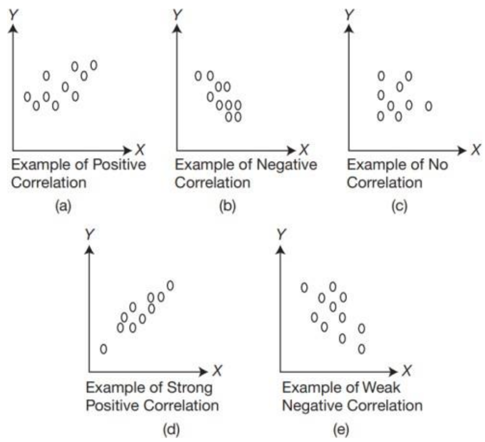
1. Collect data on causes and effects for variables

2. Draw the causes on the X–axis

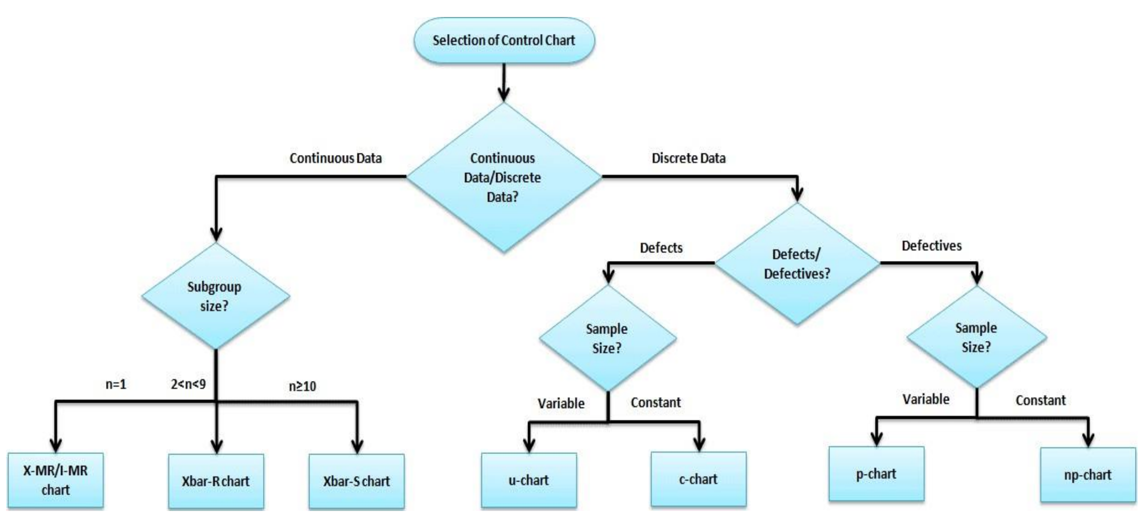
3. Draw the effect on the Y–axis

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



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.

Types of control charts

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 $\hat{p}(i)$ = 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 $\bar{p}$; there are k subgroups:

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

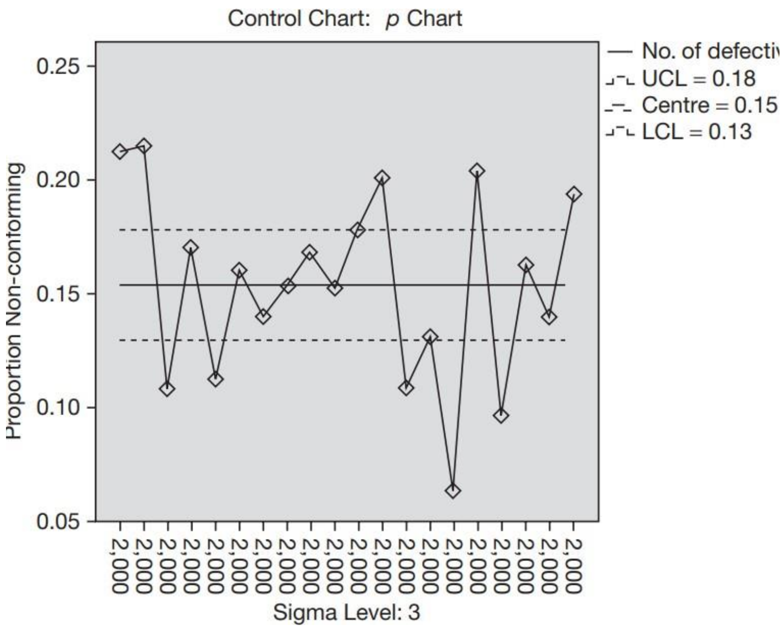
5. Estimate $\hat{\sigma}_p$ if needed and determine the UCL and LCL:

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

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

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-chart (chart for defects)

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 $u(i) = c(i)/n(i)$
3. Determine the central line of the u chart:

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

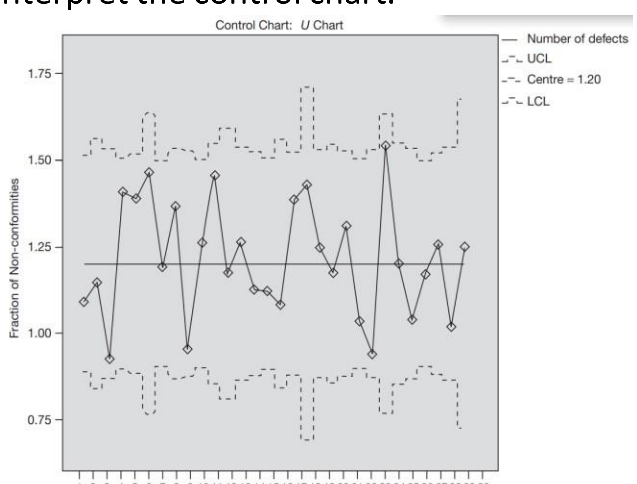
$$\bar{u} = \frac{c_1 + c_2 + \cdots + c_k}{n_1 + n_2 + \cdots + n_k}$$

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

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

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

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



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 item.

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

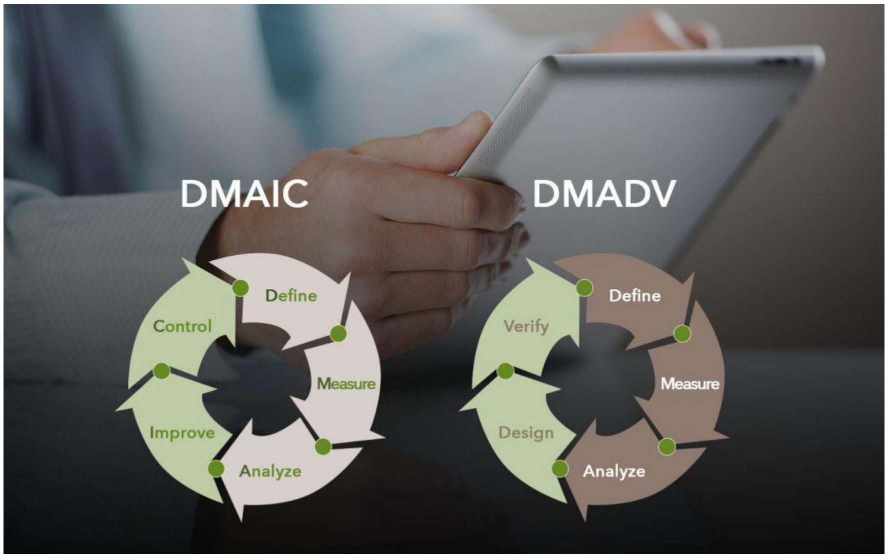
DEFECTS PER MILLION OPPORTUNITES (DPMO)

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.

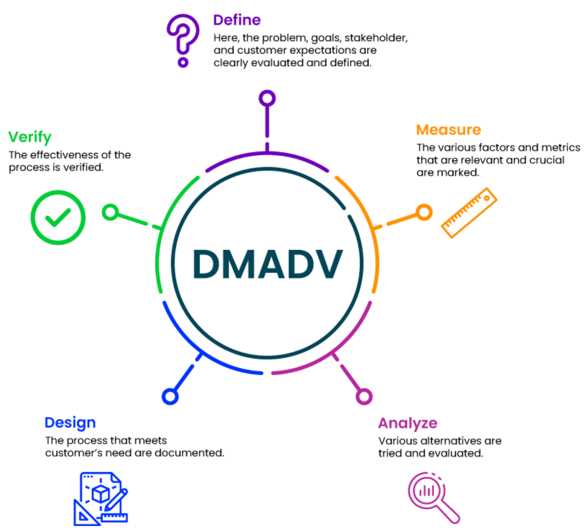
Measure key aspects of the current process and collect relevant data; calculate the 'as-is' Process Capability. We measure the existing system. Establish valid and reliable metrics to help monitor progress towards the goal(s) defined in the previous step. Begin by determining the current baseline. Use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

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. Matrix formulation:-

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, $w = [w_1, w_2, \ldots\ldots, w_n]$, 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:

JAY AAY ALLOYS PVT. LTD.

JAY AAY ALLOYS(P) LIMITED

Jay Aay Alloys Private Limited is a Private incorporated on 07 February 2003. It is classified as Non-govt company and is registered at Registrar of Companies, Himachal Pradesh. Its authorized share capital is Rs. 30,000,000 and its paid up capital is Rs. 30,000,000. It is involved in Manufacture of Basic Iron & Steel.

Jay Aay Alloys Private Limited's Annual General Meeting (AGM) was last held on 30 November 2021 and as per records from Ministry of Corporate Affairs (MCA), its balance sheet was last filed on 31 March 2021.

We have established an efficient process for the production of ERW pipes which involves the process of uncoiling, welding, levelling, trimming, accumulation, roll forming, electric resistance welding, extrusion , straightening and flying cutting.

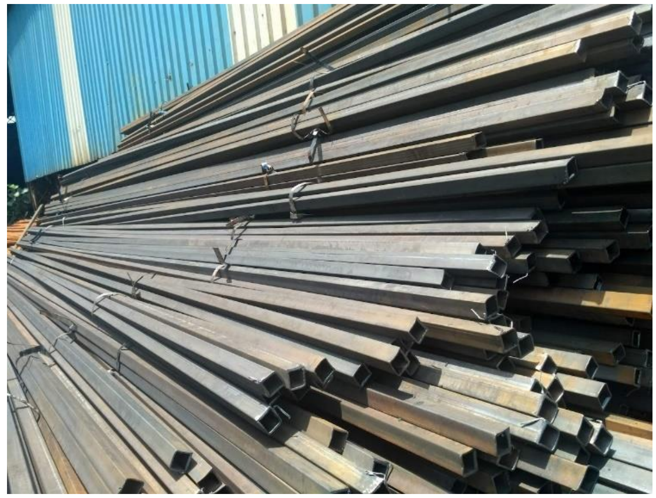
As the manufacturing of ERW pipes requires HR coil strip as a raw material and the production of HR coil strip is itself takes place in the company from the billet and the billet is also manufactured in the company by the help of scrap.

They take scrap from almost all states in North India.

They sell various sizes and shapes of pipes and along with that they also sell billets and HR coil strip according to the demand of the customer.

HR coil strip

Billets

Cuboidal shaped MS pipes

- **Mission**: Our Mission is to provide total customer satisfaction and continual improvement to our products quality to meet customers' expectations.
- **Values**: How we accomplish our mission is as important as the mission itself. Fundamentals to success for JAY AAY ALLOYS are these basic values.
- **Product:** Our products are replicas of all our systems and practices followed and exceed the customer's expectation.
- **Vision:** To achieve world class standards in Quality of Products, Services and Huma Resource.
- **People:** Our People are the source of our strength. They provide our corporate intelligence and determine our reputation and vitality, involvement and teamwork.
- **Services:** Our committed and prompt services shall be focused on customer's expectation.

Other details regarding JAY AAY ALLOYS(P) LIMITED

Address	TARLOKPUR ROAD, KALA AMB,DISTT.SIRMAUR, PRADEDH. HP 173030 **Company's location:https://www.zaubacorp.com/company-map/JAY-AAY-ALLOYS-PRIVATE-LIMITED/U27106HP2002PTC025783/India**
TEL	91-9810259565
Activity	Manufacture of Basic Iron & Steel Click here to see other companies involved in same activity.
Company Subcategory	Non-govt company
Age of company	20 years, 3 months
CIN	U27106HP2002PTC025783
Company status	Active
Class of company	Private

Certifications

ISO 9001 Certified

Problem Definition

JAY AAY ALLOYS(P) LIMITED is one of the company engaged in service for making the product billets, hr coil strip and different size and shape pipes. They are using their standard process used to manufacture the MS pipes. JAY AAY ALLOYS is manufacturing **cuboidal** shape MS pipe with dimension **20ft long, 3inch width, 1inch height and 2.6mm thick** and these type of pipe is having major defects of irregular surfacing, irregular edges, rusting, indentation(dent) etc. so that's why we are focusing on improving the process control of manufacturing the cuboidal pipes.

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 cuboidal shaped pipe**, 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. This is a **first-time quality check** method. Hence, rework and scrap are taken as defectives. 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. **JAY AAY ALLOYS(P) LIMITED** want the sigma level of their product nearly **equal or greater than 4.0.**

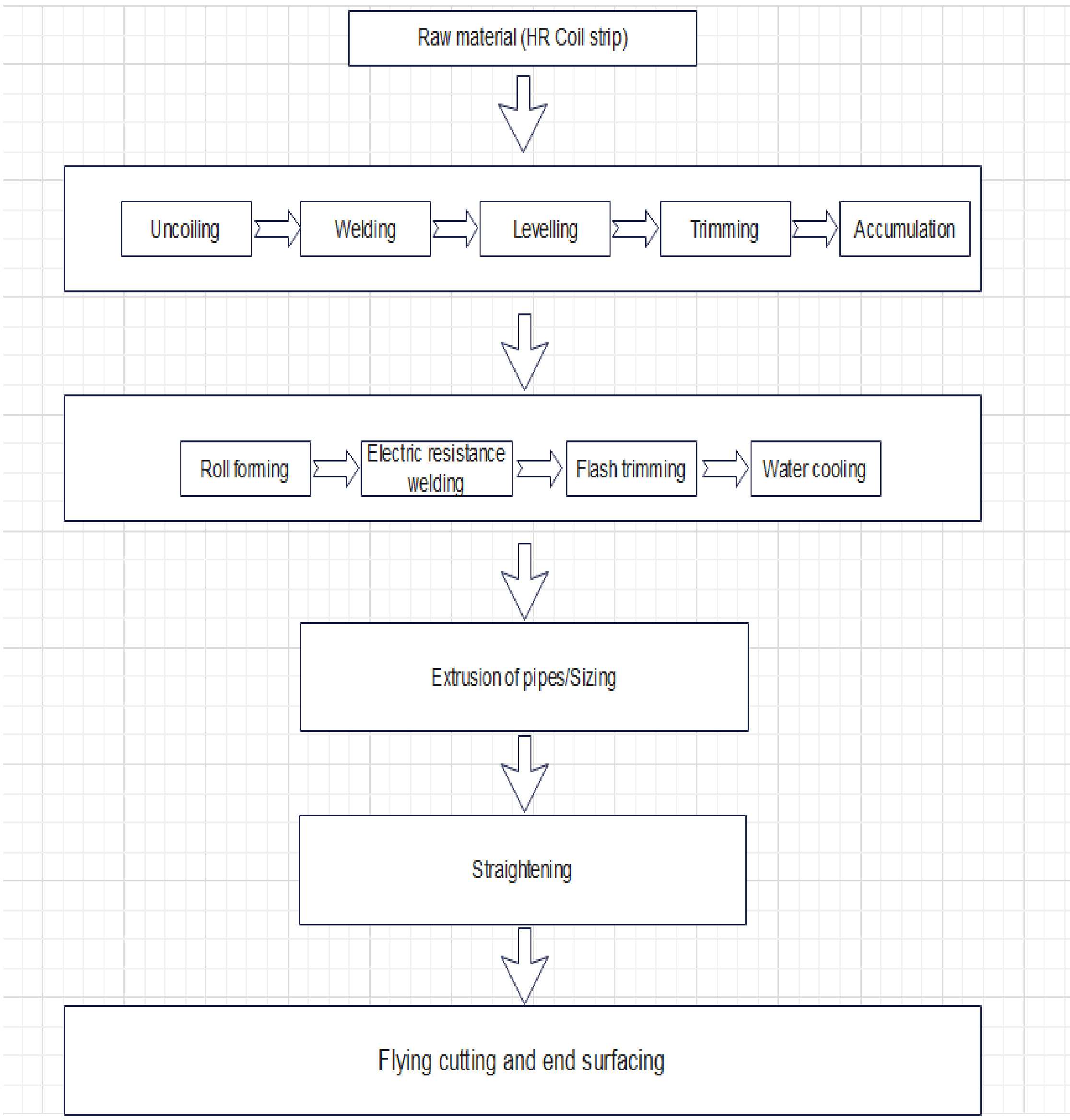
This project mainly focused on six sigma quality philosophy and other related philosophy that would be implemented in these studies in order to identify the current problem or rejection criteria facing by the company. The "**Six Sigma**" DMAIC Model is used because, it provides a step-by-step quality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

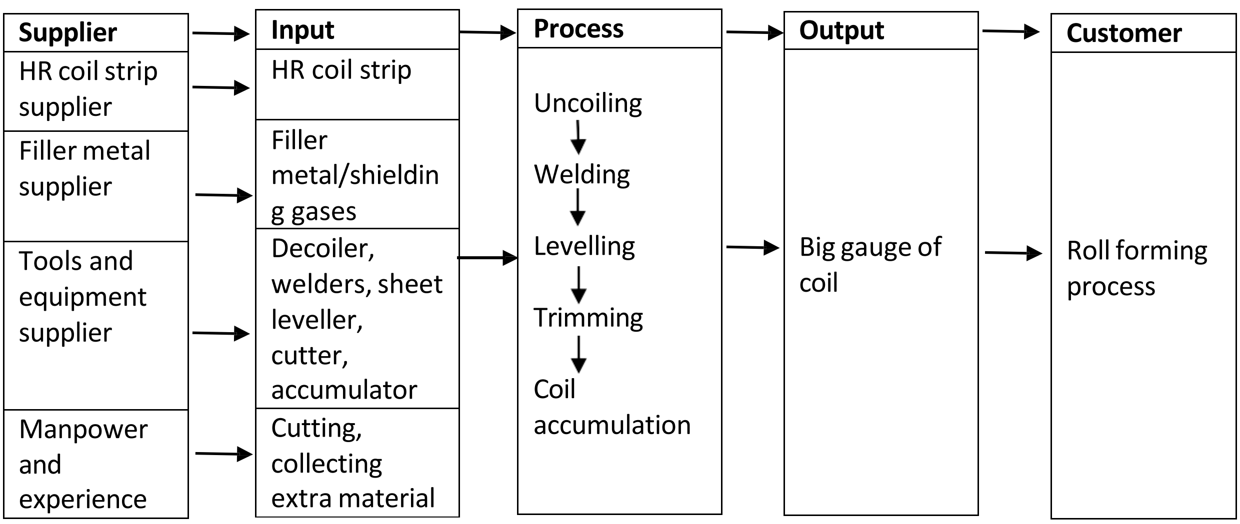
Stage 1

DEFINE

Stage 1 comprises of five process welding, uncoiling, levelling, trimming and accumulation. Firstly, they will uncoil the HR coil strip and then they weld the number of HR coil strip by the help of welding and then level that strip if there is some bulges in the strip and then remove the extra material by the trimming process and then accumulate the welded strip in to big coil gauge.

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

a) 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

b) Defects in the various process of Stage 1 which are identified by the company are:

- **Solid Inclusion**

- **Overlapping**

- **Spattering**

- **Undercutting**

- **Porosity/Blow holes**

- **Lack of penetration**

- **Distortion in the coil**

c) Project Charter

Helps in defining the problem, setting up the project team and time-line, defining responsibilities and roles to the team members and stating the desired outputs that can be synchronized with the business demand and customer's requirements.

Project Charter	
Project Title: Defect reduction in stage 1 which involves **welding, uncoiling, levelling, trimming and accumulation process**.	
Project objective and goal: To reduce the **porosity/blow holes and lack of penetration** defect in the mentioned processes of stage 1	
Project location: JAY AAY Alloys(P) Limited an ERW pipe manufacturing facility near Panchkula, India	
Background and Rational for project selection:	
In the baseline process, Prioritize the defects in which **Porosity/blow holes and lack of penetration** 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
	Floor operator
Expected benefits: Reduction in the defects due to **porosity/blow holes and lack of penetration** which would lead to cost benefits.	
Project plan: Application of DMAIC model of Six-Sigma	
Project timeline: Four months	

Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the seven defects identified in the define stage is established, followed by defect prioritization with the help of pareto chart.

Process specifications are followed to inspect the items with defects. As we are dealing with the continuous material so we are collecting the data of defects in 1 sq. ft. area which is considered as one unit to be inspected. There is also the possibility that one type of defect is present more than once in 1 unit so with the help of company's quality team we also record how many maximum no. of

Defects	Distortion	Solid Inclusion	Overlapping	Spattering	Undercutting	Porosity/Blow holes	Lack of Penetration
No. of Defects in 1 sq. ft	2	1	2	1	1	2	3

opportunity of a particular defect is possible shown in table 1.1

The process output is sampled for 13 days and 25 data points are collected as JAY AAY ALLOY works in 2 shifts. In total, 7177.3 units are observed in 13 days were recorded using check sheets and the data is collected at different times in one shift.

To check whether process is in control or not, u-chart that resulted into identification of 471 defects. The sampling data charts for fraction defects are drawn.

Di/Sj denotes the number of defects at day i in shift j where j=1,2

a) Check sheet for Pre-Analysis

Defects\Shifts	Distortion	Solid Inclusion	Overlapping	Spattering	Undercutting	Porosity/Blow holes	Lack of Penetration	Total Defects(c(i))	Total Inspected Units(n(i))
D1/S1	2	0	1	1	0	11	12	27	399.6
D1/S2	3	0	1	1	1	13	9	28	336.33
D2/S1	2	0	2	0	1	15	10	30	366.3
D2/S2	3	0	2	0	2	13	9	29	399.6
D3/S1	1	1	0	0	0	6	7	15	316.35
D3/S2	4	0	0	1	2	8	7	22	323.6
D4/S1	0	1	1	1	3	8	9	23	257.07
D4/S2	0	1	2	0	2	14	9	28	349.6
D5/S1	3	1	0	0	3	7	5	19	317
D5/S2	1	0	1	2	1	13	4	22	399.6
D6/S1	2	2	0	0	1	12	4	21	233.1
D6/S2	0	0	0	1	0	8	3	12	206.46
D7/S1	0	0	0	0	0	5	5	10	206.46
D7/S2	2	1	1	0	0	12	8	24	283.71
D8/S1	3	1	0	1	0	4	2	11	233.1
D8/S2	1	2	0	2	0	7	6	18	288.3

D9/S1	0	2	1	2	1	2	7	15	233.1
D9/S2	1	3	0	1	1	2	3	11	216.45
D10/S1	0	2	0	0	1	6	4	13	253.08
D10/S2	0	0	3	1	1	2	5	12	259.74
D11/S1	1	0	2	3	0	4	6	16	259.74
D11/S2	1	0	2	1	0	11	6	21	253.08
D12/S1	0	0	1	2	0	12	2	17	316.35
D12/S2	1	0	1	1	1	4	3	11	253.08
D13/S1	1	0	0	1	0	8	6	16	216.45
Total	32	17	21	22	21	207	151	471	7177.3

From the above table we can see that we have total inspected 7177.3 units where 1 unit is 1 sq. ft. area and total no. of defects are 471.

