PRODUCT IMPROVEMENT USING DMAIC IN AUTOMOBILE PARTS MANUFACTURING COMPANY

M.TECH. DISSERTATION

BY

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DEPARTMENT OF MECHANICAL ENGINEERING

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A

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ON

PRODUCT IMPROVEMENT USING DMAIC IN AUTOMOBILE PARTS MANUFACTURING COMPANY

Submitted in partial fulfillment of the requirements for the award of degree of

MASTER OF TECHNOLOGY
IN
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Certificate

This is to certify that the dissertation work entitled "Product Improvement Using DMAIC in Automobile Parts Manufacturing Company" by **Mr. Pradeep Kumar** is a bona fide work completed under my supervision and guidance, and hence approved for submission to The Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur in partial fulfillment of the requirements for the award of the degree of Master of Technology with specialization in Industrial Engineering. The matter embodied in this Seminar Report has not been submitted for the award of any other degree, or diploma.

(Dr. M. L. MEENA)

Assistant Professor

Place: Jaipur

Date: 25 June, 2015

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Candidate's Declaration

I hereby certify that the work which is being presented in the dissertation entitled "Product Improvement Using DMAIC in Automobile Parts Manufacturing Company", in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Industrial Engineering, submitted in the Department of Mechanical Engineering, Malaviya National Institute of Technology Jaipur is an authentic record of my own work carried out for a period of one year under the supervision of Dr. M. L. Meena, Assistant Professor of Mechanical Engineering Department, Malaviya National Institute of Technology Jaipur.

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It has been a great experience working on this dissertation project **"Product Improvement Using DMAIC in Automobile Parts Manufacturing Company"** towards the partial fulfillment of the requirements for the award of the Degree of Master of Technology in Industrial Engineering.

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Abstract

Sustainability has been widely discussed from different points of view. Manufacturing is contributing a critical part of incompliance to environment and human rights in our modern society. This research is supplying a systematic framework for firms to achieve sustainability in manufacturing environment with the widely used problem solving tool Six Sigma. Inexperienced professionals will be able to implement the sustainability practice from defining problems to achieving leadership in sustainability. It has also supplied a case study where it illustrates how to customize the framework content based on individual needs. The research related with an application of Six Sigma DMAIC methodology (Define–Measure-Analyze-Improve-Control) in an automotive industry which provides a frame work to identify, quantify and eliminate sources of variation in an operational process in problem, to optimize the problem variables, improve and sustainable performance viz. process yield with well executed control plans. Six-Sigma improves the operational performance (process yield) of the critical operational process, leading to better utilization of resources, decreases maintains & variations consistent quality of the process outcome.

Six Sigma methodology is a business performance improvement strategy that aims to reduce the number of mistakes/defects to as low as possible per million opportunities. Sigma is a measure of “variation about the average” in a process which could be in manufacturing or service industry mostly led by practitioners, Six Sigma has acquired a strong perspective with practices often being advocated as universally applicable. Six-Sigma has a major impact on the quality management approach, while still based in the fundamental methods & tools of traditional quality management. Six-Sigma is a strategic initiative to improve profitability, increase market value and improve customer satisfaction through statistical tools that can lead to breakthrough quantum gains in quality.

This report shows the step-by-step application of the Six Sigma DMAIC methodology to eliminate the defects in a VE pump assembly process of an automotive company. This has helped to reduce defects in the process there by improve productivity and on time delivery to customer. During the Measure and Analyse phases of the project, data were collected from the processes to understand the baseline performance and for validation of causes. These data were observed through various graphical and statistical analyses. The statistical processing of data revealed that a relationship does exist between number of defects and total break down time and that 76.4% of defects are related to maintenance practices and wear issues. This can happen if, for instance, we produce both work orders and job guidelines of improvement type

during the implementation the Improve and Control phases. Another interesting aspect of the data is the fact that 7.3% of causes of defects are assigned to employee skills. This is quite controversial since it is not easy to distinguish if a defect is related to a badly maintained machine and is linked to a number of issues like lack of training, limited resources etc.