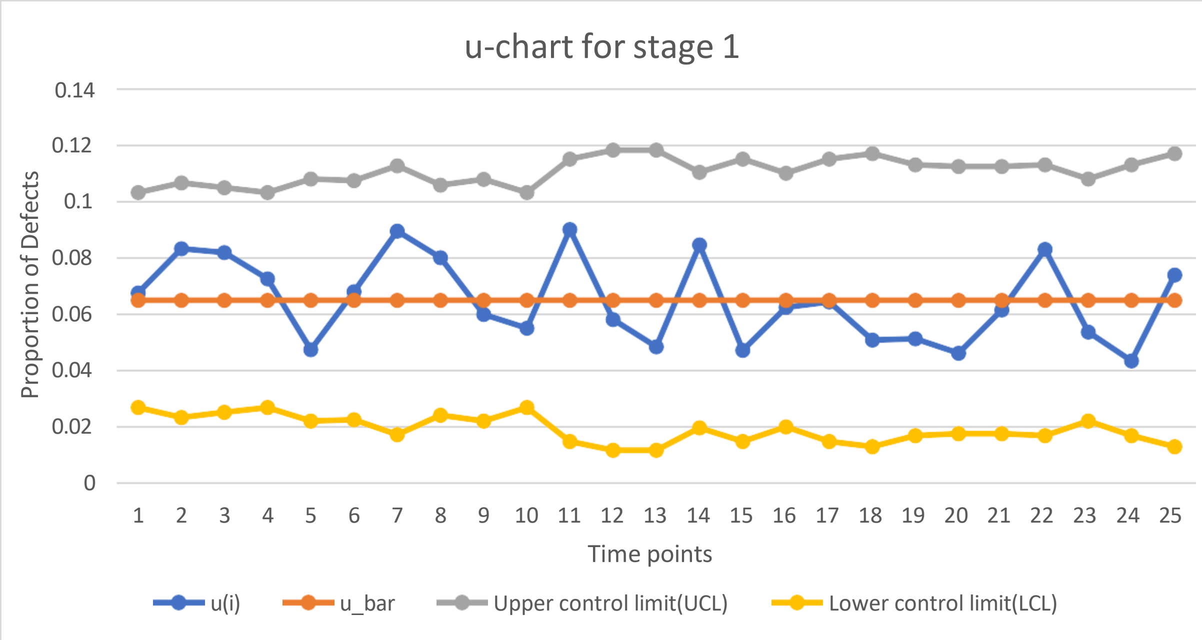
Now we will plot the u-chart

b) Construction of u-chart

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

Defects\Shifts	Total Defects(c(i))	Total Inspected Units(n(i))	u(i)	u_bar	Upper control limit(UCL)	Lower control limit(LCL)
D1/S1	27	399.6	0.067568	0.064982	0.103239	0.026726
D1/S2	28	336.33	0.083252	0.064982	0.106682	0.023282
D2/S1	30	366.3	0.0819	0.064982	0.10494	0.025024
D2/S2	29	399.6	0.072573	0.064982	0.103239	0.026726
D3/S1	15	316.35	0.047416	0.064982	0.107979	0.021985
D3/S2	22	323.6	0.067985	0.064982	0.107494	0.02247
D4/S1	23	257.07	0.08947	0.064982	0.112679	0.017285
D4/S2	28	349.6	0.080092	0.064982	0.105883	0.024081
D5/S1	19	317	0.059937	0.064982	0.107934	0.02203
D5/S2	22	399.6	0.055055	0.064982	0.103239	0.026726
D6/S1	21	233.1	0.09009	0.064982	0.115072	0.014893
D6/S2	12	206.46	0.058123	0.064982	0.118205	0.011759
D7/S1	10	206.46	0.048436	0.064982	0.118205	0.011759
D7/S2	24	283.71	0.084593	0.064982	0.110385	0.019579
D8/S1	11	233.1	0.04719	0.064982	0.115072	0.014893
D8/S2	18	288.3	0.062435	0.064982	0.110022	0.019942
D9/S1	15	233.1	0.06435	0.064982	0.115072	0.014893
D9/S2	11	216.45	0.05082	0.064982	0.116962	0.013002
D10/S1	13	253.08	0.051367	0.064982	0.113054	0.01691
D10/S2	12	259.74	0.0462	0.064982	0.112433	0.017531
D11/S1	16	259.74	0.0616	0.064982	0.112433	0.017531
D11/S2	21	253.08	0.082978	0.064982	0.113054	0.01691
D12/S1	17	316.35	0.053738	0.064982	0.107979	0.021985
D12/S2	11	253.08	0.043465	0.064982	0.113054	0.01691
D13/S1	16	216.45	0.07392	0.064982	0.116962	0.013002

c) u-chart



From the u-chart it is clearly visible that the process is operating statistical control because the only reason of variation is by chance cause.

From control chart it is only clear that our process is consistent to check whether our process is producing products with less defects we need to calculate the sigma level.

The baseline sigma level of the process is estimated by the help of DPMO (defects per million opportunities)

Total number of opportunities we calculate from table 1.1

Total number of defects	471
Total no. of opportunities	12
Total inspected units	7177.3

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table given below:

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	5468.86
Sigma level	4.04

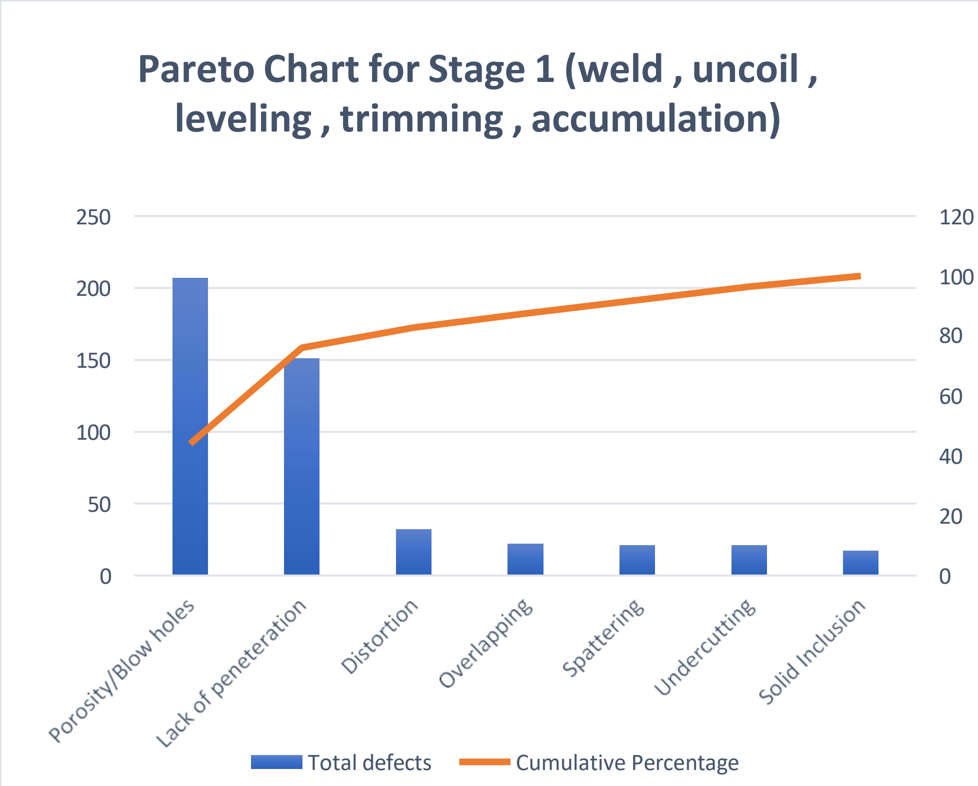
As we can see the sigma level of this stage is 4.04 which means that we can work on some defects to reduce them so that sigma level improves.

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.

DEFECTS	Total defects		Cumulative Defects		Cumulative Percentage
Porosity/Blow holes	207		207		43.949
Lack of penetration	151		358		76.008
Distortion	32		390		82.803
Overlapping	22		412		87.473
Spattering	21		433		91.932
Undercutting	21		454		96.391
Solid Inclusion	17		471		100

a) **Pareto chart**



We can see from the pareto chart that elbow is forming at the defect 'lack of penetration'. Therefore, we need to work upon two defects which are **Porosity** and **Lack of penetration.**

So, now we will work on these two defects to improve the sigma level**.**

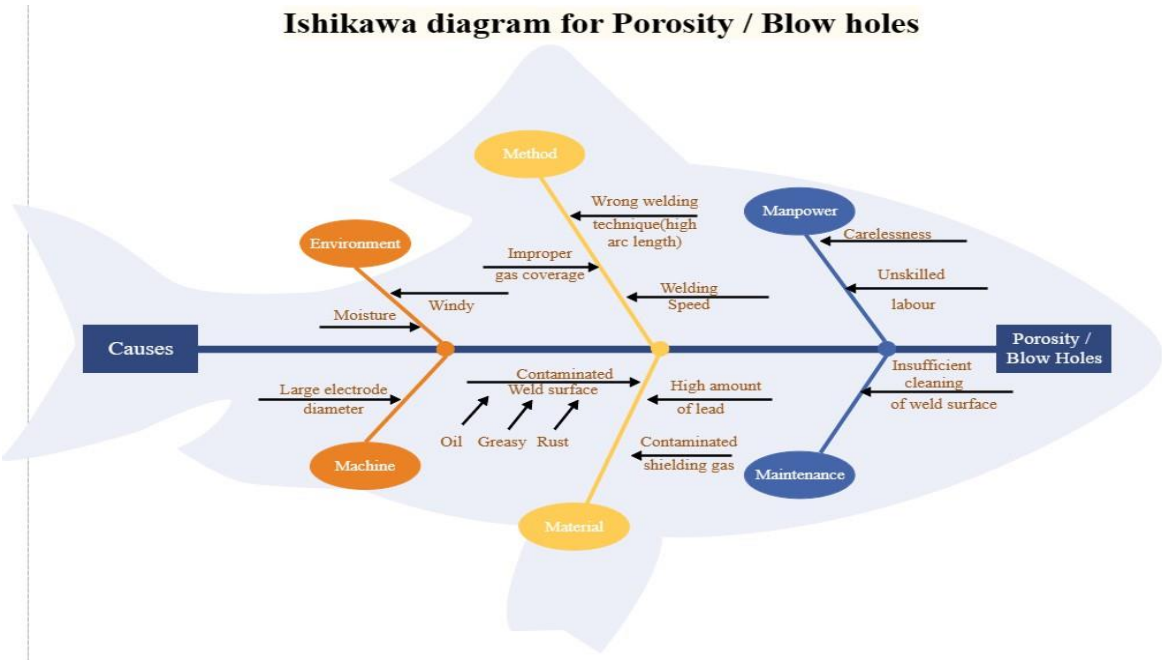
Cause & Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in six generic categories was prepared as shown

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 Diagram</u>**

- **Cause and Effect for Porosity/Blow holes**

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



-

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

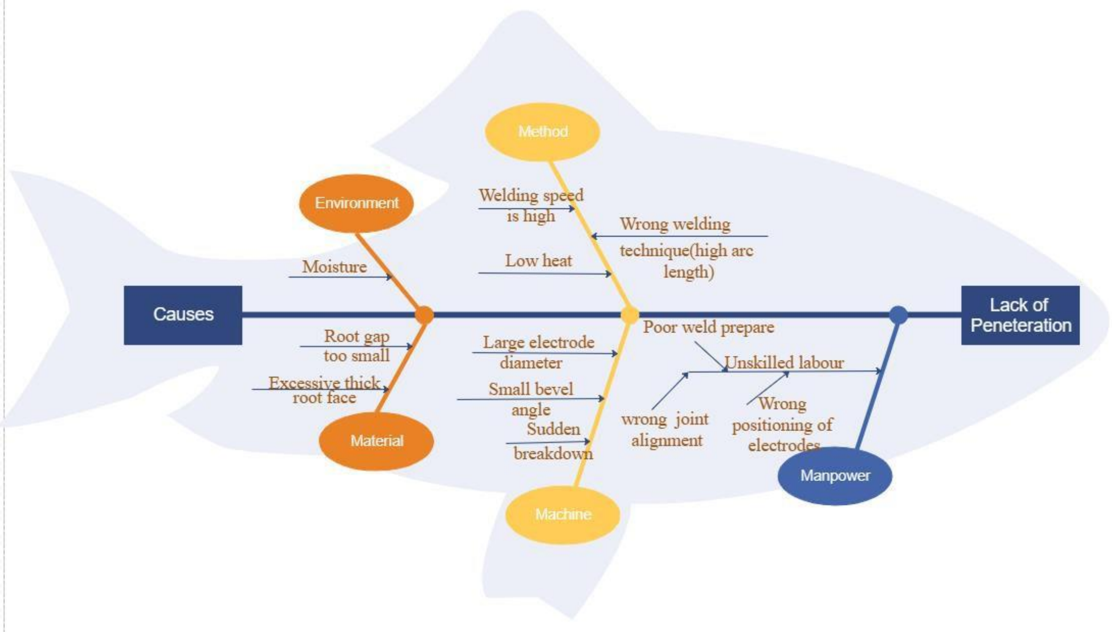
<u>Corrective measures to reduce Porosity defect:</u>

i. Proper cleaning of the weld surface.
ii. Material should not be contaminated with oil, grease also taking care of the contaminated shielding gas.
iii. In material there should not be hight amount of lead.
iv. Welding speed should not be very high.
v. Diameter of electrode used should not be large.

- **Cause and Effect diagram for Lack of penetration**

  Fishbone diagram of Lack of penetration categorize the causes into 5 categories as shown below

Ishikawa diagram for Lack of peneteration



The causes listed above for Lack of penetration and independent of each other therefore we can suggest the improvement directly to improve the sigma level

<u>Corrective measures to reduce Porosity defect:</u>

i. Bevel angle should be small.
ii. Electrode of the diameter should not be large.
iii. Material does not have excessive thick root face and root gap is not very small.
iv. Labour should be skilled properly so that they will prepare proper weld, do the right joint alignment and positioning of electrodes.
v. Welding speed should not be very high.
vi. Heat should not be very low.
vii. Correct welding technique to be used.

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 Porosity and then of Lack of penetration.

IMPROVEMENT

a) Improvement of Porosity:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

Check sheet for improving Porosity

Defects\Shifts	Distortion	Solid Inclusion	Overlapping	Spattering	Undercutting	Porosity/Blow holes	Lack of Penetration	Total Defects(c(i))	Total Inspected Units(n(i))
D1/S1	2	0	1	1	0	2	15	21	399.6
D1/S2	1	0	1	1	1	1	9	14	336.33
D2/S1	1	0	1	0	1	0	8	11	366.3
D2/S2	2	0	2	0	2	3	9	18	399.6
D3/S1	1	1	0	0	0	2	9	13	316.35
D3/S2	2	0	0	1	1	4	7	15	323.6
D4/S1	0	1	1	1	0	0	9	12	399.6
D4/S2	0	1	1	0	2	3	9	16	349.6
D5/S1	1	1	0	0	3	2	5	12	317
D5/S2	1	0	1	0	1	4	4	11	399.6

D6/S1	1	1	0	0	1	3	4	10	233.1
D6/S2	0	0	0	1	0	2	3	6	366.3
D7/S1	0	0	0	0	0	1	5	6	206.46
D7/S2	2	1	1	0	0	1	8	13	283.71
D8/S1	2	0	0	1	0	0	2	5	399.6
Total	16	6	9	6	12	28	106	183	5096.75

From the above check sheet we can see that the no. of occurrence of defect Porosity is reduced. There will also be decrease in some other defects as most of the defects are occurring because of welding. So, correcting one will also have impact on others.

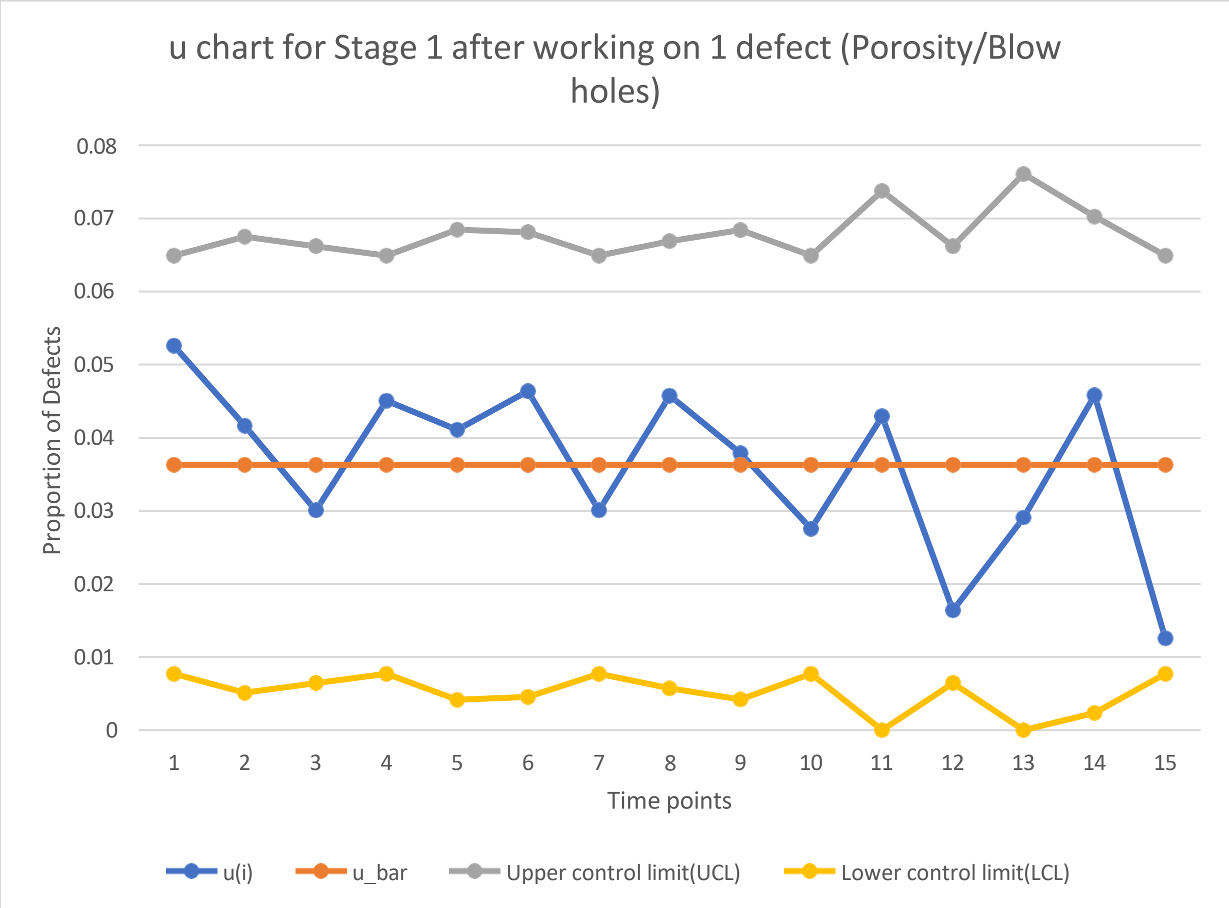
Now we will draw the u-chart to check whether the process is still in control or not.

Construction of u-chart

Defects\Shifts	Total Defects(c(i))	Total Inspected Units(n(i))	u(i)	u_bar	Upper control limit(UCL)	Lower control limit(LCL)
D1/S1	21	399.6	0.052553	0.036304	0.064898	0.007709
D1/S2	14	336.33	0.041626	0.036304	0.067472	0.005135

D2/S1	11	366.3	0.03003	0.036304	0.06617	0.006438
D2/S2	18	399.6	0.045045	0.036304	0.064898	0.007709
D3/S1	13	316.35	0.041094	0.036304	0.068441	0.004166
D3/S2	15	323.6	0.046354	0.036304	0.068079	0.004528
D4/S1	12	399.6	0.03003	0.036304	0.064898	0.007709
D4/S2	16	349.6	0.045767	0.036304	0.066875	0.005733
D5/S1	12	317	0.037855	0.036304	0.068408	0.004199
D5/S2	11	399.6	0.027528	0.036304	0.064898	0.007709
D6/S1	10	233.1	0.0429	0.036304	0.073743	0
D6/S2	6	366.3	0.01638	0.036304	0.06617	0.006438
D7/S1	6	206.46	0.029061	0.036304	0.076085	0
D7/S2	13	283.71	0.045821	0.036304	0.07024	0.002368
D8/S1	5	399.6	0.012513	0.036304	0.064898	0.007709

u-chart



u chart for Stage 1 after working on 1 defect (Porosity/Blow holes)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Proportion of Defects
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time points
u(i)
u_bar
Upper control limit(UCL)
Lower control limit(LCL)

As we can see from the above u chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not.

Total number of opportunities we calculate from table 1.1

Total number of defects	183
Total no. of opportunities	12
Total inspected units	5096.75

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	2124.84
Sigma level	4.36

As we can see by working on Porosity sigma level improves.

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

b) Improvement of Lack of penetration:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

Check sheet for improving Lack of penetration

Defects\Shifts	Distortion	Solid Inclusion	Overlapping	Spattering	Undercutting	Porosity/Blow holes	Lack of Penetration	Total Defects(c(i))	Total Inspected Units(n(i))
D1/S1	2	0	1	1	0	2	2	8	399.6
D1/S2	1	0	1	1	1	1	3	8	336.33
D2/S1	1	0	1	0	1	2	4	9	366.3
D2/S2	2	0	2	0	2	3	3	12	399.6
D3/S1	1	1	0	0	0	2	3	7	316.35
D3/S2	2	0	0	1	1	4	4	12	323.6
D4/S1	0	1	1	1	0	2	3	8	399.6
D4/S2	0	1	1	0	2	3	4	11	349.6
D5/S1	1	1	0	0	3	2	2	9	317
D5/S2	1	0	1	0	1	4	1	8	399.6
D6/S1	1	1	0	0	1	3	1	7	233.1
D6/S2	0	0	0	1	0	2	0	3	366.3
D7/S1	0	0	0	0	0	1	0	1	206.46

D7/S2	2	1	1	0	0	1	4	9	283.71
D8/S1	2	0	0	1	0	0	0	3	399.6
Total	16	6	9	6	12	32	34	115	5096.75

From the above check sheet we can see that the no. of occurrence of defect Porosity and Lack of penetration both are reduced. There will also be decrease in some other defects as most of the defects are occurring because of welding. So, correcting one will also have impact on others.