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Chapter 1 Introduction

1.1 Background

Sustainability has been widely discussed from different points of view. Except the needs to achieve the sustainable manufacturing environment, there are also plenty of benefits that have been observed. For example, a 2010 survey of UK-based manufacturing SMEs shows that 56% are already investing in low-carbon technologies and strategies. The global market for low-carbon products is already estimated to be worth over USD 5 trillion and growing. Also the sustainable manufacturing companies are receiving higher financial benefits and better company reputation than those who are facing profound sustainability problems (Wyckoff, 2014). Before companies can begin any Six Sigma initiative, they need problem-solving skills to address the difficulties in their organization. Training in problem solving and decision making provides a structured way to solve particular issues or problems.

- **Ease-of-implementation**: Implementing a Six Sigma program can be a huge undertaking for any company. The solution can be simplified by identifying process improvement projects, providing necessary problem solving training, establishing teams to work on the process improvement projects, and getting management to support the efforts by holding regular progress meetings and insisting that the problem solving processes be used.
- **Robust problem solving tools**: The problem solving tools used within a Six Sigma program are typically the same "quality tools" that were popularized during the 1980's with Total Quality Management (TQM), where management approaches long-term success through customer satisfaction. TQM requires the participation of all members of an organization in improving processes, products, services, and even the culture in which they work.
- **Ease-of-use:** During a Six Sigma implementation, people tend to think that the only time they use those skills is on a large process improvement project. The program from Action Management allows people to use the tool they precisely need in a given situation. This way, people are able to use what they learned when they encounter everyday problems regardless of whether it is part of a large process improvement project or not.

1.2 Six Sigma and Sustainability

The other core element of Six Sigma implementation is the sustainability which it brings to the organization. Generally understanding sustainability, sustainability is best defined by WCED (1987) stating that sustainable development is development that meets the need of present without compromising the ability of future generation to meet their needs. Fricker (1998) defined sustainability as vision of future that provides a road map while focusing on certain set of ethical and moral values which may guide the actions of an entity. Looking sustainability in details, it mainly focuses on three aspects i.e. economic growth, social progress and environmental protection (Munier, 2006).

Sustainability involves people, capital resources, natural resources, environment and institution. (Fricker, 1998) further added that sustainability is not merely an end result of processes rather it continuous seeking of quality behavior. An organization is said to be sustainable if its people are willing to bring a change and embrace the change ultimately leading toward sustainable organizational design (Pepper and Spedding, 2010).

In an organizational perspective particularly, sustainability refers to the value addition from Six Sigma. The dimension of sustainability includes variation elimination, control on new processes, statistical controls, reduced complexity, precision, accuracy and effectiveness in business process (Giardina, 2006). An addition in traditional Six Sigma is lean Six Sigma which primarily focuses on improved process flow (Reiling, 2008). Due to difference of focus, the perspective for sustainability also varies. In Six Sigma, the sustainability refers to utmost standardization with zero defects and zero wastes whereas lean Six Sigma emphasize sustainability as identification of value, defining value stream, determining flow, defining pull and improving process in every business function such as marketing, finance and management (Taghizadegan, 2010).

1.3 DMAIC approach

1.3.1 Need of DMAIC

Six Sigma’s most common and well-known approach is its problem-solving DMAIC approach. This section overviews the methodology and its high-level requirements for the organizations, given that the requirements define the appropriate deliverables, which dictate the tasks and the tool selection for the process.

1.3.2 Main Objective of this Approach

The DMAIC methodology (Define-Measure-Analyze-Improve-Control) is the classic Six Sigma problem-solving process. Traditionally, the approach is to be applied to a problem with an existing, steady-state process or product and/or service offering.