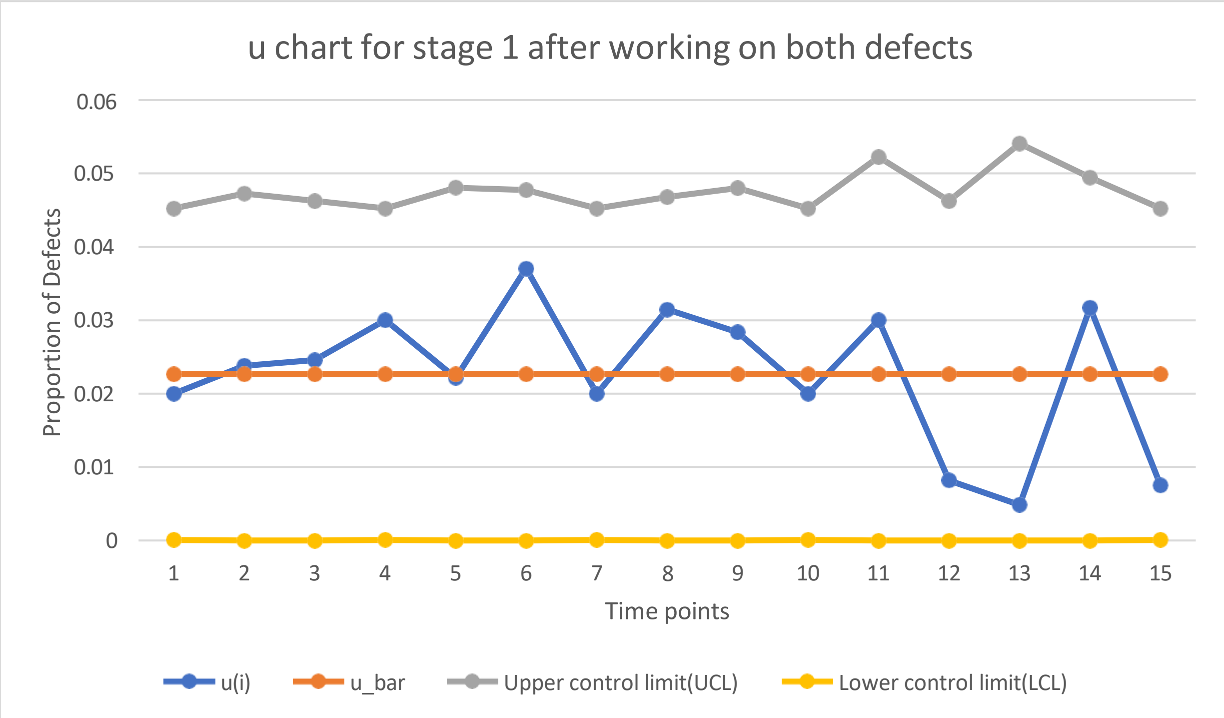
Now we will draw the u-chart to check whether the process is still in control or not.

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

Defects\Shifts	Total Defects(c(i))	Total Inspected Units(n(i))	u(i)	u_bar	Upper control limit(UCL)	Lower control limit(LCL)
D1/S1	8	399.6	0.02002	0.022654	0.045242	6.56945E-05
D1/S2	8	336.33	0.023786	0.022654	0.047275	0
D2/S1	9	366.3	0.02457	0.022654	0.046246	0
D2/S2	12	399.6	0.03003	0.022654	0.045242	6.56945E-05
D3/S1	7	316.35	0.022127	0.022654	0.04804	0
D3/S2	12	323.6	0.037083	0.022654	0.047754	0
D4/S1	8	399.6	0.02002	0.022654	0.045242	6.56945E-05
D4/S2	11	349.6	0.031465	0.022654	0.046803	0
D5/S1	9	317	0.028391	0.022654	0.048014	0
D5/S2	8	399.6	0.02002	0.022654	0.045242	6.56945E-

						05
D6/S1	7	233.1	0.03003	0.022654	0.052228	0
D6/S2	3	366.3	0.00819	0.022654	0.046246	0
D7/S1	1	206.46	0.004844	0.022654	0.054079	0
D7/S2	9	283.71	0.031723	0.022654	0.049461	0
D8/S1	3	399.6	0.007508	0.022654	0.045242	6.56945E-05

u-chart



As we can see from the above u chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not.

Total number of opportunities we calculate from table 1.1

Total number of defects	115
Total no. of opportunities	12
Total inspected units	5096.75

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	1880.56
Sigma level	4.4

An implementation of the suggestions was done to the process and studied for a period of 8 days. The sigma level showed an improvement from **4.04 to 4.4** and the defects arising due to **Porosity** and **Lack of penetration** were decreased; this may be a more optimistic picture in the reality. Thus, in control the process with improvements is maintained and standardized.

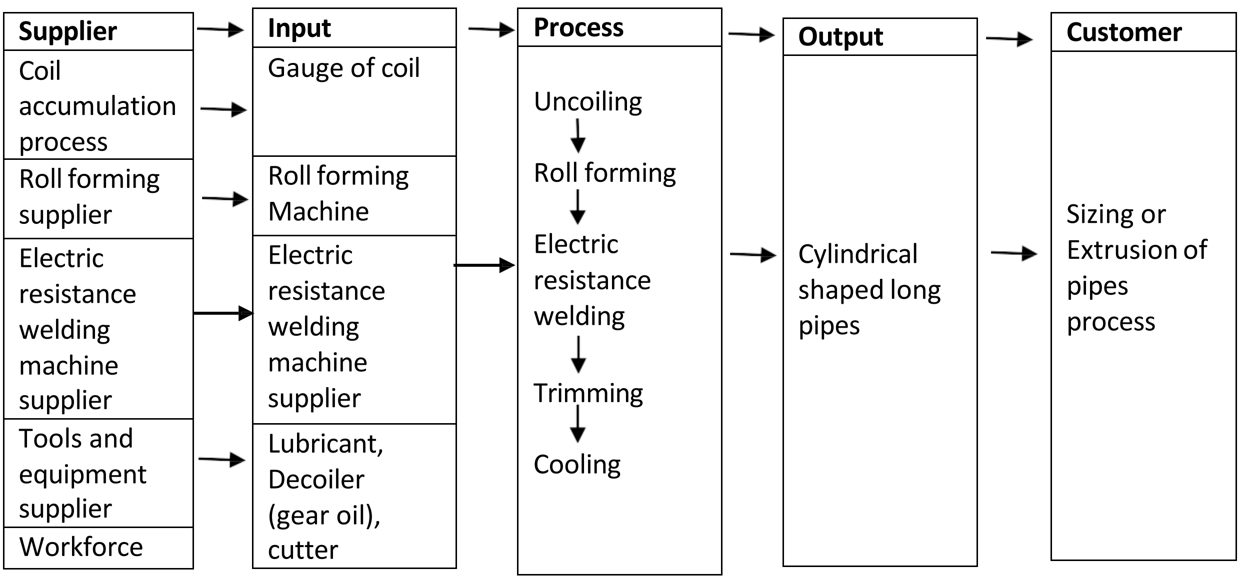
STAGE 2

Stage 2 comprises of roll forming, electric resistance welding, trimming and cooling process.

In roll forming the uncoiled coil gets cylindrical shape and then both the ends are joined by the help of electric resistance welding and then the extra material of weld will be removed by the help of trimming process and due to welding the temperature of pipe will be high so we need to cool it.

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

a) **SIPOC Diagram**



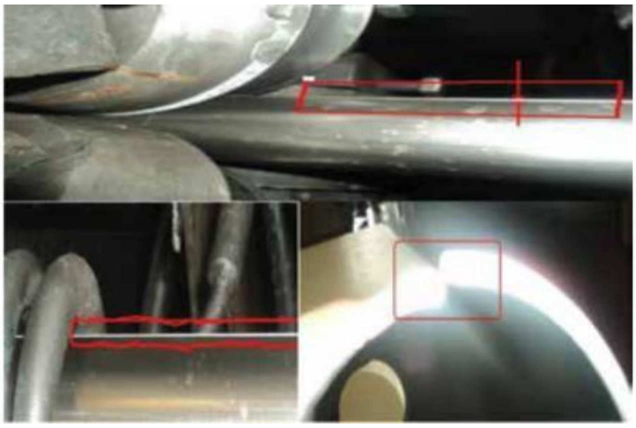
The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem

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

- **Twist**

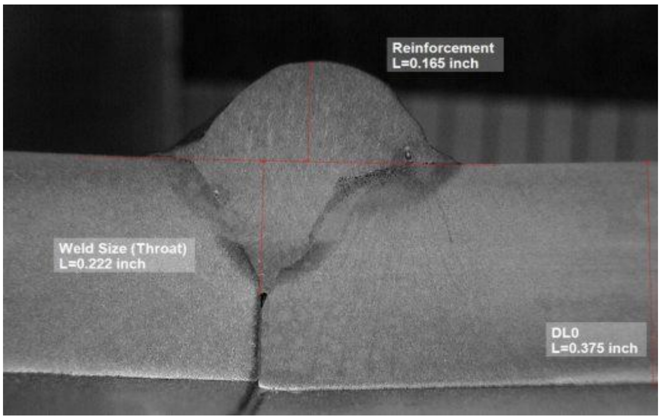
- **Overlapping**

- **Mismatch Defect**



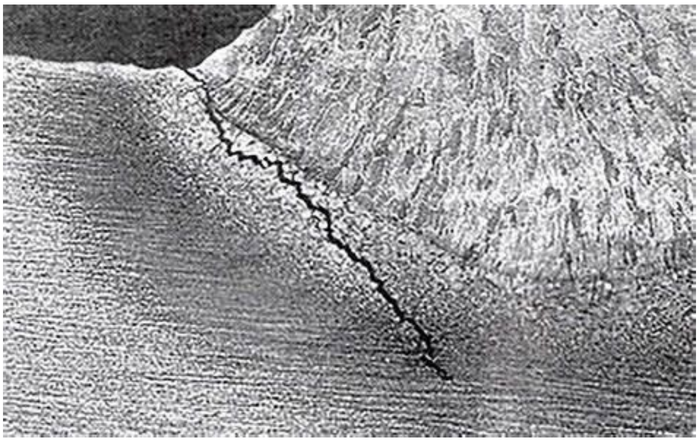
- **Solid Inclusion**

- **Excessive reinforcement**



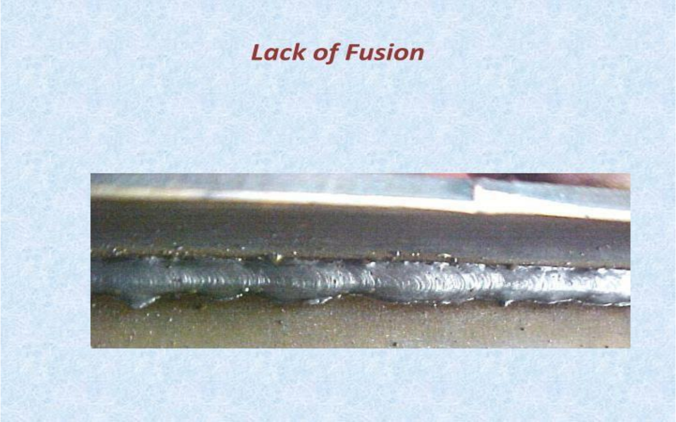
- **Lack of penetration**

- **Cracks**



- **Porosity/Blow holes**

- **Lack of fusion**



- **Undercutting**

c) Project Charter

Project Charter	
Project Title: Defect reduction in stage 2 which involves **Roll forming, electric resistance welding, trimming and cooling process**.	
Project objective and goal: To reduce the **porosity/blow holes, mismatch and lack of fusion** defect in the mentioned processes of stage 2.	
Project location: JAY AAY Alloys(P) Limited an ERW pipe manufacturing facility near Panchkula, India	
Background and Rational for project selection:	
In the baseline process, Prioritize the defects in which **Porosity/blow holes, mismatch defect and lack of fusion** defect 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
	Floor operator
Expected benefits: Reduction in the defects due to **porosity/blow holes, mismatch and lack of fusion** which would lead to cost benefits.	
Project plan: Application of DMAIC model of Six-Sigma	
Project timeline: Four months	

Project charter helps in defining the problem, setting up the project team and time-line, defining responsibilities and roles to the team members and stating the desired outputs that can be synchronized with the business demand and customer's requirements.

Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the ten defects identified in the define stage is established, followed by defect prioritization with the help of pareto chart.

Process specifications are followed to inspect the items with defects. As we are dealing with the continuous material so we are collecting the data of defects in 1 sq. ft. area which is considered as one unit to be inspected. There is also the possibility that one type of defect is present more than once in 1 unit so with the help of company's quality team we also record how many maximum no. of opportunity of a particular defect is possible shown in table 2.1

Defects	No. of defects in 1 sq. ft of area
Twist	3
Overlapping	3
Mismatch Defect	2
Solid Inclusion	2
Excessive Reinforcement	1
Lack of Penetration	1
Cracks	2
Porosity/Blow holes	1
Lack of fusion	1
Undercutting	1

The process output is sampled for 13 days and 25 data points are collected as JAY AAY ALLOY works in 2 shifts. In total, 7266.494 units are observed in 13 days were recorded using check sheets and the data is collected at different times in one shift.

To check whether process is in control or not, u- sampling that resulted into identification of 597 defects. The sampling data charts for fraction defects are drawn.

Di/Sj denotes the number of defects at day i in shift j where j=1,2

a) Check sheet for Pre-Analysis

Defects\Shifts	Twist	Overlapping	Mismatch Defect	Solid Inclusion	Excessive Reinforcement	Lack of Penetration	Cracks	Porosity/Blow holes	Lack of fusion	Undercutting	Total Defects(c(i))	Total Inspected Units(n(i))
D1/S1	1	3	13	0	1	2	1	10	10	1	42	412.92
D1/S2	1	1	10	0	1	0	0	14	11	1	39	399.6
D2/S1	0	2	11	0	2	1	2	14	9	0	41	366.3
D2/S2	0	1	9	0	3	0	3	12	8	0	36	399.6
D3/S1	1	0	3	0	1	0	0	7	7	1	20	317.682
D3/S2	1	1	9	0	0	0	1	10	8	0	30	323.6
D4/S1	1	0	6	1	1	1	2	13	6	0	31	257.07
D4/S2	0	0	0	1	0	3	1	7	8	1	21	349.6
D5/S1	0	0	10	1	2	1	2	9	2	0	27	317
D5/S2	1	0	9	1	1	5	1	13	7	0	38	399.6
D6/S1	2	1	3	0	1	0	2	5	3	0	17	244.422
D6/S2	2	0	5	1	0	1	0	2	9	0	20	206.46
D7/S1	1	1	3	0	0	0	0	3	8	0	16	206.46
D7/S2	0	0	7	0	3	0	0	2	4	0	16	283.71
D8/S1	0	0	4	0	4	1	0	8	2	2	21	233.1
D8/S2	0	2	5	1	0	2	0	6	4	2	22	288.3
D9/S1	0	1	4	2	1	2	2	9	3	0	24	233.1
D9/S2	0	1	1	1	0	1	2	2	3	0	11	216.45
D10/S1	1	0	4	1	0	2	2	8	2	0	20	253.08
D10/S2	2	0	1	0	2	0	1	4	7	0	17	259.74
D11/S1	1	0	5	0	4	1	0	4	6	1	22	259.74
D11/S2	0	3	6	0	2	0	0	5	4	2	22	253.08

D12/S1	1	1	1	0	2	1	1	4	5	1	17	316.35
D12/S2	0	0	5	0	1	0	1	5	3	0	15	253.08
D13/S1	0	0	6	0	1	1	0	3	1	0	12	216.45
Total	16	18	140	10	33	25	24	179	140	12	597	7266.494

From the above table we can see that we have total inspected 7266.49 units where 1 unit is 1 sq. ft. area and total no. of defects are 597.

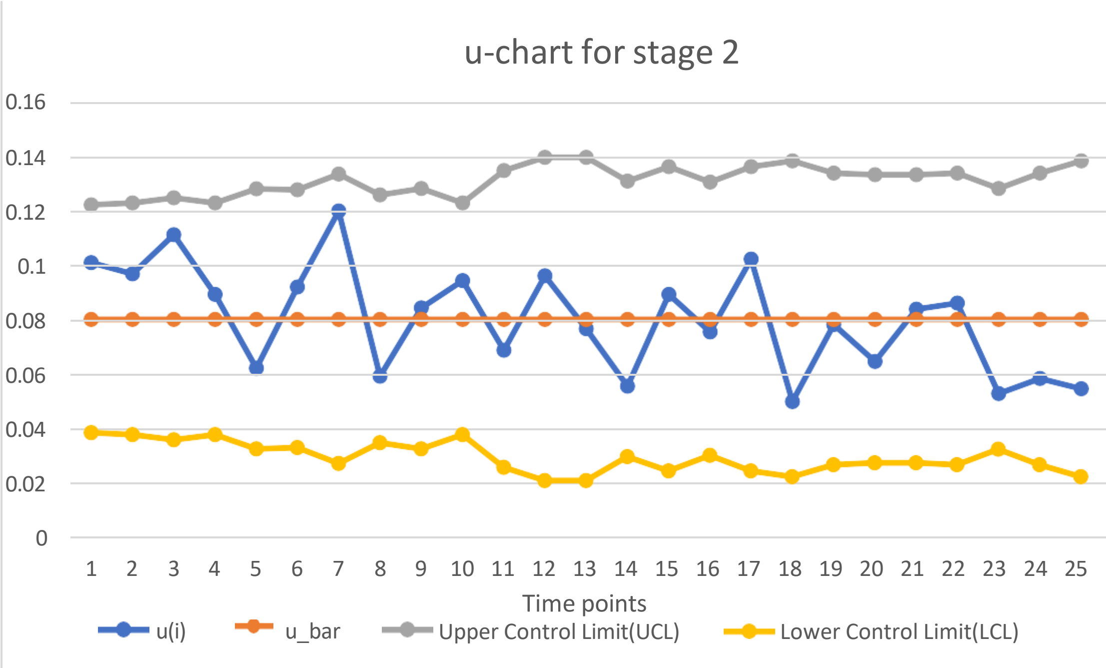
Now we will plot the u-chart

b) Construction of u-chart

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

Defects\Shifts	Total Defects(c(i))	Total Inspected Units(n(i))	u(i)	u_bar	Upper Control Limit(UCL)	Lower Control Limit(LCL)
D1/S1	42	412.92	0.101715	0.080919	0.122915	0.038922
D1/S2	39	399.6	0.097598	0.080919	0.12361	0.038228
D2/S1	41	366.3	0.11193	0.080919	0.125508	0.03633
D2/S2	36	399.6	0.09009	0.080919	0.12361	0.038228
D3/S1	20	317.682	0.062956	0.080919	0.128798	0.033039
D3/S2	30	323.6	0.092707	0.080919	0.128359	0.033479
D4/S1	31	257.07	0.12059	0.080919	0.134144	0.027693
D4/S2	21	349.6	0.060069	0.080919	0.12656	0.035277
D5/S1	27	317	0.085174	0.080919	0.12885	0.032988
D5/S2	38	399.6	0.095095	0.080919	0.12361	0.038228
D6/S1	17	244.422	0.069552	0.080919	0.135504	0.026334
D6/S2	20	206.46	0.096871	0.080919	0.140311	0.021527
D7/S1	16	206.46	0.077497	0.080919	0.140311	0.021527
D7/S2	16	283.71	0.056396	0.080919	0.131584	0.030254
D8/S1	21	233.1	0.09009	0.080919	0.136814	0.025024
D8/S2	22	288.3	0.076309	0.080919	0.131179	0.030659
D9/S1	24	233.1	0.10296	0.080919	0.136814	0.025024
D9/S2	11	216.45	0.05082	0.080919	0.138924	0.022914
D10/S1	20	253.08	0.079026	0.080919	0.134562	0.027275
D10/S2	17	259.74	0.06545	0.080919	0.13387	0.027968
D11/S1	22	259.74	0.0847	0.080919	0.13387	0.027968
D11/S2	22	253.08	0.086929	0.080919	0.134562	0.027275
D12/S1	17	316.35	0.053738	0.080919	0.128899	0.032939
D12/S2	15	253.08	0.05927	0.080919	0.134562	0.027275
D13/S1	12	216.45	0.05544	0.080919	0.138924	0.022914

c) u-chart



From the u-chart it is clearly visible that the process is operating statistical control because the only reason of variation is by chance cause.

From control chart it is only clear that our process is consistent to check whether our process is producing products with less defects we need to calculate the sigma level.

The baseline sigma level of the process is estimated by the help of DPMO (defects per million opportunities)

Total number of opportunities we calculate from table 1.1

Total number of defects	597
Total no. of opportunities	17
Total inspected units	7266.494

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table given below:

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	4833.15
Sigma level	4.09

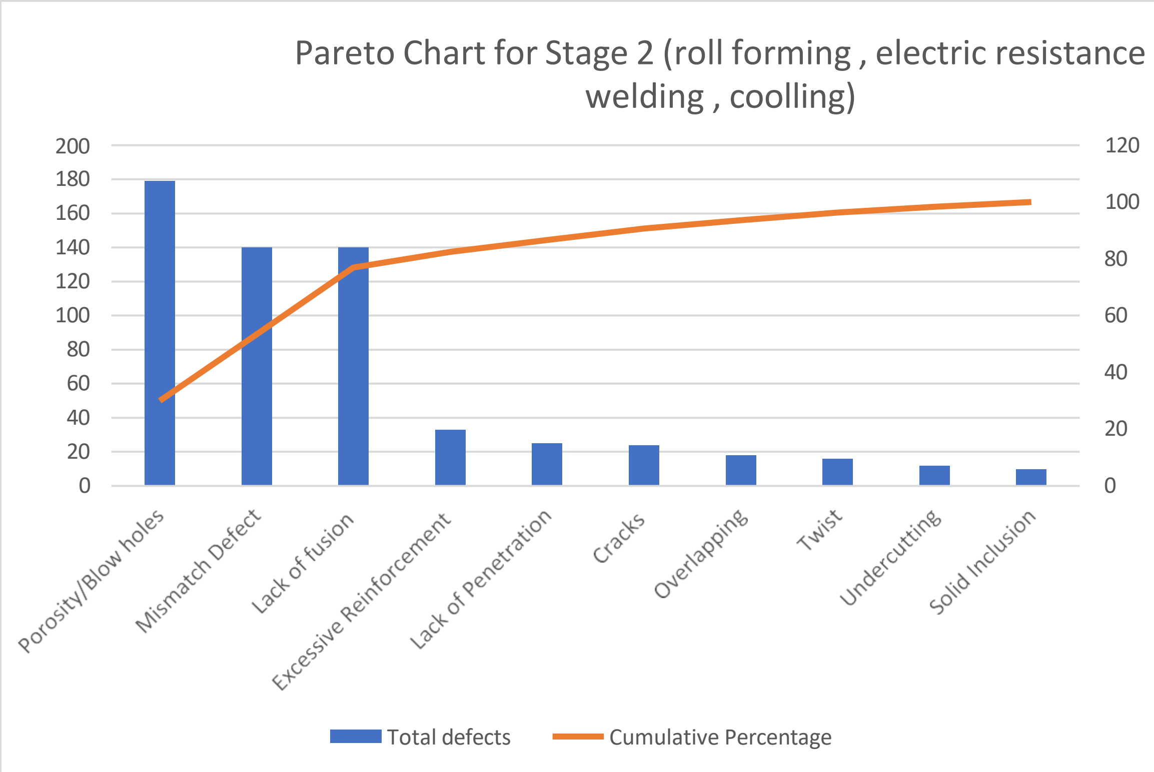
As we can see the sigma level of this stage is 4.09 which means that we can work on some defects to reduce them so that sigma level improves.

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.

Defects	Total defects		Cumulative Defects		Cumulative Percentage
Porosity/Blow holes	179		179		29.9832
Mismatch Defect	140		319		53.4338
Lack of fusion	140		459		76.8844
Excessive Reinforcement	33		492		82.4121
Lack of Penetration	25		517		86.5997
Cracks	24		541		90.6198
Overlapping	18		559		93.6348
Twist	16		575		96.3149
Undercutting	12		587		98.325
Solid Inclusion	10		597		100

a) Pareto chart



We can see from the pareto chart that elbow is forming at the defect 'lack of fusion'. Therefore, we need to work upon three defects which are **Porosity/Blow holes , Mismatch defect** and **Lack of fusion.**

So, now we will work on these three defects to improve the sigma level**.**

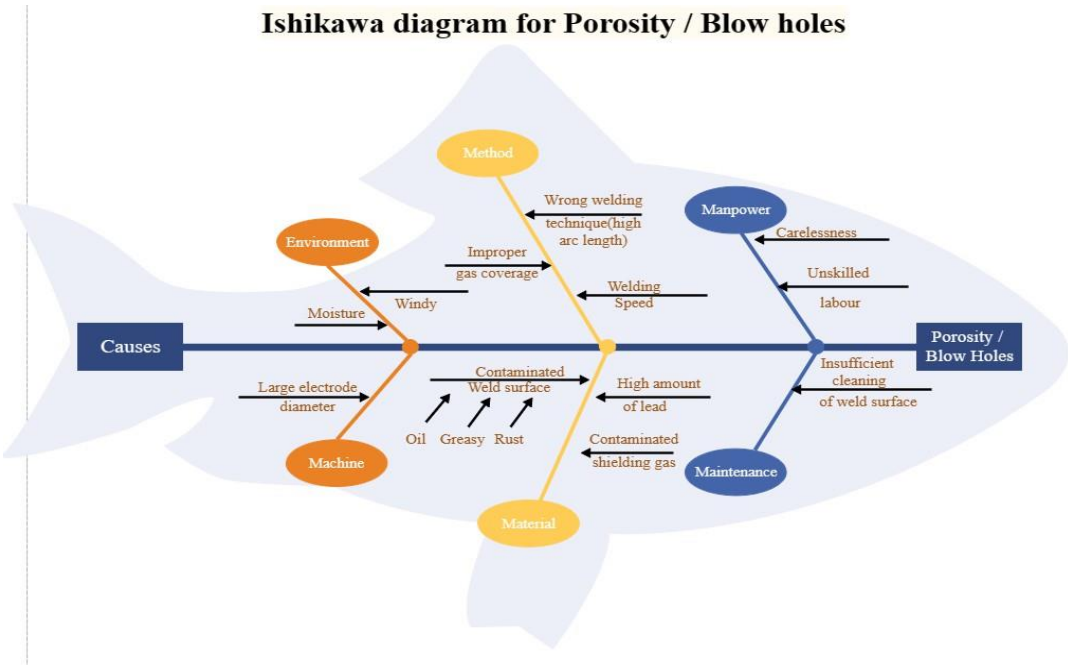
Cause & Effect analysis was conducted and a Cause & Effect diagram categorizing the causes in six generic categories was prepared as shown

We will be working with one defect at a time because implementing all the corrective measures simultaneously is not practical.

c) **Cause and Effect Diagram**

- **Cause and Effect for Porosity/Blow holes**

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



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

Corrective measures to reduce Porosity defect:

i. Proper cleaning of the weld surface.

ii. Material should not be contaminated with oil, grease also taking care of the contaminated shielding gas.

iii. In material there should not be hight amount of lead.

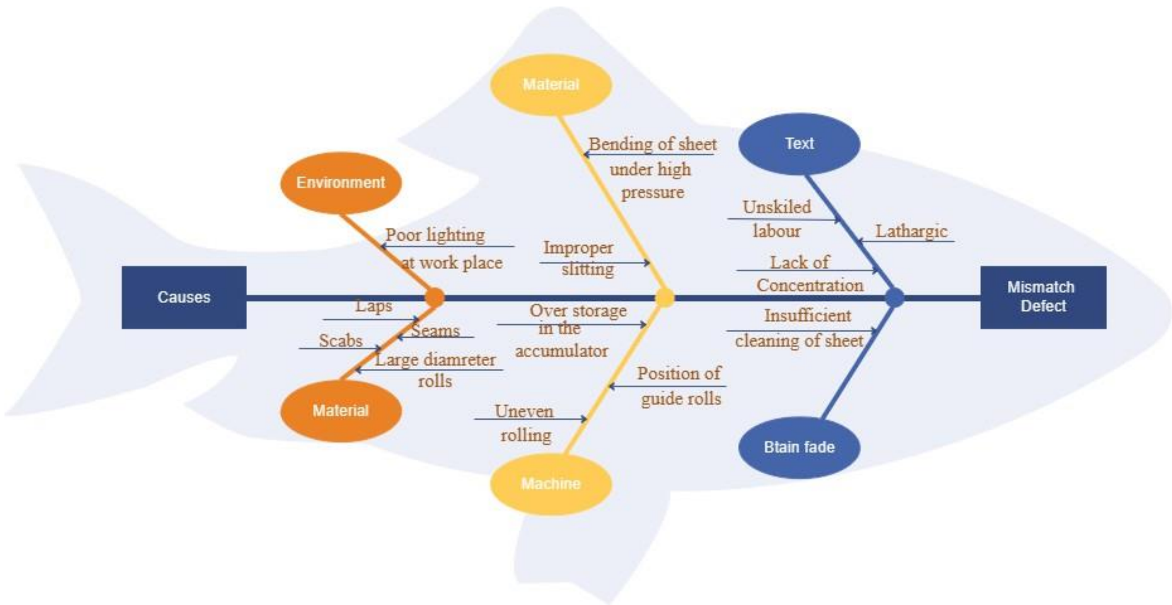
iv. Welding speed should not be very high.

v. Diameter of electrode used should not be large.

- **Cause and Effect diagram for Mismatch Defect**

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

Ishikawa Diagram of Mismatch Defect



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

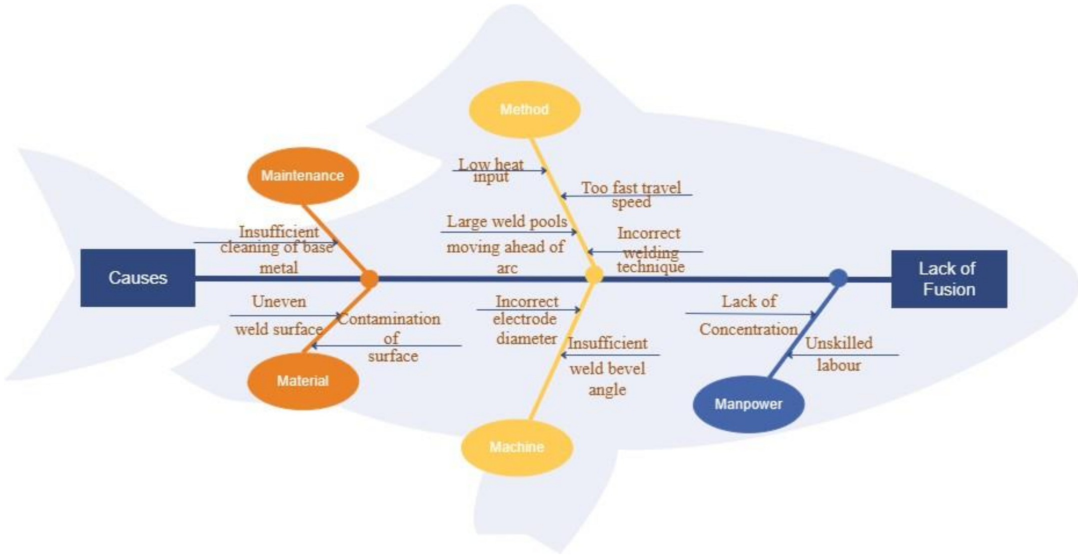
<u>Corrective measures to reduce Mismatch defect:</u>

- **i.** Material should not contain any laps, scabs, seams.
- **ii.** Diameter of rolls should not be very large.
- **iii.** Bending of sheet under should not be under high pressure.
- **iv.** Slitting should be proper.
- **v.** Sheet should be cleaned properly.
- **vi.** Over storage of the coil in the accumulator should be avoided.

- **Cause and Effect diagram for Lack of fusion**

  Fishbone diagram of Lack of fusion defect categorize the causes into 5 categories as shown below.

Ishikawa Diagram of Lack of Fusion Defect



As the causes of Lack of fusion defect is independent of each other therefore we can directly suggest some improvement measures to the company in order to improve the sigma level.

<u>Corrective measures to reduce Lack of fusion defect</u>

i. Base metal should be cleaned properly.
ii. Welding technique should be proper.
iii. Travelling speed should not be very fast.
iv. Heat input should be proper.
v. Weld bevel angle should be sufficient and proper electrode diameter.

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 Porosity and then of Lack of penetration.

IMPROVEMENT

a) Improvement of Porosity:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

Check Sheet for improving Porosity

Defects\Shifts	Twist	Overlapping	Mismatch Defect	Solid Inclusion	Excessive Reinforcement	Lack of Penetration	Cracks	Porosity/ Blow holes	Lack of fusion	Undercutting	Total Defects(c(i))	Total Inspected Units(n(i))
D1/S1	1	1	13	0	1	2	1	3	10	1	33	412.92
D1/S2	1	0	10	0	1	0	0	4	11	1	28	399.6
D2/S1	0	1	11	0	0	1	2	4	9	0	28	366.3
D2/S2	0	1	9	0	1	0	1	2	8	0	22	412.92
D3/S1	1	0	6	0	1	0	0	1	7	1	17	317.682
D3/S2	1	1	9	0	0	0	1	1	8	0	21	323.6
D4/S1	1	0	6	1	1	1	2	3	6	0	21	323.6
D4/S2	0	0	0	1	0	3	1	2	8	1	16	349.6
D5/S1	0	0	10	1	2	1	2	1	2	0	19	399.6
D5/S2	1	0	9	1	1	5	1	0	7	0	25	399.6
D6/S1	1	1	6	0	1	0	2	0	6	0	17	412.92
D6/S2	0	0	5	1	0	1	0	1	9	0	17	366.3
D7/S1	0	1	3	0	0	0	0	2	8	0	14	317.682
D7/S2	0	0	7	0	3	0	0	2	4	0	16	317.682
D8/S1	0	0	4	0	2	1	0	3	2	2	14	233.1

Total	7	6	108	5	14	15	13	29	105	6	308	5353.106

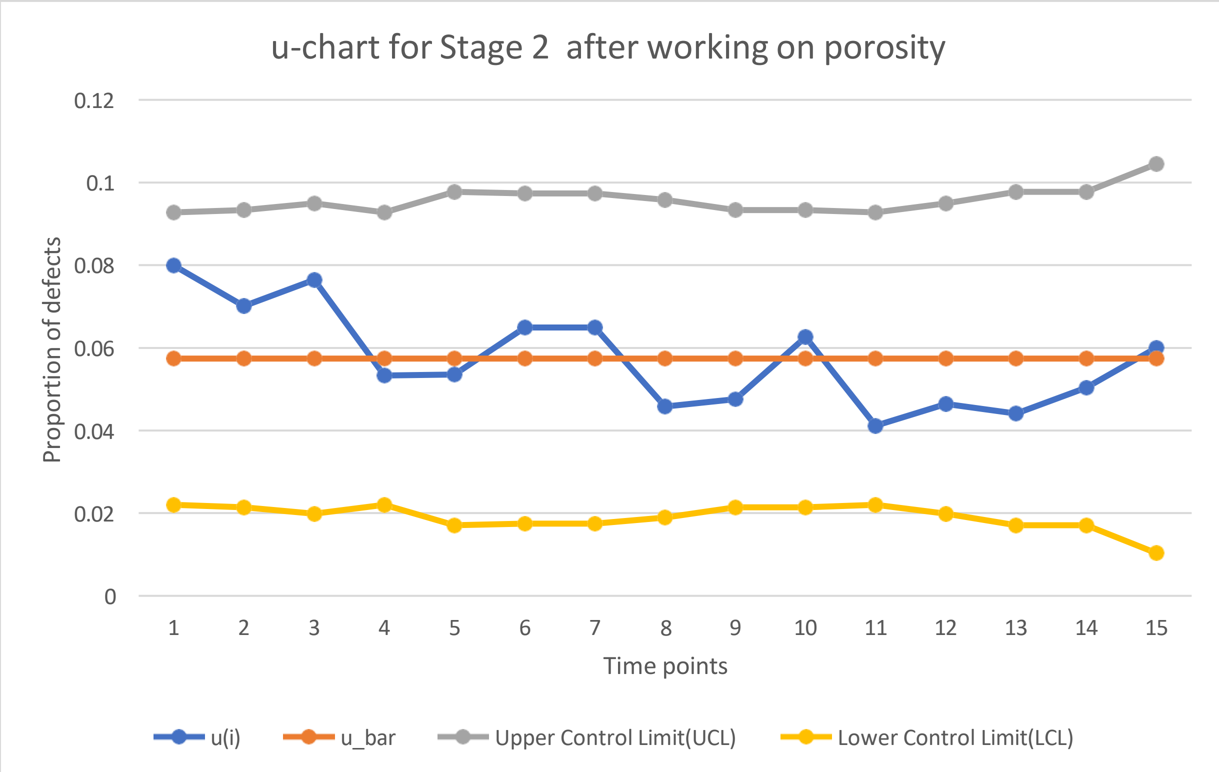
From the above check sheet we can see that the no. of occurrence of defect Porosity is reduced. There will also be decrease in some other defects as most of the defects are occurring because of welding. So, correcting one will also have impact on others.

Now we will draw the u-chart to check whether the process is still in control or not.

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

Defects\Shifts	Total Defects(c(i))	Total Inspected Units(n(i))	u(i)	u_bar	Upper Control Limit(UCL)	Lower Control Limit(LCL)
D1/S1	33	412.92	0.079919	0.057397	0.092767	0.022027
D1/S2	28	399.6	0.07007	0.057397	0.093352	0.021443
D2/S1	28	366.3	0.07644	0.057397	0.094951	0.019844
D2/S2	22	412.92	0.053279	0.057397	0.092767	0.022027
D3/S1	17	317.682	0.053513	0.057397	0.097722	0.017073
D3/S2	21	323.6	0.064895	0.057397	0.097352	0.017443
D4/S1	21	323.6	0.064895	0.057397	0.097352	0.017443
D4/S2	16	349.6	0.045767	0.057397	0.095837	0.018958
D5/S1	19	399.6	0.047548	0.057397	0.093352	0.021443
D5/S2	25	399.6	0.062563	0.057397	0.093352	0.021443
D6/S1	17	412.92	0.04117	0.057397	0.092767	0.022027
D6/S2	17	366.3	0.04641	0.057397	0.094951	0.019844
D7/S1	14	317.682	0.044069	0.057397	0.097722	0.017073
D7/S2	16	317.682	0.050365	0.057397	0.097722	0.017073
D8/S1	14	233.1	0.06006	0.057397	0.104473	0.010322

u-chart



As we can see from the above u chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not.

Total number of opportunities we calculate from table 2.1

Total number of defects	308
Total no. of opportunities	17
Total inspected units	5353.106

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	3384.511
Sigma level	4.21

As we can see by working on Porosity sigma level improves.

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

b) Improvement of Mismatch defect:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

Check sheet for improving Mismatch defect

Defects\Shifts	Twist	Overlapping	Mismatch Defect	Solid Inclusion	Excessive Reinforcement	Lack of Penetration	Cracks	Porosity /Blow holes	Lack of fusion	Undercutting	Total Defects(c(i))	Total Inspected Units(n(i))
D1/S1	1	1	3	0	1	2	1	3	10	1	23	412.92
D1/S2	1	0	4	0	1	0	0	4	11	1	22	399.6
D2/S1	0	1	2	0	0	1	2	4	9	0	19	366.3
D2/S2	0	1	3	0	1	0	1	2	8	0	16	412.92
D3/S1	1	0	4	0	1	0	0	1	7	1	15	317.682
D3/S2	1	1	2	0	0	0	1	1	8	0	14	323.6
D4/S1	1	0	3	1	1	1	2	3	6	0	18	323.6
D4/S2	0	0	0	1	0	3	1	2	8	1	16	349.6
D5/S1	0	0	2	1	2	1	2	1	2	0	11	399.6
D5/S2	1	0	3	1	1	5	1	0	7	0	19	399.6
D6/S1	1	1	3	0	1	0	2	0	6	0	14	412.92
D6/S2	0	0	1	1	0	1	0	1	9	0	13	366.3
D7/S1	0	1	0	0	0	0	0	2	8	0	11	317.682
D7/S2	0	0	1	0	3	0	0	2	4	0	10	317.682
D8/S1	0	0	0	0	2	1	0	3	2	2	10	233.1
Total	7	6	31	5	14	15	13	29	105	6	231	5353.106

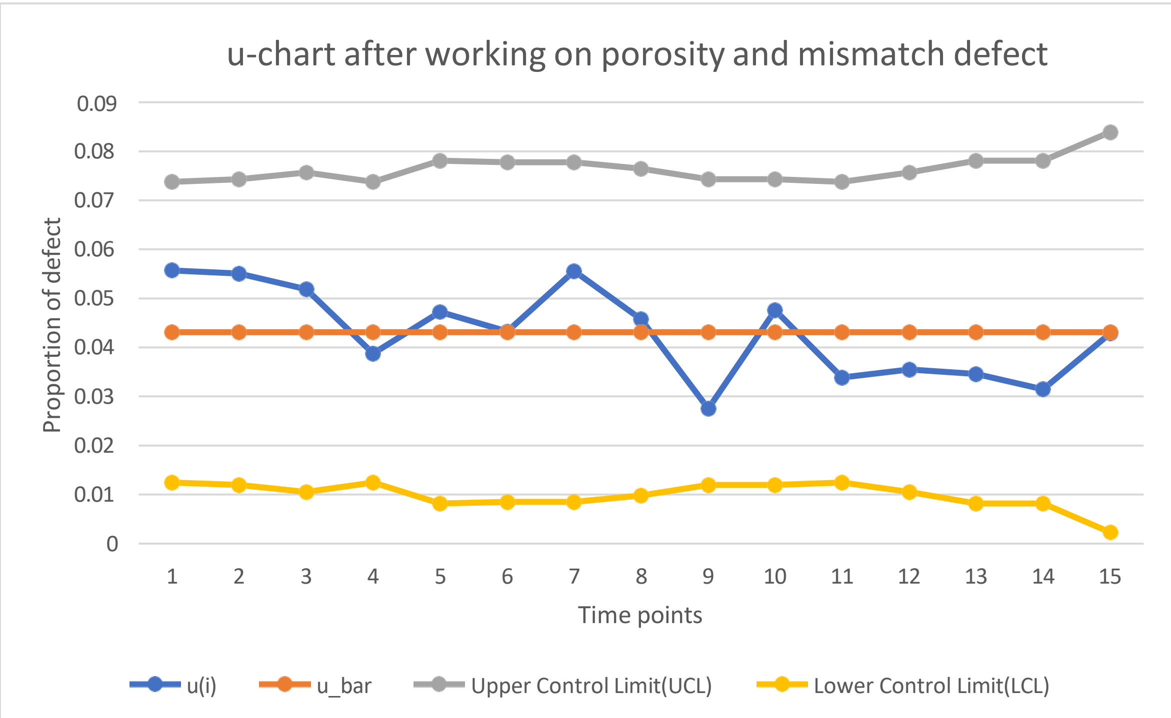
From the above check sheet we can see that the no. of occurrence of defect Porosity and Mismatch defect is reduced. There will also be decrease in some other defects as most of the defects are occurring because of welding. So, correcting one will also have impact on others.

Now we will draw the u-chart to check whether the process is still in control or not.

Construction of u-chart

Defects\Shifts	Total Defects(c(i))	Total Inspected Units(n(i))	u(i)	u_bar	Upper Control Limit(UCL)	Lower Control Limit(LCL)
D1/S1	23	412.92	0.055701	0.043115	0.07377	0.01246
D1/S2	22	399.6	0.055055	0.043115	0.074276	0.011953
D2/S1	19	366.3	0.05187	0.043115	0.075662	0.010567
D2/S2	16	412.92	0.038748	0.043115	0.07377	0.01246
D3/S1	15	317.682	0.047217	0.043115	0.078064	0.008165
D3/S2	14	323.6	0.043263	0.043115	0.077743	0.008486
D4/S1	18	323.6	0.055624	0.043115	0.077743	0.008486
D4/S2	16	349.6	0.045767	0.043115	0.07643	0.009799
D5/S1	11	399.6	0.027528	0.043115	0.074276	0.011953
D5/S2	19	399.6	0.047548	0.043115	0.074276	0.011953
D6/S1	14	412.92	0.033905	0.043115	0.07377	0.01246
D6/S2	13	366.3	0.03549	0.043115	0.075662	0.010567
D7/S1	11	317.682	0.034626	0.043115	0.078064	0.008165
D7/S2	10	317.682	0.031478	0.043115	0.078064	0.008165
D8/S1	10	233.1	0.0429	0.043115	0.083915	0.002314

u-chart



As we can see from the above u chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not.

Total number of opportunities we calculate from table 2.1

Total number of defects	231
Total no. of opportunities	17
Total inspected units	5353.106

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	2538.383
Sigma level	4.3

As we can see by working on Mismatch and Porosity sigma level improves from 4.21 to 4.3.