Variation from customer's specifications in either a product or process is the primary problem. Variation can take on many forms. DMAIC resolves issues of defects or variation within and across the value-adding steps in a process. DMAIC identifies key requirements, deliverables, tasks, and standard tools for a project team to utilize when tackling a problem. Failures, deviation from a target, excess cost or time, and deterioration.

1.4 Objectives of Dissertation

In order to help companies to achieve sustainable manufacturing environment, there should be flexible and comprehensive framework to help companies who are new into this area to understand their current situations and find corresponding solutions while still can be controlled and improved in a continuous behavior.

- Six-Sigma as a problem solving tool has been widely used for different sectors to achieve higher performance in an organization. It supplies a comprehensive framework to solve any critical problems, especially there are a lot of tools can be used.
- The combination of Six Sigma and Sustainable Manufacturing can give any organization a systematic framework with abundant tools to make changes to current manufacturing environment in order to achieve sustainability goals. Due to the flexibility and various tools that can be used, different organization can customize its own specific execution routine based on their own resources and vision. It won't restrict to any industry, and it can be also applied to others when the detailed industry information is supplied.
- The research and work practice mentioned in these literatures are putting a lot of efforts on the concepts of sustainable manufacturing and the measurement methods that can be used to measure the performance of sustainability.
- While for a lot of organizations, it is necessary to understand how to align these separate concepts, tools together to successfully achieve sustainable manufacturing from zero. There needs systematical way to help organizations to execute sustainable manufacturing from understanding to real implementation.

1.5 Organization of Dissertation

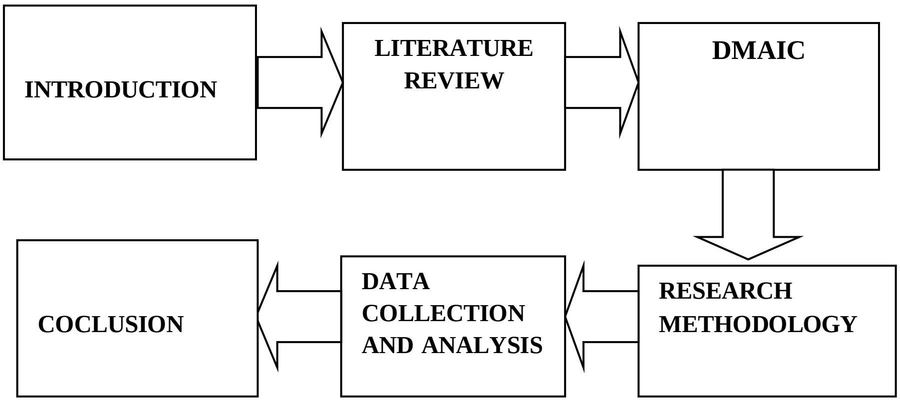


Figure 1- 1: Organization of Dissertation

Above Figure 1-1 shows the flow diagram of dissertation working for my work.

Chapter I introduces the concept of sustainable manufacturing with help of six sigma concept, improvement of productivity to minimize the waste using DMAIC methodology, inter relationship between sustainable manufacturing and DMAIC in the organization of this dissertation.

Chapter II presents a literature review of the sustainable manufacturing with help of six sigma concept. In this chapter basically the whole knowledge database is explained about the three main point's studies:

1. Literature review on sustainable manufacturing.
2. Literature review on six sigma methodology.
3. Literature review on DMAIC.

This chapter also discusses about definition and classification of sustainable manufacturing techniques and six sigma strategies available for productivity improvements are examined in the organization. Six-Sigma is a systematic method to help organizations to investigate critical problems and find out solutions to implement continuously. There is sufficient consensus within the Six Sigma literature to offer the following additional details about the Six Sigma method in its definition: The Six Sigma method for completed projects includes as its phases Define, Measure, Analyze, Improve, and Control (DMAIC) for process improvement of existing product or line.