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

c) Improvement of Lack of fusion:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

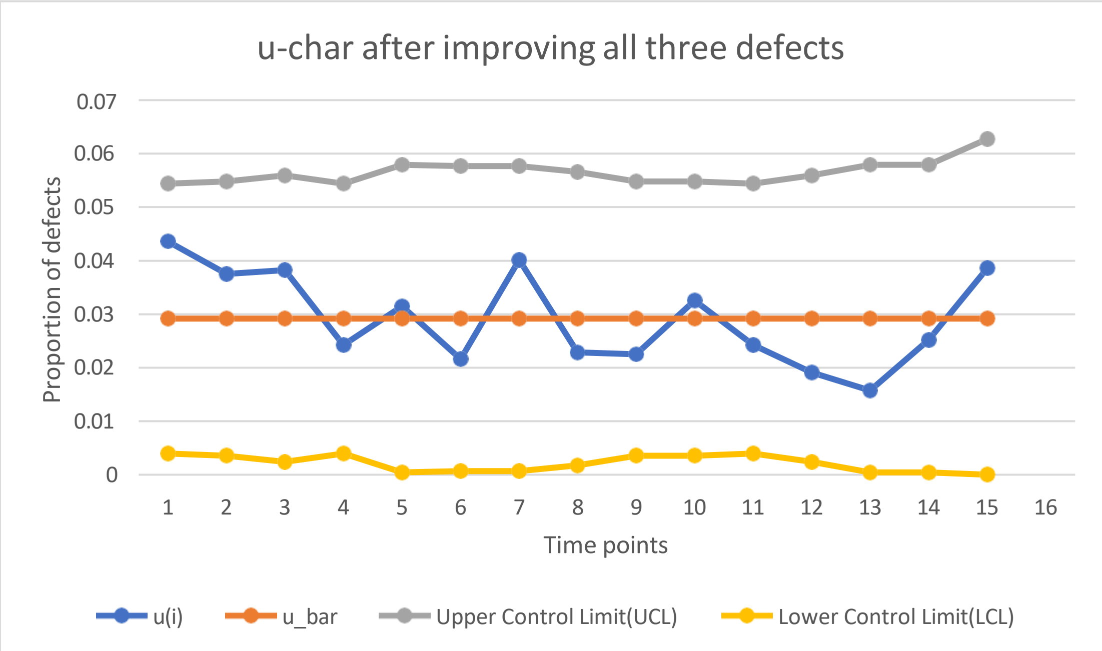
Check sheet for improving Lack of fusion

Defects\Shifts	Twist	Overlapping	Mismatch Defect	Solid Inclusion	Excessive Reinforcement	Lack of Penetration	Cracks	Porosity/Blow holes	Lack of fusion	Undercutting	Total Defects(c(i))	Total Inspected Units(n(i))
D1/S1	1	1	3	0	1	2	1	3	5	1	18	412.92
D1/S2	1	0	4	0	1	0	0	4	4	1	15	399.6
D2/S1	0	1	2	0	0	1	2	4	4	0	14	366.3
D2/S2	0	1	3	0	1	0	1	2	2	0	10	412.92
D3/S1	1	0	4	0	1	0	0	1	2	1	10	317.682
D3/S2	1	1	2	0	0	0	1	1	1	0	7	323.6
D4/S1	1	0	3	1	1	1	2	3	1	0	13	323.6
D4/S2	0	0	0	1	0	3	1	2	0	1	8	349.6
D5/S1	0	0	2	1	2	1	2	1	0	0	9	399.6
D5/S2	1	0	3	1	1	5	1	0	1	0	13	399.6
D6/S1	1	1	3	0	1	0	2	0	2	0	10	412.92
D6/S2	0	0	1	1	0	1	0	1	3	0	7	366.3
D7/S1	0	1	0	0	0	0	0	2	2	0	5	317.682

D7/S2	0	0	1	0	3	0	0	2	2	0	8	317.682
D8/S1	0	0	0	0	2	1	0	3	1	2	9	233.1
Total	7	6	31	5	14	15	13	29	30	6	156	5353.106

From the above check sheet we can see that the no. of occurrence of defect Porosity, Mismatch defect and lack of fusion is reduced. There will also be decrease in some other defects as most of the defects are occurring because of welding. So, correcting one will also have impact on others.

Now we will draw the u-chart to check whether the process is still in control or not.



As we can see from the above u chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not.

Total number of opportunities we calculate from table 2.1

Total number of defects	156
Total no. of opportunities	17
Total inspected units	5353.106

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	1714.233
Sigma level	4.43

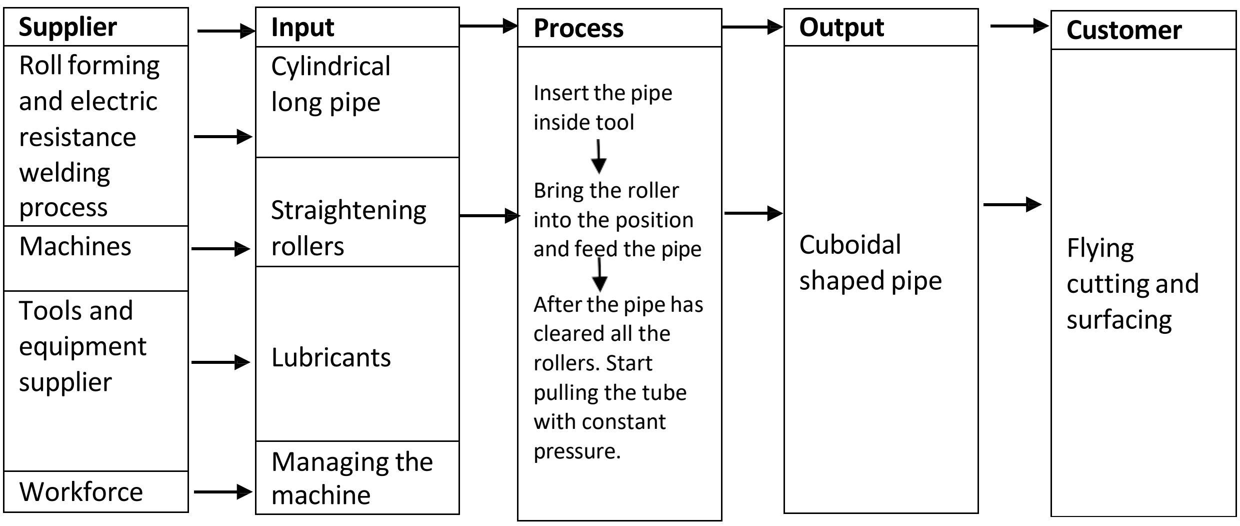
An implementation of the suggestions was done to the process and studied for a period of 8 days. The sigma level showed an improvement from **4.21 to 4.4** and the defects arising due to **Porosity**, **Mismatch defect** and **Lack of penetration** were decreased; this may be a more optimistic picture in the reality. Thus, in control the process with improvements is maintained and standardized

Stage 3

Stage 3 comprises of only one process which is Sizing or Extrusion of pipes. This process is used to change the shape of the pipe. As we are working on the cuboidal shape MS pipes therefore Sizing is used to convert cylindrical pipe into cuboidal one.

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

a) SIPOC Diagram

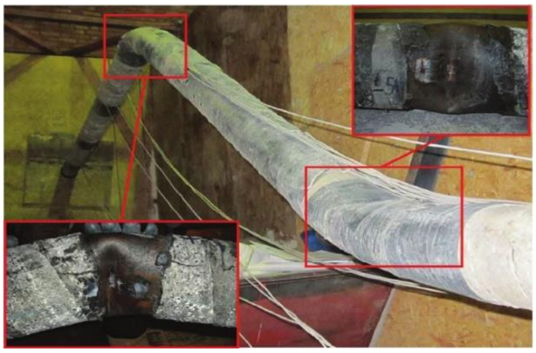


The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem

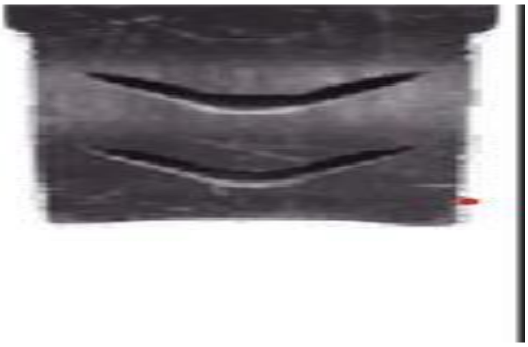
b) Defects in the various process of Stage 3 which are identified by the company are:

- **Die lines**

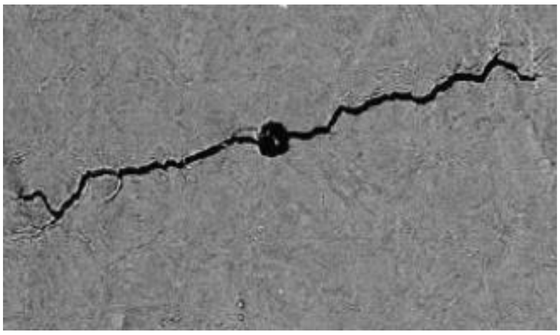
- **Inhomogeneous deformation**



- **Centre burst**



- **Surface cracking**



c) Project charter

Project Charter	
Project Title: Defect reduction in stage 3 which involves **Extrusion of pipes**.	
Project objective and goal: To reduce the **inhomogeneous deformation** defect during Extrusion of pipes.	
Project location: JAY AAY Alloys(P) Limited an ERW pipe manufacturing facility near Panchkula, India	
Background and Rational for project selection:	
In the baseline process, Prioritize the defects in which **inhomogeneous deformation** defect has found to be highest priority as compared to the other defects based on expected values of multiple factors like cost, time, quality improvement etc.	
Project team:	Quality Head
	Mangers from Manufacturing, Purchasing and Maintenance
	Quality control inspector
	Research advisor and associates
	Floor operator
Expected benefits: Reduction in the defects due to **inhomogeneous deformation** which would lead to cost benefits.	
Project plan: Application of DMAIC model of Six-Sigma	
Project timeline: Four months	

Project charter helps in defining the problem, setting up the project team and time-line, defining responsibilities and roles to the team members and stating the desired outputs that can be synchronized with the business demand and customer's requirements.

Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the four defects identified in the define stage is established, followed by defect prioritization with the help of Analytical hierarchy process (AHP).

Process specifications are followed to inspect the items with defects. As we are dealing with the continuous material so we are collecting the data of defects in 1 sq. ft. area which is considered as one unit to be inspected. There is also the possibility that one type of defect is present more than once in 1 unit so with the help of company's quality team we also record how many maximum no. of opportunity of a particular defect is possible shown in table 3.1

Defects	Defects in 1 sq. ft of area
Die lines	2
Inhomogeneous Deformation	3
Centre burst	1
Surface cracking	2

The process output is sampled for 13 days and 25 data points are collected as JAY AAY ALLOY works in 2 shifts. In total, 7188.572 units are observed in 13 days were recorded using check sheets and the data is collected at different times in one shift.

To check whether process is in control or not, u- sampling that resulted into identification of 430 defects. The sampling data charts for fraction defects are drawn.

Di/Sj denotes the number of defects at day i in shift j where j=1,2

a) Check sheet for Pre-Analysis

Defects\Shifts	Die Lines	Inhomogeneous Deformation	Centre burst	Surface Cracking	Total defects(c(i))	Total inspected units (n(i))
D1/S1	8	15	5	8	36	399.6
D1/S2	8	12	4	8	32	336.33
D2/S1	7	10	4	8	29	366.3
D2/S2	8	9	4	8	29	399.6
D3/S1	7	7	5	7	26	316.35
D3/S2	7	8	3	5	23	323.6
D4/S1	6	7	3	4	20	257.07
D4/S2	5	7	4	5	21	349.6
D5/S1	7	8	2	3	20	317
D5/S2	7	9	1	5	22	399.6
D6/S1	8	8	2	3	21	244.422
D6/S2	7	7	1	3	18	206.46
D7/S1	6	6	1	1	14	206.46
D7/S2	5	5	0	2	12	283.71
D8/S1	3	4	0	2	9	233.1
D8/S2	4	4	3	1	12	288.3
D9/S1	4	3	1	0	8	233.1
D9/S2	2	4	4	0	10	216.45
D10/S1	2	5	0	1	8	253.08
D10/S2	1	5	0	2	8	259.74
D11/S1	4	4	0	3	11	259.74
D11/S2	4	3	1	4	12	253.08
D12/S1	0	2	3	5	10	316.35
D12/S2	1	3	2	5	11	253.08
D13/S1	0	4	2	2	8	216.45

Total	121	159	55	95	430	7188.572

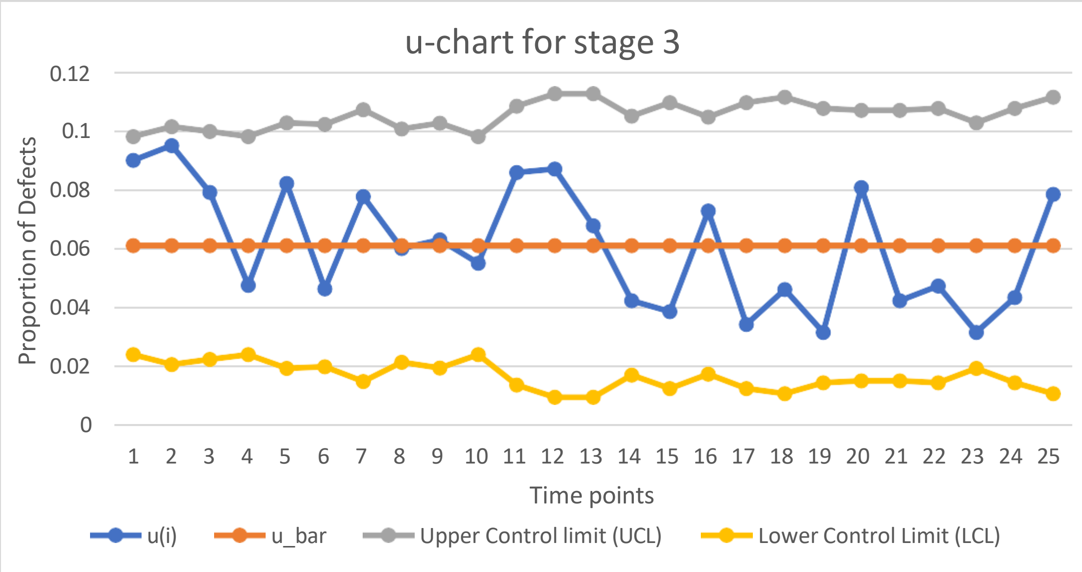
From the above table we can see that total number of units inspected are 7188.572 where 1 unit is 1 sq. ft area and total number of defects are 430.

Now we plot the u-chart

b) Construction of u-chart

Defects\Shifts	Total defects(c(i))	Total inspected units (n(i))	u(i)	u_bar	Upper Control limit (UCL)	Lower Control Limit (LCL)
D1/S1	36	399.6	0.09009	0.058177	0.094375	0.021979
D1/S2	32	336.33	0.095145	0.058177	0.097633	0.018721
D2/S1	29	366.3	0.07917	0.058177	0.095985	0.02037
D2/S2	29	399.6	0.072573	0.058177	0.094375	0.021979
D3/S1	26	316.35	0.082187	0.058177	0.09886	0.017494
D3/S2	23	323.6	0.071075	0.058177	0.098402	0.017952
D4/S1	20	257.07	0.0778	0.058177	0.103308	0.013046
D4/S2	21	349.6	0.060069	0.058177	0.096877	0.019477
D5/S1	20	317	0.063091	0.058177	0.098818	0.017536
D5/S2	22	399.6	0.055055	0.058177	0.094375	0.021979
D6/S1	21	244.422	0.085917	0.058177	0.104461	0.011894
D6/S2	18	206.46	0.087184	0.058177	0.108536	0.007818
D7/S1	14	206.46	0.06781	0.058177	0.108536	0.007818
D7/S2	12	283.71	0.042297	0.058177	0.101137	0.015218
D8/S1	9	233.1	0.03861	0.058177	0.105571	0.010783
D8/S2	12	288.3	0.041623	0.058177	0.100793	0.015561
D9/S1	8	233.1	0.03432	0.058177	0.105571	0.010783
D9/S2	10	216.45	0.0462	0.058177	0.107361	0.008994
D10/S1	8	253.08	0.031611	0.058177	0.103662	0.012692
D10/S2	8	259.74	0.0308	0.058177	0.103075	0.013279
D11/S1	11	259.74	0.04235	0.058177	0.103075	0.013279
D11/S2	12	253.08	0.047416	0.058177	0.103662	0.012692
D12/S1	10	316.35	0.031611	0.058177	0.09886	0.017494
D12/S2	11	253.08	0.043465	0.058177	0.103662	0.012692
D13/S1	8	216.45	0.03696	0.058177	0.107361	0.008994

c) u-chart



From the u-chart it is clearly visible that the process is operating statistical control because the only reason of variation is by chance cause.

From control chart it is only clear that our process is consistent to check whether our process is producing products with less defects we need to calculate the sigma level.

The baseline sigma level of the process is estimated by the help of DPMO (defects per million opportunities)

Total number of opportunities we calculate from table 3.1

Total number of defects	430
Total no. of opportunities	8
Total inspected units	7188.572

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table given below:

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	7703.81
Sigma level	3.92

As we can see the sigma level of this stage is 3.92 which means that we can work on some defects to reduce them so that sigma level improves.

Now we wish to improve the current level of sigma. For this, we create Pareto Chart which will give information regarding which defectives has to be taken care or analyzed in order to reduce the number of defectives so that we can further improve the process. But this approach limits the gains realized from the project as other attributes such as criticality of defects; expected gains in monetary terms etc. are ignored while selecting the key defects. Therefore, we propose a Multi Criteria Decision Making (MCDM) approach for identification of key defects considering other attributes, including criticality of defect as per customer requirement, expected monetary and time requirements to deal with a defect and expected improvement in the process. The selection of key defects based on customers' and management's preference leads to greater customer satisfaction and higher monetary gains.

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 five criteria points which are as follows:

1. Cost Requirement

2. Criticality to Customer

3. Frequency of defects

4. Time requirement

5. Expected improvement

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that criticality to customer is the most important criteria followed by expected improvement, frequency of defects, time requirement and at last monetary requirement.

Now we develop the pairwise comparison matrix to prioritize the defects as suggested by the company.

i. Pairwise comparison matrix for criterion

Criteria	Freq	Critical	Time	Improve	Monetary
Frequency of Defects	1	0.333333	0.5	0.5	4
Criticality to Customers	3	1	3	2	3
Time Requirement	2	0.333333	1	0.25	1
Expected improvement	2	0.5	3	1	2
Monetary requirement	0.25	0.333333	1	0.5	1
Sum	8.25	2.5	8.5	4.25	11

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Criteria	Freq	Critical	Time	Monetary	Improve
Frequency of Defects	0.121212	0.133333	0.058823529	0.117647	0.363636
Criticality to Customers	0.363636	0.4	0.352941176	0.470588	0.272727
Time Requirement	0.242424	0.133333	0.117647059	0.058824	0.090909
Expected Improvement	0.242424	0.2	0.352941176	0.235294	0.181818
Monetary requirement	0.030303	0.133333	0.117647059	0.117647	0.090909

So the corresponding average priority vector is

Average Priority Vector
0.15893
0.371979
0.128627
0.242496
0.097968

We can see from the average priority vector criticality to customer is most preferred as suggested by the company also. Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	5.43869
CI	0.109672
CR	0.097922

As we can see CR is 0.09 which is <0.1 and thus the matrix is consistent.

Now we do the pairwise comparison of defects on the basis of each of the criteria by the help of quality team of the company.

After collecting data in check sheet we get to know that Die line is the most important defect need to focus upon followed by inhomogeneous deformation, surface cracking and at last centre burst on the basis of frequency of defects criteria.

ii. <u>Pairwise comparison matrix of defects on the basis of frequency of defects:</u>

Frequency of Defects	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	1	2	3	5
Inhomogeneous Deformation	0.5	1	2	3
Surface Cracking	0.333333	0.5	1	2
Centre Burst	0.2	0.333333	0.5	1
Sum	2.033333	3.833333	6.5	11

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Frequency of Defects	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	0.491803	0.521739	0.461538462	0.454545
Inhomogeneous Deformation	0.245902	0.26087	0.307692308	0.272727
Surface Cracking	0.163934	0.130435	0.153846154	0.181818
Centre Burst	0.098361	0.086957	0.076923077	0.090909

So, the corresponding average priority vector is

Average Priority Vector
0.482407
0.271798

0.157508
0.088287

So, according to the average priority vector Die lines is the defect need to consider on the basis of frequency of defects criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**4.014536**
CI	0.004845
CR	0.005384

As we can see CR is 0.005 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that inhomogeneous deformation is the most important defect need to focus upon followed by surface cracking, die lines and at last centre burst on the basis of criticality to customer criteria.

iii. Pairwise comparison matrix of defects on the basis of criticality to customers:

Criticality to Customers	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	1	0.333333	0.25	2
Inhomogeneous Deformation	3	1	2	2
Surface Cracking	3	0.5	1	3
Centre Burst	0.5	0.5	0.333333333	1
sum	7.5	2.333333	3.583333333	8

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Criticality to Customers	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	0.133333	0.142857	0.069767442	0.25
Inhomogeneous Deformation	0.4	0.428571	0.558139535	0.25
Surface Cracking	0.4	0.214286	0.279069767	0.375
Centre Burst	0.066667	0.214286	0.093023256	0.125

So, the corresponding average priority vector is

Average Priority Vector
0.148989
0.409178
0.317089
0.124744

So, according to the average priority vector Inhomogeneous deformation is the defect need to consider on the basis of criticality to customer criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	4.1734
CI	0.0578
CR	0.064222

As we can see CR is 0.005 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that surface cracking is the most important defect need to focus upon followed by die line, inhomogeneous deformation and at last centre burst on the basis of time requirement criteria.

iv. Pairwise comparison matrix of defects on the basis of time requirement .

Time Requirement	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	1	3	0.333	2
Inhomogeneous Deformation	0.333333	1	0.33333	2
Surface Cracking	3	3	1	4
Centre Burst	0.5	0.5	0.25	1
Sum	4.833333	7.5	1.91633	9

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Time Requirement	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	0.206897	0.4	0.173769653	0.222222
Inhomogeneous Deformation	0.068966	0.133333	0.173941858	0.222222
Surface Cracking	0.62069	0.4	0.521830791	0.444444
Centre Burst	0.103448	0.066667	0.130457698	0.111111

So, the corresponding average priority vector is

Average Priority Vector
0.250722
0.149616
0.496741
0.102921

So, according to the average priority vector surface cracking is the defect need to consider on the basis of time criticality criteria because it will take less time to correct.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	4.177525
CI	0.059175
CR	0.06575

As we can see CR is 0.06 which is <0.1 and thus the matrix is consistent

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that surface cracking is the most important defect need to focus upon followed by die lines, inhomogeneous deformation and at last centre burst on the basis of monetary requirement criteria.

v. Pairwise comparison matrix of defects on the basis of monetary requirement:

Monetary Requirement	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	1	3	0.5	2
Inhomogeneous Deformation	0.333333	1	0.333333333	3
Surface Cracking	2	3	1	4
Centre Burst	0.5	0.333333	0.25	1
Sum	3.833333	7.333333	2.083333333	10

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Monetary Requirement	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	0.26087	0.409091	0.24	0.2
Inhomogeneous	0.086957	0.136364	0.16	0.3

Deformation				
Surface Cracking	0.521739	0.409091	0.48	0.4
Centre Burst	0.130435	0.045455	0.12	0.1

So, the corresponding average priority vector is

Average Priority Vector
0.27749
0.17083
0.452708
0.098972

So, according to the average priority vector surface cracking is the defect need to consider on the basis of monetary requirement criteria because that would require less amount of money.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**4.223002**
CI	0.074334
CR	0.082593

As we can see CR is 0.08 which is <0.1 and thus the matrix is consistent

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that centre burst is the most important defect need to focus upon followed by inhomogeneous deformation, surface cracking and at last die lines on the basis of expected improvement criteria.

vi. Pairwise comparison matrix of defects on the basis of expected improvement:

Expected Improvement	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	1	0.25	0.5	0.2
Inhomogeneous Deformation	4	1	3	0.333333
Surface Cracking	2	0.333333	1	0.25
Centre Burst	5	3	4	1
Sum	12	4.583333	8.5	1.783333

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Expected Improvement	Die lines	In. Deform	S. Cracking	Centre Burst
Die lines	0.083333	0.054545	0.058823529	0.11215
Inhomogeneous Deformation	0.333333	0.218182	0.352941176	0.186916
Surface Cracking	0.166667	0.072727	0.117647059	0.140187
Centre Burst	0.416667	0.654545	0.470588235	0.560748

So, the corresponding average priority vector is

Average Priority Vector
0.077213
0.272843
0.124307
0.525637

So, according to the average priority vector inhomogeneous deformation is the defect need to consider on the basis of expected improvement criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	4.114887
CI	0.038296
CR	0.042551

As we can see CR is 0.04 which is <0.1 and thus the matrix is consistent

vii. 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.

	Freq	Critical	Time	Improve	Monetary
Die lines	0.48241	0.14899	0.25072	0.07721	0.27749
Inhomogeneous Deformation	0.2718	0.40918	0.14962	0.27284	0.17083
Surface Cracking	0.15751	0.31709	0.49674	0.12431	0.45271
Centre Burst	0.08829	0.12474	0.10292	0.52564	0.09897

Priority Vector
0.15893
0.37198
0.12863
0.2425
0.09797

Die lines	0.21025
Inhomogeneous Deformation	0.297549
Surface Cracking	0.281377
Centre Burst	0.210835

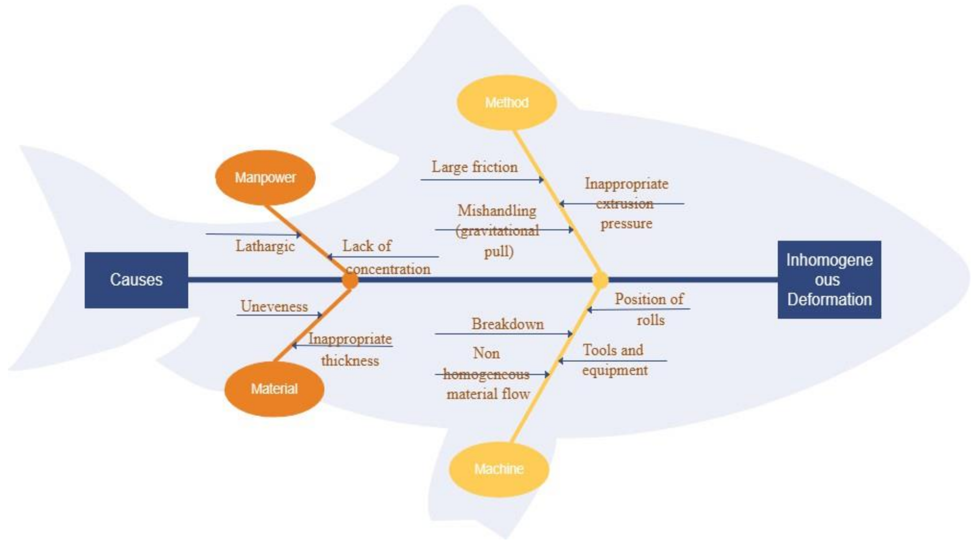
So according to AHP we need to work upon Inhomogeneous deformation defect. We are now going to find the causes of this defect by the help of cause and effect diagram.

b) Cause and effect diagram

- **Cause and Effect for Inhomogeneous deformation**

  Fishbone diagram of inhomogeneous deformation categorize the causes into 4 categories as shown below.

Ishikawa Diagram of Inhomogeneous Deformation



As the causes of inhomogeneous deformation defect is independent of each other therefore we can directly suggest some improvement measures to the company in order to improve the sigma level.

Corrective measures to reduce inhomogeneous deformation:

- There should be proper extrusion pressure.
- Proper handling of the pipes due to gravitational pull there occur deformation.
- Friction should be proper.
- Accurate positioning of guided rolls.
- Flow of material should be homogeneous.
- Thickness of the material should be proper.

After suggesting the corrective measure company will work on them to improve the sigma level .

IMPROVEMENT

a) Improvement of Inhomogeneous deformation:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

Check sheet for improving Inhomogeneous deformation

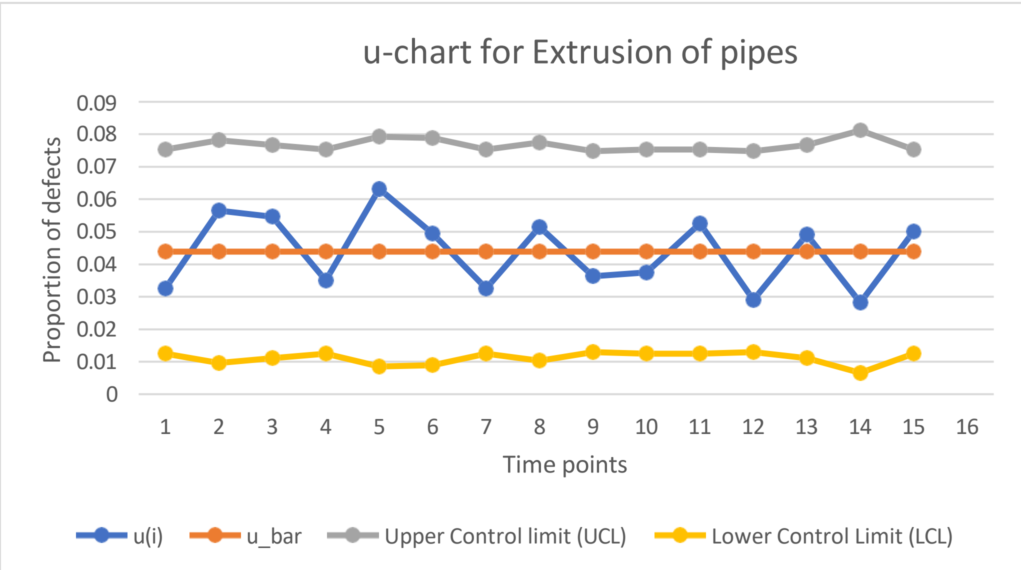
Defects\Shifts	Die Lines	Inhomogeneous Deformation	Centre burst	Surface Cracking	Total defects(c(i))	Total inspected units (n(i))
D1/S1	4	1	3	5	13	399.6
D1/S2	7	2	4	6	19	336.33
D2/S1	6	3	4	7	20	366.3
D2/S2	5	1	3	5	14	399.6
D3/S1	7	1	5	7	20	316.35
D3/S2	7	1	3	5	16	323.6
D4/S1	6	0	3	4	13	399.6
D4/S2	5	4	4	5	18	349.6
D5/S1	7	3	2	3	15	412.92
D5/S2	7	2	1	5	15	399.6
D6/S1	9	4	3	5	21	399.6
D6/S2	7	1	1	3	12	412.92
D7/S1	8	4	3	3	18	366.3
D7/S2	5	1	0	2	8	283.71
D8/S1	6	4	5	5	20	399.6
Total	96	32	44	70	242	5565.63

As we can see from the above table that the defects for inhomogeneous deformation reduces. Other defects also reduced simultaneously at some extent by working on this defect.

Construction of u-chart

Defects\Shifts	Total defects(c(i))	Total inspected units (n(i))	u(i)	u_bar	Upper Control limit (UCL)	Lower Control Limit (LCL)
D1/S1	13	399.6	0.032533	0.043881	0.075318	0.012443
D1/S2	19	336.33	0.056492	0.043881	0.078148	0.009614
D2/S1	20	366.3	0.0546	0.043881	0.076716	0.011046
D2/S2	14	399.6	0.035035	0.043881	0.075318	0.012443
D3/S1	20	316.35	0.063221	0.043881	0.079213	0.008548
D3/S2	16	323.6	0.049444	0.043881	0.078815	0.008946
D4/S1	13	399.6	0.032533	0.043881	0.075318	0.012443
D4/S2	18	349.6	0.051487	0.043881	0.077491	0.01027
D5/S1	15	412.92	0.036327	0.043881	0.074807	0.012955
D5/S2	15	399.6	0.037538	0.043881	0.075318	0.012443
D6/S1	21	399.6	0.052553	0.043881	0.075318	0.012443
D6/S2	12	412.92	0.029061	0.043881	0.074807	0.012955
D7/S1	18	366.3	0.04914	0.043881	0.076716	0.011046
D7/S2	8	283.71	0.028198	0.043881	0.08119	0.006571
D8/S1	20	399.6	0.05005	0.043881	0.075318	0.012443

u-chart



As we can see from the above u chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not.

Total number of opportunities we calculate from table 3.1

Total number of defects	242
Total no. of opportunities	8
Total inspected units	5565.63

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	5435.76
Sigma level	4.05

As we can see by working on Inhomogeneous deformation sigma level improves.

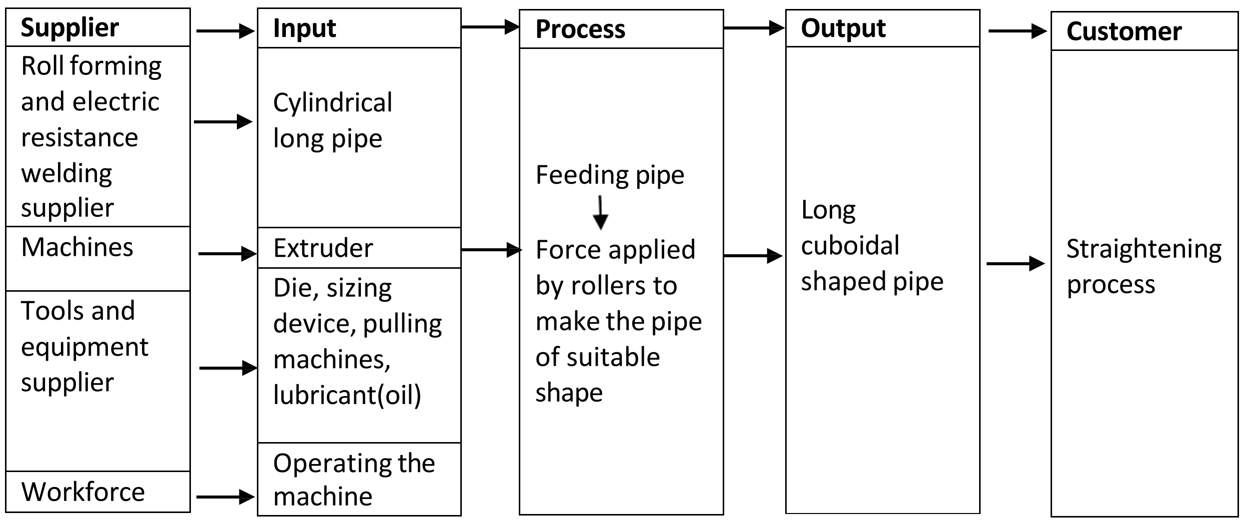
An implementation of the suggestions was done to the process and studied for a period of 8 days. The sigma level showed an improvement from **3.92 to 4.05** and the defects arising due to **Inhomogeneous deformation** were decreased; this may be a more optimistic picture in the reality. Thus, in control the process with improvements is maintained and standardized

Stage 4

Stage 4 comprises of the process Straightening which helps to straight the pipe because of deformation occurs at the previous stages.

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

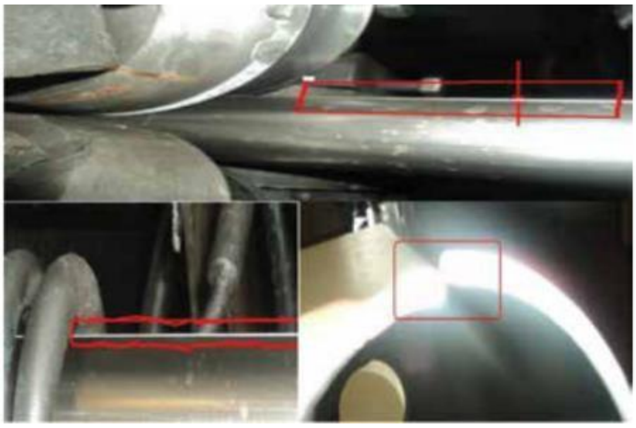
a) SIPOC Diagram



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

b) Defects in the various process of Stage 4 which are identified by the company are:

- **Mismatch Defect**



- **Indentation**

- **Cracks**

- **Concaves**

- **Twist**

c) Project charter

Project Charter	
Project Title: Defect reduction in stage 4 which involves **straightening**.	
Project objective and goal: To reduce the **indentation/dent** defect during the straightening process.	
Project location: JAY AAY Alloys(P) Limited an ERW pipe manufacturing facility near Panchkula, India	
Background and Rational for project selection:	
In the baseline process, Prioritize the defects in which **indentation/dent** defect has found to be highest priority as compared to the other defects based on expected values of multiple factors like cost, time, quality improvement etc.	
Project team:	Quality Head
	Mangers from Manufacturing, Purchasing and Maintenance
	Quality control inspector
	Research advisor and associates
	Floor operator
Expected benefits: Reduction in the defects due to **indentation/dent** which would lead to cost benefits.	
Project plan: Application of DMAIC model of Six-Sigma	
Project timeline: Four months	

Project charter helps in defining the problem, setting up the project team and time-line, defining responsibilities and roles to the team members and stating the desired outputs that can be synchronized with the business demand and customer’s requirements.

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 define stage is established, followed by defect prioritization with the help of Analytical hierarchy process (AHP).

Process specifications are followed to inspect the items with defects. As we are dealing with the continuous material so we are collecting the data of defects in 1 sq. ft. area which is considered as one unit to be inspected. There is also the possibility that one type of defect is present more than once in 1 unit so with the help of company's quality team we also record how many maximum no. of opportunity of a particular defect is possible shown in table 4.1

Defects	Defects in 1 sq. ft of area
Mismatch defect	2
Indentation(dent)	3
Concaves(bulging)	1
Surface cracks	3
Twist	1

The process output is sampled for 13 days and 25 data points are collected as JAY AAY ALLOY works in 2 shifts. In total, 7188.57 units are observed in 13 days were recorded using check sheets and the data is collected at different times in one shift.

To check whether process is in control or not, u- sampling that resulted into identification of 801 defects. The sampling data charts for fraction defects are drawn.

Di/Sj denotes the number of defects at day i in shift j where j=1,2

a) Check sheet for Pre-Analysis

Defects\Shifts	Mismatch defect	Indentation	**Concaves** (bulging)	Twist	Surface Cracks	Total Defects(c(i))	Total inspected units(n(i))
D1/S1	7	14	4	4	23	52	399.6
D1/S2	6	13	5	3	23	50	336.33
D2/S1	5	14	3	3	21	46	366.3
D2/S2	7	12	3	4	20	46	399.6
D3/S1	6	12	3	3	18	42	316.35
D3/S2	4	11	2	2	19	38	323.6
D4/S1	4	11	2	2	17	36	257.07
D4/S2	4	10	1	1	16	32	349.6
D5/S1	5	11	3	1	16	36	317
D5/S2	5	10	4	0	15	34	399.6

D6/S1	4	10	2	0	14	30	244.422
D6/S2	3	9	4	0	13	29	206.46
D7/S1	2	9	3	0	12	26	206.46
D7/S2	2	11	1	1	12	27	283.71
D8/S1	4	12	2	1	14	33	233.1
D8/S2	4	12	4	1	9	30	288.3
D9/S1	3	9	3	0	9	24	233.1
D9/S2	3	12	4	0	7	26	216.45
D10/S1	4	11	2	3	8	28	253.08
D10/S2	5	12	1	1	6	25	259.74
D11/S1	5	14	1	2	9	31	259.74
D11/S2	2	14	1	0	6	23	253.08
D12/S1	1	12	3	1	8	25	316.35
D12/S2	0	10	1	0	6	17	253.08
D13/S1	0	8	0	0	7	15	216.45
Total	95	283	62	33	328	801	7188.572

From the above table we can see that total number of units inspected are 7188.572 where 1 unit is 1 sq. ft area and total number of defects are 801.

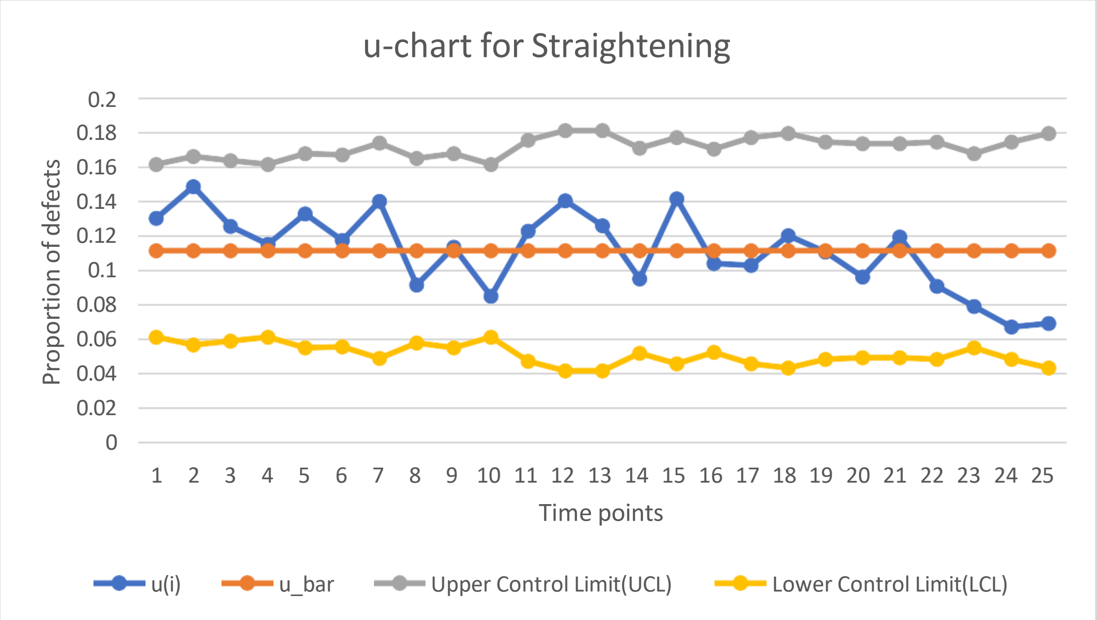
Now we plot the u-chart

b) Construction of u-chart

Defects\Shifts	Total Defects(c(i))	Total inspected units(n(i))	u(i)	u_bar	Upper Control Limit(UCL)	Lower Control Limit(LCL)
D1/S1	52	399.6	0.13013	0.111421	0.161516	0.061326
D1/S2	50	336.33	0.148664	0.111421	0.166025	0.056818
D2/S1	46	366.3	0.12558	0.111421	0.163744	0.059099
D2/S2	46	399.6	0.115115	0.111421	0.161516	0.061326
D3/S1	42	316.35	0.132764	0.111421	0.167723	0.05512
D3/S2	38	323.6	0.117429	0.111421	0.167089	0.055754
D4/S1	36	257.07	0.14004	0.111421	0.173878	0.048964
D4/S2	32	349.6	0.091533	0.111421	0.164979	0.057864
D5/S1	36	317	0.113565	0.111421	0.167665	0.055177
D5/S2	34	399.6	0.085085	0.111421	0.161516	0.061326
D6/S1	30	244.422	0.122739	0.111421	0.175474	0.047369
D6/S2	29	206.46	0.140463	0.111421	0.181114	0.041729
D7/S1	26	206.46	0.125932	0.111421	0.181114	0.041729
D7/S2	27	283.71	0.095168	0.111421	0.170873	0.051969
D8/S1	33	233.1	0.14157	0.111421	0.177011	0.045832
D8/S2	30	288.3	0.104058	0.111421	0.170398	0.052444
D9/S1	24	233.1	0.10296	0.111421	0.177011	0.045832
D9/S2	26	216.45	0.12012	0.111421	0.179487	0.043356

D10/S1	28	253.08	0.110637	0.111421	0.174368	0.048474
D10/S2	25	259.74	0.09625	0.111421	0.173556	0.049286
D11/S1	31	259.74	0.11935	0.111421	0.173556	0.049286
D11/S2	23	253.08	0.09088	0.111421	0.174368	0.048474
D12/S1	25	316.35	0.079026	0.111421	0.167723	0.05512
D12/S2	17	253.08	0.067172	0.111421	0.174368	0.048474
D13/S1	15	216.45	0.0693	0.111421	0.179487	0.043356

c) u-chart



From the u-chart it is clearly visible that the process is operating statistical control because the only reason of variation is by chance cause.

From control chart it is only clear that our process is consistent to check whether our process is producing products with less defects we need to calculate the sigma level.

The baseline sigma level of the process is estimated by the help of DPMO (defects per million opportunities)

Total number of opportunities we calculate from table 3.1

Total number of defects	801
Total no. of opportunities	10
Total inspected units	7188.572

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table given below:

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	11142.7
Sigma level	3.79

As we can see the sigma level of this stage is 3.79 which means that we can work on some defects to reduce them so that sigma level improves.

Now we wish to improve the current level of sigma. For this, we create Pareto Chart which will give information regarding which defectives has to be taken care or analyzed in order to reduce the number of defectives so that we can further improve the process. BUT this approach limits the gains realized from the project as other attributes such as criticality of defects; expected gains in monetary terms etc. are ignored while selecting the key defects. Therefore, we propose a Multi Criteria Decision Making (MCDM) approach for identification of key defects considering other attributes, including criticality of defect as per customer requirement, expected monetary and time requirements to deal with a defect and expected improvement in the process. The selection of key defects based on customers' and management's preference leads to greater customer satisfaction and higher monetary gains.

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 five criteria points which are as follows:

1. Cost Requirement
2. Criticality to Customer
3. Frequency of defects
4. Time requirement
5. Expected improvement

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that criticality to customer is the most important criteria followed by time requirement, frequency of defects, monetary requirement and at last expected improvement.

Now we develop the pairwise comparison matrix to prioritize the defects as suggested by the company.

i. Pairwise comparison matrix for criterion

Criteria	Freq	Critical	Time	Improve	Monetary
Frequency of Defects	1	0.166667	0.333333	4	3
Criticality to Customers	6	1	5	9	8
Time Requirement	3	0.2	1	5	4
Expected Improvement	0.25	0.111111	0.2	1	0.333333
Monetary Requirement	0.333333	0.125	0.25	3	1
Sum	10.58333	1.602778	6.783333	22	16.33333

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Criteria	Freq	Critical	Time	Improve	Monetary
Frequency of Defects	0.094488	0.103986	0.04914	0.181818	0.183673
Criticality to Customers	0.566929	0.623917	0.737101	0.409091	0.489796
Time Requirement	0.283465	0.124783	0.14742	0.227273	0.244898
Expected Improvement	0.023622	0.069324	0.029484	0.045455	0.020408
Monetary Requirement	0.031496	0.07799	0.036855	0.136364	0.061224

So the corresponding average priority vector is

Average Priority Vector
0.122621
0.565367
0.205568
0.037659
0.068786

We can see from the average priority vector criticality to customer is most preferred as suggested by the company also. Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**5.343726**
CI	0.085932
CR	0.076725

As we can see CR is 0.07 which is <0.1 and thus the matrix is consistent.

.

Now we do the pairwise comparison of defects on the basis of each of the criteria by the help of quality team of the company.