Chapter III discusses about methodology of project and the general background of the company, its product range, its customers and production capabilities. The major product group is consisting of distribution pump and its parts which contribute to greater part of the annual business to the company. A detailed study of the existing working of the company's production function has been made. Chapter IV concludes with the selection of this process as the focus in this dissertation project.

Chapter IV describes the implementation of six sigma based on the methodology formulated in Chapter III. Several steps have been implemented in the organization, whereas DMAIC applied on the process for finding defect in manufacturing of VE pumps and it is also used for improvement in the process. The DMAIC methodology on the process has been explained in this chapter as a case study.

Chapter V gives the concluding remarks. It shows the utility of the DMAIC methodology and the improvement tool to other manufacturing companies characterized by the following features:

1. Time saving process.
2. Better Quality.
3. Zero waste.

The Dissertation concludes that the SIX SIGMA for productivity improvement is equally well applicable to manufacturing companies in general, and can be used as the first tool to effectively implement a productivity improvement program because of its simplicity and ease of implementation and capability to generate immediate demonstrable gains without disrupting the on-going operations of the company.

Chapter 2 Literature Review

2.1 Introduction

Two and a half decades ago, Bill Smith of Motorola started Six Sigma methodology, principles and methods based on Total Quality Management. Since then, a huge number of organizations have been involved in Six Sigma practice (Brady and Allen, 2006).

Linton et al. (2007) defines that 'Six Sigma is an organized and systematic method for strategic process improvement new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates.' Even though Six Sigma is associated with abundant statistics tools, such as factor analysis, statistical control chart, etc. Brady and Allen (2006) states that Practitioners applying Six Sigma can and should benefit from applying statistical methods without the aid of statistical experts. Hence Six Sigma is a systematic approach to help organizations to investigate critical problems and find out solutions to implement continuously, a classified literature has been done which underlies in these three categories which are also discussed briefly in the next sections of this chapter.

- **Literature review on Sustainable Manufacturing:** It told why an organisation required sustainable manufacturing.
- **Literature review on Six Sigma:** Six Sigma has brought large cost savings and benefits to very small companies as well. Besides, Bonn and Fisher (2007) suggest that organizations adapt a new wave of Six Sigma known as Fit Sigma. The Fit Sigma philosophy is the adaptation of the Six Sigma approach to "fit" an organization's needs so as to maintain performance and organizational fitness.
- **Literature review on DMAIC:** DMAIC model is a systematic method for analysing & improving business processes. DMAIC is a data-driven quality strategy used to improve processes. It is an integral part of a Six Sigma initiative, but in general can be implemented as a standalone quality improvement procedure (Salonen and Deleryd, 2007) or as part of other process improvement initiatives.

2.2 Sustainable Manufacturing

According to the WCED (1987), sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This statement made sustainability a unidentified concept and idea that says countries and organizations were willing to embrace. As time passed, the focus of sustainability began to evolve to what sustainability was and how it could be more widely incorporated. The most common concepts have seen sustainability broken down into three major focus areas: economic, social, and environmental. Several companies and organizations have in recent times shifted reporting from a pure financial perspective to one that gives stakeholders information regarding the involvement of their company in all areas of sustainability. This is often referred to as the Triple Bottom Line (Wang and Lin, 2007). The rise in corporate approach to sustainability has seen several large corporations such as Weyerhae user Company, The Boeing Company, Price water house Coopers, The Procter & Gamble Company, Sony Corporation, and Toyota Motor Corporation, along with others create the World Business Council for Sustainable Development (Jackson et al., 2011). The main focus of this council is creating changes in a varying ways from government structures, economic frameworks, along with other aspects of business and personal behavior.