After collecting data in check sheet we get to know that surface cracks is the most important defect need to focus upon followed by indentation(dent), mismatch, concaves and at last centre twist on the basis of frequency of defects criteria.

ii. **Pairwise comparison matrix of defects on the basis of frequency of defects:**

Frequency of Defects	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	1	1	3	5	10
Indentation(Dent)	1	1	2	2	6
Mismatch defect	0.333333	0.5	1	1	3
Concaves(bulging)	0.2	0.5	1	1	3
Twist	0.1	0.166667	0.333333	0.333333	1
Sum	2.633333	3.166667	7.333333	9.333333	23

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Frequency of Defects	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	0.379747	0.315789	0.409091	0.535714	0.434783
Indentation(Dent)	0.379747	0.315789	0.272727	0.214286	0.26087
Mismatch defect	0.126582	0.157895	0.136364	0.107143	0.130435
Concaves(bulging)	0.075949	0.157895	0.136364	0.107143	0.130435
Twist	0.037975	0.052632	0.045455	0.035714	0.043478

So, the corresponding average priority vector is

Average Priority Vector
0.415025
0.288684
0.131684
0.121557
0.043051

So, according to the average priority vector surface cracks is the defect need to consider on the basis of frequency of defects criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**5.069032**
CI	0.017258
CR	0.015409

As we can see CR is 0.01 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that indentation (dent) is the most important defect need to focus upon followed by concaves, twist, surface cracks and at last mismatch defect on the basis of criticality to customer criteria.

iii. <u>Pairwise comparison matrix of defects on the basis of criticality to customers</u>:

Criticality to Customers	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	1	0.2	3	0.25	0.5
Indentation(Dent)	5	1	2	1	2
Mismatch defect	0.333333	0.5	1	0.333333	0.25
Concaves(bulging)	4	1	3	1	2
Twist	2	0.5	4	0.5	1
Sum	12.33333	3.2	13	3.083333	5.75

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Criticality to Customers	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	0.081081	0.0625	0.230769	0.081081	0.086957
Indentation(Dent)	0.405405	0.3125	0.153846	0.324324	0.347826
Mismatch defect	0.027027	0.15625	0.076923	0.108108	0.043478
Concaves(bulging)	0.324324	0.3125	0.230769	0.324324	0.347826
Twist	0.162162	0.15625	0.307692	0.162162	0.173913

So, the corresponding average priority vector is

Average Priority Vector
0.108478
0.30878
0.082357
0.307949
0.192436

So, according to the average priority vector Indentation(dent) is the defect need to consider on the basis of criticality to customer criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	5.405429
CI	0.101357
CR	0.090498

As we can see CR is 0.09 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that surface cracks is the most important defect need to focus upon followed by mismatch, twist, indentation and at last concaves on the basis of time requirement criteria.

iv. **<u>Pairwise comparison matrix of defects on the basis of time requirement</u>** .

Time Requirement	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	1	2	3	2	2
Indentation (Dent)	0.5	1	0.5	1	0.25
Mismatch defect	0.333333	2	1	3	2
Concaves(bulging)	0.5	1	0.333333	1	0.333333
Twist	0.5	4	0.5	3	1
Sum	2.833333	10	5.333333	10	5.583333

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Time Requirement	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	0.352941	0.2	0.5625	0.2	0.358209
Indentation(Dent)	0.176471	0.1	0.09375	0.1	0.044776
Mismatch defect	0.117647	0.2	0.1875	0.3	0.358209
Concaves(bulging)	0.176471	0.1	0.0625	0.1	0.059701
Twist	0.176471	0.4	0.09375	0.3	0.179104

So, the corresponding average priority vector is

Average Priority Vector
0.33473
0.102999
0.232671
0.099734
0.229865

So, according to the average priority vector surface cracks is the defect need to consider on the basis of time criticality criteria because it will take less time to correct.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**5.432472**
CI	0.108118
CR	0.096534

As we can see CR is 0.09 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that surface cracking is the most important defect need to focus upon followed by mismatch defect, concaves, twist and at last indentation (dent) on the basis of monetary requirement criteria.

v. <u>Pairwise comparison matrix of defects on the basis of monetary requirement</u>:

Monetary Requirement	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	1	2	3	2	2
Indentation(Dent)	0.5	1	0.333333	0.25	0.5
Mismatch defect	0.333333	3	1	3	2
Concaves(bulging)	0.5	4	0.333333	1	1
Twist	0.5	2	0.5	1	1
Sum	2.833333	12	5.166667	7.25	6.5

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Monetary Requirement	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	0.352941	0.166667	0.580645	0.275862	0.307692
Indentation(Dent)	0.176471	0.083333	0.064516	0.034483	0.076923
Mismatch defect	0.117647	0.25	0.193548	0.413793	0.307692
Concaves(bulging)	0.176471	0.333333	0.064516	0.137931	0.153846
Twist	0.176471	0.166667	0.096774	0.137931	0.153846

So, the corresponding average priority vector is

Average Priority Vector
0.336761
0.087145
0.256536
0.173219
0.146338

So, according to the average priority vector surface cracks is the defect need to consider on the basis of monetary requirement criteria because that would require less amount of money.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	5.459736
CI	0.114934
CR	0.10262

As we can see CR is 0.1 which is <=0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that indentation(dent) is the most important defect need to focus upon followed by mismatch, twist, concaves and at last surface cracks on the basis of expected improvement criteria.

vi. Pairwise comparison matrix of defects on the basis of expected improvement:

Expected Improvement	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	1	0.25	0.333333	0.5	0.2
Indentation(Dent)	4	1	3	4	3
Mismatch defect	3	0.333333	1	2	3
Concaves(bulging)	2	0.25	0.5	1	1

Twist	5	0.333333	0.333333	1	1
Sum	15	2.166667	5.166667	8.5	8.2

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Expected Improvement	Cracks	Dent	Mismatch	Concaves	Twist
Surface cracks	0.066667	0.115385	0.064516	0.058824	0.02439
Indentation(Dent)	0.266667	0.461538	0.580645	0.470588	0.365854
Mismatch defect	0.2	0.153846	0.193548	0.235294	0.365854
Concaves(bulging)	0.133333	0.115385	0.096774	0.117647	0.121951
Twist	0.333333	0.153846	0.064516	0.117647	0.121951

So, the corresponding average priority vector is

Average Priority Vector
0.065956
0.429058
0.229708
0.117018
0.158259

So, according to the average priority vector indentation is the defect need to consider on the basis of expected improvement criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**5.346206**
CI	0.086552
CR	0.077278

As we can see CR is 0.07 which is <0.1 and thus the matrix is consistent.

vii. 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.

	Freq	Critical	Time	Improve	Monetary
Surface cracks	0.434828	0.108478	0.33473	0.065956	0.336761
Indentation (Dent)	0.253382	0.30878	0.102999	0.429058	0.087145
Mismatch defect	0.134044	0.082357	0.232671	0.229708	0.256536
Concaves(bulging)	0.134044	0.307949	0.099734	0.117018	0.173219
Twist	0.043701	0.192436	0.229865	0.158259	0.146338

Priority Vector
0.122621
0.565367
0.205568
0.037659
0.068786

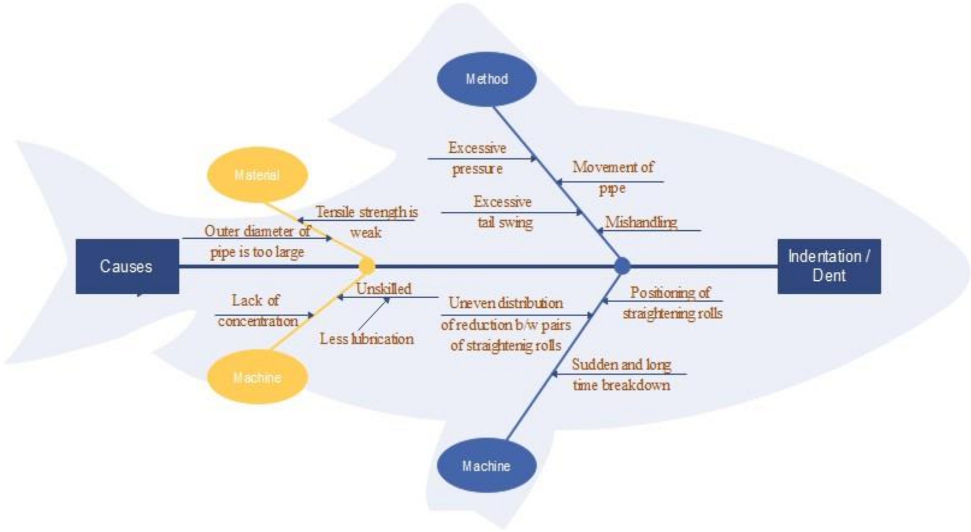
Surface cracks	0.209107
Indentation (Dent)	0.24897
Mismatch defect	0.137125
Concaves(bulging)	0.227365
Twist	0.177434

So according to AHP we need to work upon indentation (dent) defect. We are now going to find the causes of this defect by the help of cause and effect diagram.

b) Cause and effect diagram

- **Cause and Effect for indentation(dent)**
  Fishbone diagram of Indentation categorize the causes into 4 categories as shown below.

Ishikawa Diagram of Indententation/Dent Defect



As the causes of indentation(dent) defect is independent of each other therefore we can directly suggest some improvement measures to the company in order to improve the sigma level.

<u>Corrective measures to reduce inhomogeneous deformation:</u>

- There should not be excessive pressure.
- There should not be excessive tail swing.
- Pipe should be moved in proper manner.
- Accurate positioning of straightening rolls.
- There should be proper lubrication.
- There should be even distribution of reduction between straightening rolls.

After suggesting the corrective measure company will work on them to improve the sigma level .

IMPROVEMENT

a) Improvement of Indentation:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

Check sheet for improving Indentation

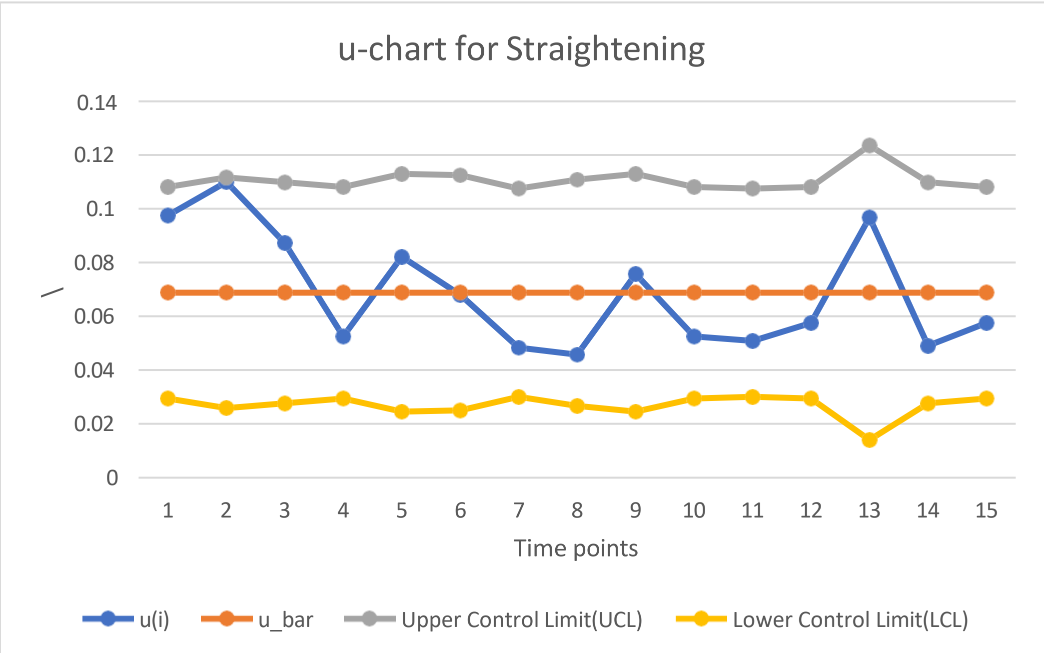
Defects\Shifts	Mismatch defect	Indentation	Concaves(bulging)	Twist	Surface Cracks	Total Defects(c(i))	Total inspected units(n(i))
D1/S1	7	4	4	4	20	39	399.6
D1/S2	6	3	5	3	20	37	336.33
D2/S1	5	4	3	3	17	32	366.3
D2/S2	3	0	2	4	12	21	399.6
D3/S1	6	2	3	3	12	26	316.35
D3/S2	4	1	2	2	13	22	323.6
D4/S1	4	1	2	2	11	20	412.92
D4/S2	4	0	1	1	10	16	349.6
D5/S1	5	1	3	1	11	24	317
D5/S2	5	1	4	0	11	21	399.6
D6/S1	4	1	2	0	14	21	412.92
D6/S2	3	3	4	0	13	23	399.6
D7/S1	2	3	3	0	12	20	206.46
D7/S2	2	2	1	1	12	18	366.3
D8/S1	4	2	2	1	14	23	399.6
Total	64	28	41	25	202	363	5405.78

As we can see from the above table that the defects for indentation (dent) reduces. Other defects also reduced simultaneously at some extent by working on this defect.

Construction of u-chart

Defects\Shifts	Total Defects(c(i))	Total inspected units(n(i))	u(i)	u_bar	Upper Control Limit(UCL)	Lower Control Limit(LCL)
D1/S1	39	399.6	0.097598	0.068809	0.108176	0.029442
D1/S2	37	336.33	0.110011	0.068809	0.11172	0.025899
D2/S1	32	366.3	0.08736	0.068809	0.109927	0.027692
D2/S2	21	399.6	0.052553	0.068809	0.108176	0.029442
D3/S1	26	316.35	0.082187	0.068809	0.113054	0.024565
D3/S2	22	323.6	0.067985	0.068809	0.112556	0.025063
D4/S1	20	412.92	0.048436	0.068809	0.107536	0.030083
D4/S2	16	349.6	0.045767	0.068809	0.110898	0.026721
D5/S1	24	317	0.07571	0.068809	0.113009	0.02461
D5/S2	21	399.6	0.052553	0.068809	0.108176	0.029442
D6/S1	21	412.92	0.050857	0.068809	0.107536	0.030083
D6/S2	23	399.6	0.057558	0.068809	0.108176	0.029442
D7/S1	20	206.46	0.096871	0.068809	0.123578	0.014041
D7/S2	18	366.3	0.04914	0.068809	0.109927	0.027692
D8/S1	23	399.6	0.057558	0.068809	0.108176	0.029442

u-chart



As we can see from the above u chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not.

Total number of opportunities we calculate from table 4.1

Total number of defects	363
Total no. of opportunities	10
Total inspected units	5405.78

DPMO is calculated using the following

DPMO=Total no. of Defects/ ((Total no. of opportunities) * (Total no. of inspected units))

Sigma level is now calculated from the table

Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO	Sigma	DPMO
6.00	3.4	5.00	233	4.00	6210	3.00	66807	2.00	308538	1.00	691462
5.95	4.3	4.95	280	3.95	7143	2.95	73529	1.95	326355	0.95	706840
5.90	5.4	4.90	337	3.90	8196	2.90	80757	1.90	344578	0.90	725747
5.85	6.8	4.85	404	3.85	9387	2.85	88508	1.85	363169	0.85	742154
5.80	8.5	4.80	483	3.80	10724	2.80	96801	1.80	382089	0.80	758036
5.75	11	4.75	577	3.75	12224	2.75	105650	1.75	401294	0.75	773373
5.70	13	4.70	687	3.70	13903	2.70	115070	1.70	420740	0.70	788145
5.65	17	4.65	816	3.65	15778	2.65	125072	1.65	440382	0.65	802338
5.60	21	4.60	968	3.60	17864	2.60	135666	1.60	460172	0.60	815940
5.55	26	4.55	1144	3.55	20182	2.55	146859	1.55	480061	0.55	828944
5.50	32	4.50	1350	3.50	22750	2.50	158655	1.50	500000	0.50	841345
5.45	39	4.45	1589	3.45	25588	2.45	171056	1.45	519939	0.45	853141
5.40	48	4.40	1806	3.40	28716	2.40	184060	1.40	539828	0.40	864334
5.35	59	4.35	2186	3.35	32157	2.35	197662	1.35	559618	0.35	874928
5.30	72	4.30	2555	3.30	35930	2.30	211855	1.30	579260	0.30	884930
5.25	88	4.25	2980	3.25	40059	2.25	226627	1.25	596706	0.25	894350
5.20	108	4.20	3467	3.20	44565	2.20	241964	1.20	617911	0.20	903199
5.15	131	4.15	4025	3.15	49471	2.15	257846	1.15	636831	0.15	911492
5.10	159	4.10	4661	3.10	54799	2.10	274253	1.10	655422	0.10	919243
5.05	193	4.05	5386	3.05	60571	2.05	291160	1.05	673645	0.05	926471

DPMO	6716
Sigma level	3.97

As we can see by working on Indentation (dent) sigma level improves.

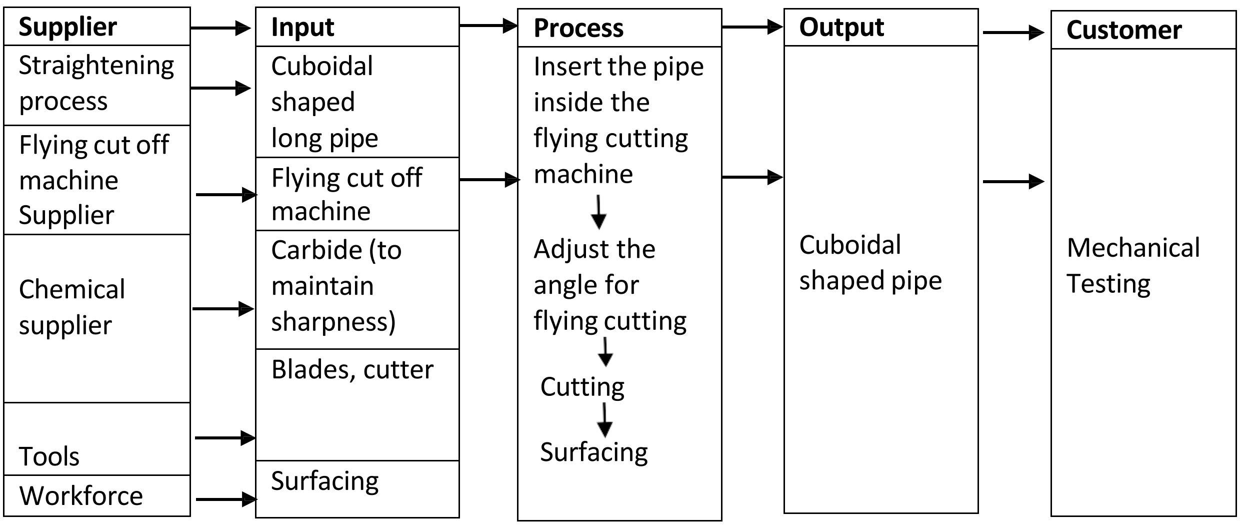
An implementation of the suggestions was done to the process and studied for a period of 8 days. The sigma level showed an improvement from **3.79 to 3.97** and the defects arising due to **Indentation (dent)** were decreased; this may be a more optimistic picture in the reality. Thus, in control the process with improvements is maintained and standardized

Stage 5

Stage 5 comprises of flying cutting and end surfacing. Flying cutting is used to cut the pipe into required size and then at last there would be end surfacing of the pipe takes place.

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

a) SIPOC Diagram

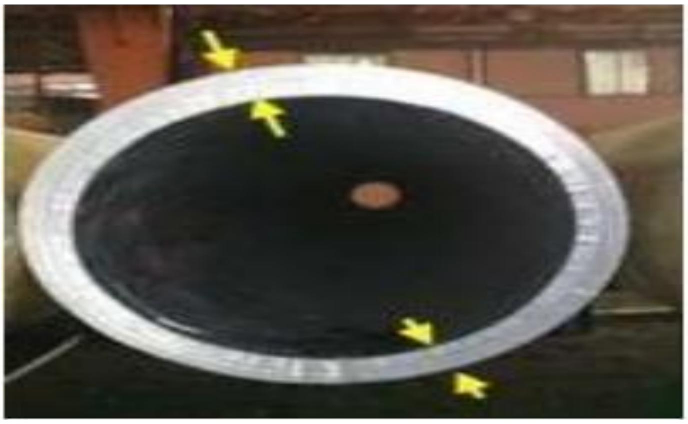


The SIPOC diagram maps process flows, enumerating the supplier, inputs process, output and customers of the process that helps further investigation of the problem

b) Defects in the various process of Stage 4 which are identified by the company are

- **Irregular edges**

- **Improper dimension**



- **Irregular surfacing**
- **Undercut**

c) Project charter

Project Charter	
Project Title: Defect reduction in stage 5 which involves **flying cutting and surfacing**.	
Project objective and goal: To reduce the **irregular surfacing** defect in the mentioned processes of stage 5.	
Project location: JAY AAY Alloys(P) Limited an ERW pipe manufacturing facility near Panchkula, India	
Background and Rational for project selection:	
In the baseline process, Prioritize the defects in which **irregular surfacing** defect has found to be highest priority as compared to the other defects based on expected values of multiple factors like cost, time, quality improvement etc.	
Project team:	Quality Head
	Mangers from Manufacturing, Purchasing and Maintenance
	Quality control inspector
	Research advisor and associates
	Floor operator
Expected benefits: Reduction in the defects due to **irregular surfacing** which would lead to cost benefits.	
Project plan: Application of DMAIC model of Six-Sigma	
Project timeline: Four months	

Project charter helps in defining the problem, setting up the project team and time-line, defining responsibilities and roles to the team members and stating the desired outputs that can be synchronized with the business demand and customer's requirements.

Measure

In the measure phase of DMAIC methodology, the current level of the process performance (in terms of sigma level) based on the four defects identified in the define stage is established, followed by defect prioritization with the help of Analytical hierarchy process (AHP).

Now as in this process we do not have continuous material we have the pipes so that's why we need to consider the defectives rather than defects.

Process specifications are followed to inspect the items for four types of defects. The items are labelled as defective due to the presence of any of these defects. In total, 6009 units are observed in 13 days sampling that resulted into identification of 467 defective units. The sampling data were recorded using check sheet.

a) Check sheet for pre analysis

Defects\Shifts	Undercut	Irregular edges	Improper Dimension	Irregular surfacing	Total Defectives(d(i))	Total Inspected Units(n(i))
D1/S1	10	9	7	6	32	250
D1/S2	7	7	6	7	27	220
D2/S1	6	8	8	6	28	223
D2/S2	3	4	5	6	18	251
D3/S1	6	7	7	9	29	229
D3/S2	6	8	5	9	28	232
D4/S1	6	7	4	8	25	257
D4/S2	5	7	5	7	24	263
D5/S1	5	8	3	9	25	223
D5/S2	2	3	4	3	12	250
D6/S1	7	6	3	6	22	218
D6/S2	4	6	3	7	20	211
D7/S1	4	8	1	5	18	220
D7/S2	3	5	2	5	15	245
D8/S1	3	6	2	3	14	234

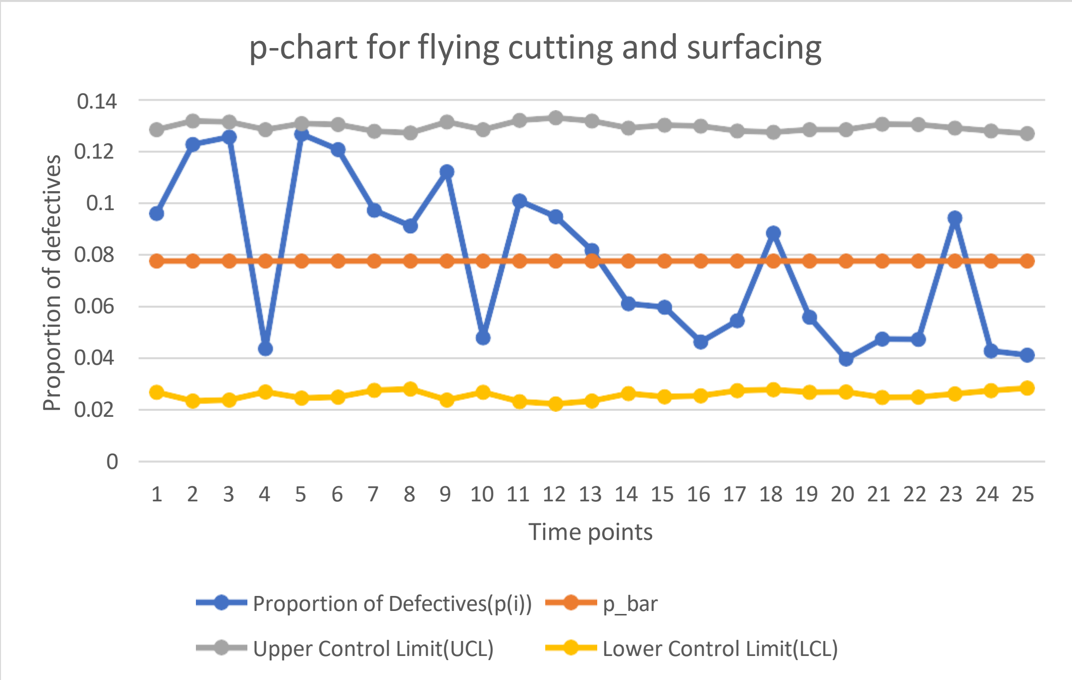
D8/S2	2	4	1	4	11	237
D9/S1	3	5	0	6	14	256
D9/S2	3	8	6	6	23	260
D10/S1	1	7	1	5	14	250
D10/S2	0	3	2	5	10	251
D11/S1	0	4	3	4	11	231
D11/S2	1	3	4	3	11	232
D12/S1	1	4	5	4	14	244
D12/S2	1	2	5	3	11	256
D13/S1	1	4	2	4	11	266
Total	90	143	94	140	467	6009

Let us first check whether the process is in statistical control or not. For that, we will plot p Chart here as we have the data for an attribute of the process i.e. the number and proportion of defectives.

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

Defects\Shifts	Total Defectives(d(i))	Total Inspected Units(n(i))	Proportion of Defectives(p(i))	p_bar	Upper Control Limit(UCL)	Lower Control Limit(LCL)
D1/S1	32	250	0.128	0.078587	0.129644	0.02753
D1/S2	27	220	0.122727	0.078587	0.133014	0.02416
D2/S1	28	223	0.125561	0.078587	0.132647	0.024528
D2/S2	18	251	0.071713	0.078587	0.129542	0.027632
D3/S1	29	229	0.126638	0.078587	0.131934	0.025241
D3/S2	28	232	0.12069	0.078587	0.131588	0.025587
D4/S1	25	257	0.097276	0.078587	0.128944	0.02823
D4/S2	24	263	0.091255	0.078587	0.128366	0.028808
D5/S1	25	223	0.112108	0.078587	0.132647	0.024528
D5/S2	12	250	0.048	0.078587	0.129644	0.02753
D6/S1	22	218	0.100917	0.078587	0.133263	0.023911
D6/S2	20	211	0.094787	0.078587	0.134163	0.023012
D7/S1	18	220	0.081818	0.078587	0.133014	0.02416
D7/S2	15	245	0.061224	0.078587	0.130162	0.027012
D8/S1	14	234	0.059829	0.078587	0.131361	0.025814
D8/S2	11	237	0.046414	0.078587	0.131026	0.026149
D9/S1	14	256	0.054688	0.078587	0.129042	0.028132
D9/S2	23	260	0.088462	0.078587	0.128652	0.028522
D10/S1	14	250	0.056	0.078587	0.129644	0.02753
D10/S2	10	251	0.039841	0.078587	0.129542	0.027632
D11/S1	11	231	0.047619	0.078587	0.131702	0.025472
D11/S2	11	232	0.047414	0.078587	0.131588	0.025587
D12/S1	14	244	0.057377	0.078587	0.130268	0.026906
D12/S2	11	256	0.042969	0.078587	0.129042	0.028132
D13/S1	11	266	0.041353	0.078587	0.128085	0.02909

c) P-chart



From the p-chart it is clearly visible that the process is operating statistical control because the only reason of variation is by chance cause.

From control chart it is only clear that our process is consistent to check whether our process is producing products with less defectives we need to calculate the sigma level.

Sigma level is calculated by the help of yield in case of defectives.

Now, Yield is the percentage of non-defective items and thus it is given by the formula as:

d) <u>Yield</u> = (1-(total number of defectives/total number of items inspected))*100

Sigma level can then be calculated as the two tailed z-value treating Yield as the area under the curve with a shift of +1.5 which is the industry standard. The formula used is given as:

e) <u>Sigma Level</u> = NORM.S.INV(0.5+(Yield/100/2)) + 1.5

Using these formulas, the results obtained are:

Yield	92.32817
σ level	3.270053

As we can see, the **Sigma Level is just 3.270053**, which is quite low as compared to the other products manufactured by the company.

Thus there is scope of improvement so we will start the defect analysis here. So we move onto the next stage of our methodology, i.e. Analyse.

Now we wish to improve the current level of sigma. For this, we create Pareto Chart which will give information regarding which defectives has to be taken care or analyzed in order to reduce the number of defectives so that we can further improve the process. BUT this approach limits the gains realized from the project as other attributes such as criticality of defects; expected gains in monetary terms etc. are ignored while selecting the key defects. Therefore, we propose a Multi Criteria Decision Making (MCDM) approach for identification of key defects considering other attributes, including criticality of defect as per customer requirement, expected monetary and time requirements to deal with a defect and expected improvement in the process. The selection of key defects based on customers' and management's preference leads to greater customer satisfaction and higher monetary gains.

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 five criteria points which are as follows:

1. Cost Requirement

2. Criticality to Customer

3. Frequency of defects

4. Time requirement

5. Expected improvement

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that expected improvement is the most important criteria followed by criticality to customer, time requirement, monetary requirement and at last frequency of defects.

Now we develop the pairwise comparison matrix to prioritize the defects as suggested by the company.

i. **Pairwise comparison matrix for criterion**

Criteria	Freq	Critical	Time	Improve	Monetary
Frequency of Defects	1	0.25	0.333333	0.2	0.5
Criticality to Customers	4	1	3	1	2
Time Requirement	3	0.333333	1	0.333333	2
Expected Improvement	5	1	3	1	3
Monetary Requirement	2	0.5	0.5	0.333333	1
Sum	15	3.083333	7.833333	2.866667	8.5

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Criteria	Freq	Critical	Time	Improve	Monetary
Frequency of Defects	0.066667	0.081081	0.042553	0.069767	0.058824
Criticality to Customers	0.266667	0.324324	0.382979	0.348837	0.235294
Time Requirement	0.2	0.108108	0.12766	0.116279	0.235294
Expected Improvement	0.333333	0.324324	0.382979	0.348837	0.352941
Monetary Requirement	0.133333	0.162162	0.06383	0.116279	0.117647

So the corresponding average priority vector is

Average Priority Vector
0.063778
0.31162
0.157468
0.348483
0.11865

We can see from the average priority vector expected improvement is most preferred as suggested by the company also. Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**5.123691**
CI	0.030923
CR	0.02761

As we can see CR is 0.02 which is <0.1 and thus the matrix is consistent.

Now we do the pairwise comparison of defects on the basis of each of the criteria by the help of quality team of the company.

After collecting data in check sheet we get to know that irregular edges is the most important defect need to focus upon followed by irregular surfacing, undercut and at last centre improper dimension on the basis of frequency of defects criteria.

ii. Pairwise comparison matrix of defects on the basis of frequency of defects:

Frequency of Defects	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	1	0.5	1	1
Irregular edges	2	1	2	1
Improper Dimension	1	0.5	1	0.5
Irregular surfacing	1	1	2	1
Sum	5	3	6	3.5

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Frequency of Defects	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	0.2	0.166667	0.166667	0.285714
Irregular edges	0.4	0.333333	0.333333	0.285714
Improper Dimension	0.2	0.166667	0.166667	0.142857
Irregular surfacing	0.2	0.333333	0.333333	0.285714

So, the corresponding average priority vector is

Average Priority Vector
0.204762
0.338095
0.169048
0.288095

So, according to the average priority vector irregular edges is the defect need to consider on the basis of frequency of defects criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	4.060688
CI	0.020229
CR	0.022477

As we can see CR is 0.02 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that improper dimension is the most important defect need to focus upon followed by irregular edges, irregular surfacing and at last undercut defect on the basis of criticality to customer criteria.

iii. **Pairwise comparison matrix of defects on the basis of criticality to customers:**

Criticality to Customers	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	1	0.25	0.333333	0.5
Irregular edges	4	1	1	2
Improper Dimension	3	1	1	3
Irregular surfacing	2	0.5	0.333333	1
Sum	10	2.75	2.666667	6.5

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Criticality to Customers	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	0.1	0.090909	0.125	0.076923
Irregular edges	0.4	0.363636	0.375	0.307692
Improper Dimension	0.3	0.363636	0.375	0.461538
Irregular surfacing	0.2	0.181818	0.125	0.153846

So, the corresponding average priority vector is

Average Priority Vector
0.098208
0.361582
0.375044
0.165166

So, according to the average priority vector Improper dimension is the defect need to consider on the basis of criticality to customer criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	**4.045774**
CI	0.015258
CR	0.016953

As we can see CR is 0.01 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that irregular edges is the most important defect need to focus upon followed by irregular surfacing, undercut and at last improper dimension on the basis of time requirement criteria.

iv. **<u>Pairwise comparison matrix of defects on the basis of time requirement</u>** :

Time Requirement	**Undercut**	**Ir. Edge**	**Imp. Dim**	**Ir. Surfacing**
Undercut	1	0.333333	2	0.5
Irregular edges	3	1	3	2
Improper Dimension	0.5	0.333333	1	0.333333
Irregular surfacing	2	0.5	3	1
Sum	6.5	2.166667	9	3.833333

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Time Requirement	**Undercut**	**Ir. Edge**	**Imp. Dim**	**Ir. Surfacing**
Undercut	0.153846	0.153846	0.222222	0.130435
Irregular edges	0.461538	0.461538	0.333333	0.521739
Improper Dimension	0.076923	0.153846	0.111111	0.086957
Irregular surfacing	0.307692	0.230769	0.333333	0.26087

So, the corresponding average priority vector is

Average Priority Vector
0.165087
0.444537
0.107209
0.283166

So, according to the average priority vector irregular edges is the defect need to consider on the basis of time criticality criteria because it will take less time to correct.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	4.071224
CI	0.023741
CR	0.026379

As we can see CR is 0.02 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that irregular edges is the most important defect need to focus upon followed by irregular surfacing, undercut and at last improper dimension on the basis of monetary requirement criteria.

v. **<u>Pairwise comparison matrix of defects on the basis of monetary requirement</u>:**

Monetary Requirement	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	1	0.333333	0.5	0.5
Irregular edges	3	1	2	3
Improper Dimension	2	0.5	1	0.5

Irregular surfacing	2	0.333333	2	1
Sum	8	2.166667	5.5	5

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Monetary Requirement	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	0.125	0.153846	0.090909	0.1
Irregular edges	0.375	0.461538	0.363636	0.6
Improper Dimension	0.25	0.230769	0.181818	0.1
Irregular surfacing	0.25	0.153846	0.363636	0.2

So, the corresponding average priority vector is

Average Priority Vector
0.117439
0.450044
0.190647
0.241871

So, according to the average priority vector irregular edges is the defect need to consider on the basis of monetary requirement criteria because that would require less amount of money.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	4.143912
CI	0.047971
CR	0.053301

As we can see CR is 0.05 which is <0.1 and thus the matrix is consistent.

After consulting from the quality team at JAY AAY Alloys Pvt. Ltd. we get to know that irregular edges is the most important defect need to focus upon followed by irregular surfacing, improper dimension and at last undercut on the basis of expected improvement criteria.

Expected Improvement	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	1	0.25	0.333333	0.5
Irregular edges	4	1	3	4
Improper Dimension	3	0.333333	1	0.5
Irregular surfacing	2	0.25	2	1
sum	10	1.833333	6.333333	6

Now we normalize the matrix by dividing each entry of the row by its corresponding row sum and we get the matrix as:

Expected Improvement	Undercut	Ir. Edge	Imp. Dim	Ir. Surfacing
Undercut	0.1	0.136364	0.052632	0.083333
Irregular edges	0.4	0.545455	0.473684	0.666667
Improper Dimension	0.3	0.181818	0.157895	0.083333
Irregular surfacing	0.2	0.136364	0.315789	0.166667

So, the corresponding average priority vector is

Average Priority Vector
0.093082
0.521451
0.180762
0.204705

So, according to the average priority vector irregular edges is the defect need to consider on the basis of expected improvement criteria.

Now, the lambda maximum, consistency index and ratio are calculated by using the respective formulas.

To check whether the matrix is consistent, we calculate Consistency Ratio (CR) as:

Lambda max	4.214162
CI	0.071387
CR	0.079319

As we can see CR is 0.07 which is <0.1 and thus the matrix is consistent.

vi. 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.

	Freq	Critical	Time	Improve	Monetary
Undercut	0.204762	0.098208	0.165087	0.093082	0.117439
Irregular edges	0.338095	0.361582	0.444537	0.521451	0.450044
Improper Dimension	0.169048	0.375044	0.107209	0.180762	0.190647
Irregular surfacing	0.288095	0.165166	0.283166	0.204705	0.241871

Priority Vector(criteria)
0.063778
0.31162
0.157468
0.348483
0.11865

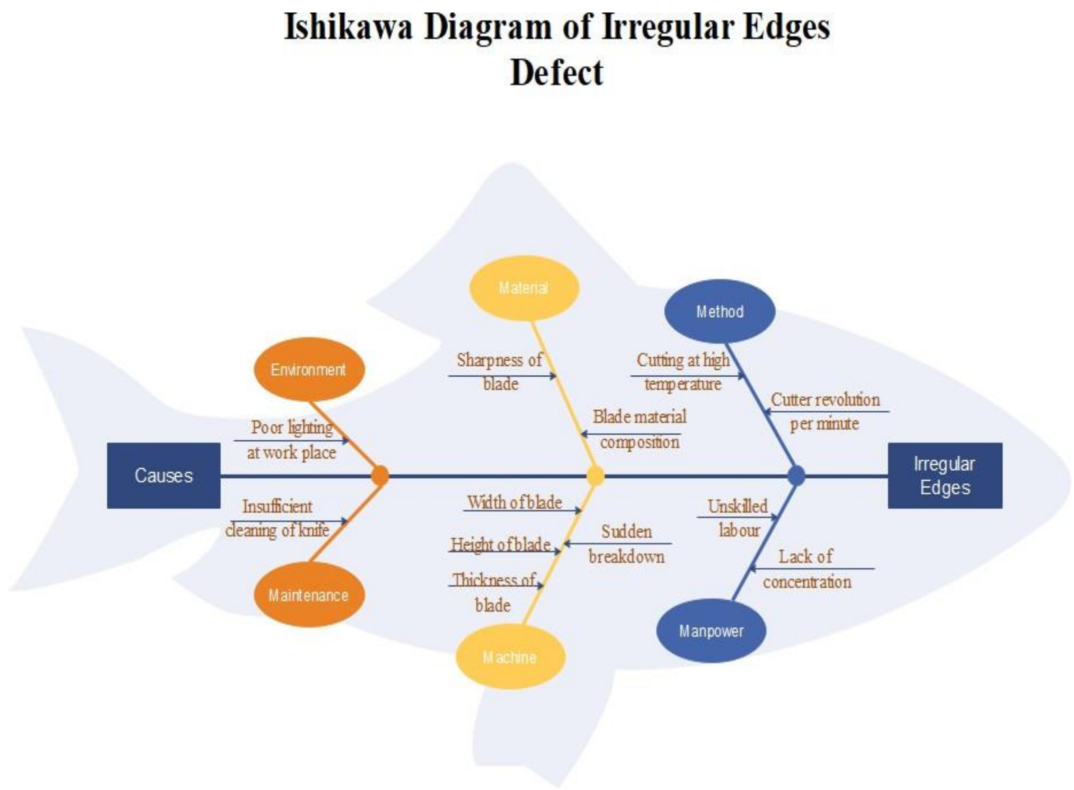
Undercut	0.116031
Irregular edges	0.439355
Improper Dimension	0.230147
Irregular surfacing	0.214467

So according to AHP we need to work upon irregular edges defect. We are now going to find the causes of this defect by the help of cause and effect diagram.

b) Cause and effect diagram

- **Cause and Effect for irregular edges**

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



As the causes of irregular edges defect is independent of each other therefore we can directly suggest some improvement measures to the company in order to improve the sigma level.

Corrective measures to reduce inhomogeneous deformation:

- There should be proper sharpness and material composition of blade.
- Width, height and thickness of the blade should be maintained .
- Knife should be properly cleaned.
- Cutter revolution per minute should not be very high.
- Labour must be properly skilled

After suggesting the corrective measure company will work on them to improve the sigma level .

IMPROVEMENT

a) Improvement of Irregular edges:

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 8 days and 15 data points are collected as JAY AAY ALLOY works in 2 shifts. The sampling data were recorded using check sheets and the data is collected at different times in one shift.

Check sheet for improving irregular edges

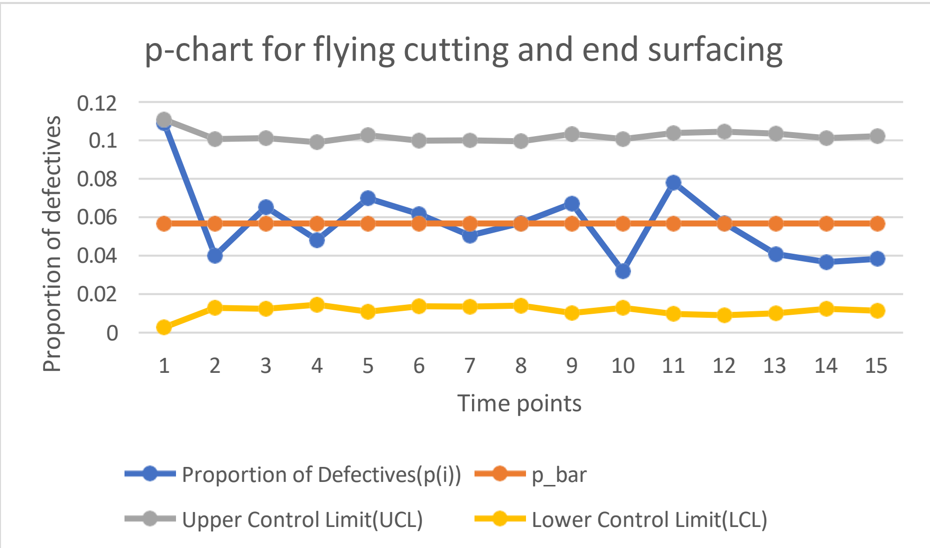
Defects\Shifts	Undercut	Irregular edges	Improper Dimension	Irregular surfacing	Total Defectives(d(i))	Total Inspected Units(n(i))
D1/S1	8	0	6	4	18	165
D1/S2	4	1	4	1	10	250
D2/S1	4	2	6	4	16	245
D2/S2	2	1	4	6	13	270
D3/S1	3	0	4	9	16	229
D3/S2	3	1	3	9	16	259
D4/S1	2	1	2	8	13	257
D4/S2	3	1	4	7	15	263
D5/S1	3	2	1	9	15	223
D5/S2	1	2	2	3	8	250
D6/S1	8	1	2	6	17	218
D6/S2	3	1	1	7	12	211
D7/S1	3	1	0	5	9	220
D7/S2	3	0	1	5	9	245
D8/S1	3	1	2	3	9	234
Total	53	15	42	86	196	3539

As we can see from the above table that the defects for irregular edges reduces. Other defects also reduced simultaneously at some extent by working on this defect.

Construction of p-chart

Defects\Shifts	Total Defectives(d(i))	Total Inspected Units(n(i))	Proportion of Defectives(p(i))	p_bar	Upper Control Limit(UCL)	Lower Control Limit(LCL)
D1/S1	18	165	0.109091	0.056802	0.11086	0.002744
D1/S2	10	250	0.04	0.056802	0.100719	0.012885
D2/S1	16	245	0.065306	0.056802	0.101165	0.012439
D2/S2	13	270	0.048148	0.056802	0.099061	0.014543
D3/S1	16	229	0.069869	0.056802	0.102689	0.010915
D3/S2	16	259	0.061776	0.056802	0.09995	0.013655
D4/S1	13	257	0.050584	0.056802	0.100117	0.013487
D4/S2	15	263	0.057034	0.056802	0.09962	0.013984
D5/S1	15	223	0.067265	0.056802	0.103302	0.010302
D5/S2	8	250	0.032	0.056802	0.100719	0.012885
D6/S1	17	218	0.077982	0.056802	0.103832	0.009772
D6/S2	12	211	0.056872	0.056802	0.104606	0.008998
D7/S1	9	220	0.040909	0.056802	0.103618	0.009986
D7/S2	9	245	0.036735	0.056802	0.101165	0.012439
D8/S1	9	234	0.038462	0.056802	0.102196	0.011408

p-chart



As we can see from the above p chart that the process is still in control this means that the variability is still not because of any assignable cause.

Now we check the sigma level to check whether we have improved it or not and in case of defectives we evaluate it with the help of yield.

Now, Yield is the percentage of non-defective items and thus it is given by the formula as:

<u>Yield</u> = (1-(total number of defectives/total number of items inspected))*100

Sigma level can then be calculated as the two tailed z-value treating Yield as the area under the curve with a shift of +1.5 which is the industry standard. The formula used is given as:

<u>Sigma Level</u> = NORM.S.INV(0.5+(Yield/100/2)) + 1.5

Using these formulas, the results obtained are:

Yield	94.46171
σ level	3.41586

As we can see by working on Irregular edges sigma level improves.

An implementation of the suggestions was done to the process and studied for a period of 8 days. The sigma level showed an improvement from **3.27 to 3.41** and the defects arising due to irregular edges 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	4.04	4.4
Stage 2	4.21	4.4
Stage 3	3.92	4.05
Stage 4	3.79	3.97
Stage 5	3.27	3.41
Overall	**3.846**	**4.046**

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) JAY AAY ALLOYS (P) LIMITED : JAY AAY ALLOYS PRIVATE LIMITED - Company, directors and contact details | Zauba Corp