2.2.1 Sustainable Business Development in Manufacturing and Services

Companies have focus on increasing pressure to seriously think about their sustainable development of business practices both in manufacturing and services. The pressure promoting sustainable business practices is both external (government regulations and rules, profit and non-profit organizations) and internal (strategic objectives, top management vision, employees safety and well-being, cost savings, productivity and quality). Many companies around the world have incorporated corporate, economic, social and environmental responsibilities in their strategic plan and actions. A kind revolution is now taking place to address the challenges of sustainable production and consumption in this century (Barber, 2007). Between 1970 and 1990, the rate of resource consumption and industrial growth has increased public awareness and concern over the environmental and social impact of the failures of industrialization: the environmental disaster is being seen for what it really is (Barber, 2007). It is time to stop viewing sustainability as a fancy strategy, but rather, consider it as a reality, the results of which support organizational competitiveness. Sustainability is about building a society in which a proper balance is created between economic, social and ecological aims. For businesses, this involves sustaining and expanding economic growth, share-holder value, prestige, corporate reputation, customer relationships, and the quality of products and services (Szekely and Knirsch, 2005). Clark (2007) suggests that an economy could be maintained by sustainable consumption that includes sustainable products and industrial processes. According to Clark (2007), process-oriented strategies can effectively reduce the environmental impact associated with product design and manufacturing. However, Clark does not discuss the environmental impact associated with design, selection, use, and disposal of products by consumers. This means that environmental impact should be considered throughout a product's life cycle. Identifying root causes of environmental and sustainability concerns and their impact on society is possibly the best approach for developing a sustainable manufacturing and service strategy. Sustainability concepts help businesses reduce risk, avoid waste generation, increase material and energy efficiency, and innovate by creating new and environmentally friendly products and services. It is a process by which companies integrate their economic, social and environmental objectives into their business strategies and optimize the balance between these three dimensions (Szekely and Knirsch, 2005).

2.2.2 Green Manufacturing

Green manufacturing deals with maintaining sustainability's environmental, economic and social objectives in the manufacturing domain. Reducing hazardous emissions, eliminating wasteful resources consumption and recycling are examples of sustainable green manufacturing activities (Deif, 2011).

The importance of Green manufacturing has been discussed in brief by a few articles below:

- Kumar et al. (1998) states that importance of green productivity as a competitive world. They defined about green productivity as all activities attempting to decrease wastes. They showed various case studies with different waste elimination practices to highlight the potential green productivity can have on the overall manufacturing performance.
- Naderi (1996) showed that green manufacturing is highly tied to waste management through the elimination of causal factors.
- Jovane et al. (2003) presented sustainable and green manufacturing as future paradigm with business model based on designing for environment using new nano/bio/material technologies. They highlighted that the new paradigm will respond to the customer need of more eco-friendly products.
- Wang and Lin (2007) proposed a broad triple bottom line framework to track and categorize sustainability information at the corporate level through a sustainability index system.
- Burk and Goughran (2007) also presented another framework for sustainability to realize green manufacturing.
- Mefford, (2011) gathered different analytical tools that have emerged from product/process design research for green manufacturing. Examples of these tools include Life Cycle Analysis (LCA), Design for the Environment (DFE), screening methods and risk analysis.
- Hui et al. (2002) proposed a model for assessment of environmental hazards in manufacturing. In their model, the network analytic method was employed to analyze the potential of each impact category created by different kinds of waste in manufacturing processes. Additionally, fuzzy set theory was used to determine a numeric fuzzy

weighting factor of each impact category contributing to the overall potential environmental impact on ecosystem. The model was limited to ecological health hazards. For realizing green manufacturing on the machine level,

- Montogomery et al. (2010) proposed environmental value systems analysis tool to evaluate the environmental performance of semiconductor processing. The tool develops environmental assessments through a "bottom-up" analysis approach, assembling equipment environmental models to describe a system.

Various analysis tools and models have also been proposed before. The framework was based on their studies of SME manufacturers who achieved ISO 14001 certification (Deif, 2011). Mcclusky (2001) proposed Green MRP tool. This tool is essentially a conventional Material Requirements Planning system that has been modified to include environmental considerations when converting the Master Production Schedule into the various component schedules. Through this inclusion, Green MRP solves the problem of minimizing environmental impact when managing industrial waste, by flagging potential component planning and environmentally related problems. Clean ability and burr reduction which are another green manufacturing aspects also on the machine level were studied in various machine tool researches to act as another optimization objectives in their attempts to improve machine tool performance. Example of this type of work was presented by Avila et al. (2006) in the aerospace industry.

2.3 Six-Sigma

The Greek alphabet letter σ is used for sigma which identifying the variability of a process or operation. A sigma quality level indicates how often defects are likely to occur and the higher six sigma quality level is the lower the possibility that the process produces defects (Hui et al., 2002). The objectives of Six Sigma are to identify and eliminate non-conformances, defects and reduction in wastes at any service or product through the disciplined use of data, statistical analysis and process thinking. If implemented properly, the Six Sigma quality level is equal to 3.4 defects per million opportunities (DPMO) and can be shown as 3.4 DPMO (the normality assumption of the process must hold a shift of up to ±1.5 σ for the mean of the process is allowed).

In simple words, the main Six Sigma objectives are:

- improve customer satisfaction;
- reduce costs;
- reduce cycle-time; and
- increase profit margins.

There is sufficient consensus within the Six Sigma literature to offer the following additional details about the Six Sigma method in its definition, The Six Sigma method for completion of projects includes as its phases either Define, Measure, Analyze, Improve, and Control (DMAIC) for process improvement or Define, Measure, Analyze, Design, and Verify (DMADV) for new product and service development (Brady and Allen, 2006; Goldstein, 2001).

The Table 2-1 summarizes the strategies and tools that are frequently used in the real industry

Table 2- 1: Six Sigma Strategies and Tools

Six Sigma Business Strategies & Principles	Six Sigma Tools & Techniques
• Project management • Data-based decision making • Knowledge discovery • Process control planning • Data collection tools and techniques • Variability reduction • Belt system (Master, Black, Green, Yellow) • DMAIC process • Change management tools • Variability reduction	• Statistical process control • Process capability analysis • Measurement system analysis • Design of experiments • Robust design • Quality function deployment • Failure mode and effects analysis • Regression analysis • Analysis of means and variances • Quality function deployment • Hypothesis testing • Root cause analysis • Process mapping

2.4 Basic Tools

- **Control Chart** – Monitors variance in a process over time and alerts the business to unexpected variance which may cause defects.
- **Defect Measurement** – Accounting for the number or frequency of defects that cause lapses in product or service quality.
- **Pareto Diagram** – Focuses on efforts or the problems that have the greatest potential for improvement by showing relative frequency and/or size in a descending bar graph. Based on the proven Pareto principle: 20% of the sources cause 80% of any problems.
- **Process Mapping** – Illustrated description of how things get done, which enables participants to visualize an entire process and identify areas of strength and weaknesses. It helps reduce cycle time and defects while recognizing the value of individual contributions.
- **Root Cause Analysis** – Study of original reason for non-conformance with a process. When the root cause is removed or corrected, the nonconformance will be eliminated.
- **Statistical Process Control** – The application of statistical methods to analyze data, study and monitor process capability and performance.

2.5 DMAIC Process

DMAIC model is a systematic method for analyzing & improving business processes. DMAIC is a data-driven quality strategy used to improve processes. It is an integral part of a Six Sigma initiative, but in general can be implemented as a standalone quality improvement procedure or as part of other process improvement initiatives (Voelkl et al., 2002). It consists of five phases:

2.5.1 Define

The Define phase focuses only on the problem – root causes and solutions come later on. The Define Phase is about making sure that all the key stakeholders have a joint understanding of the problem to be solved, the SMART objectives (S: specific, M: measurable, A: achievable, R: relevant, T: time bound) to be delivered, and the full scope of the project –before moving forward in to the detailed mapping and measurement of the process is defined in the Figure 2-1.

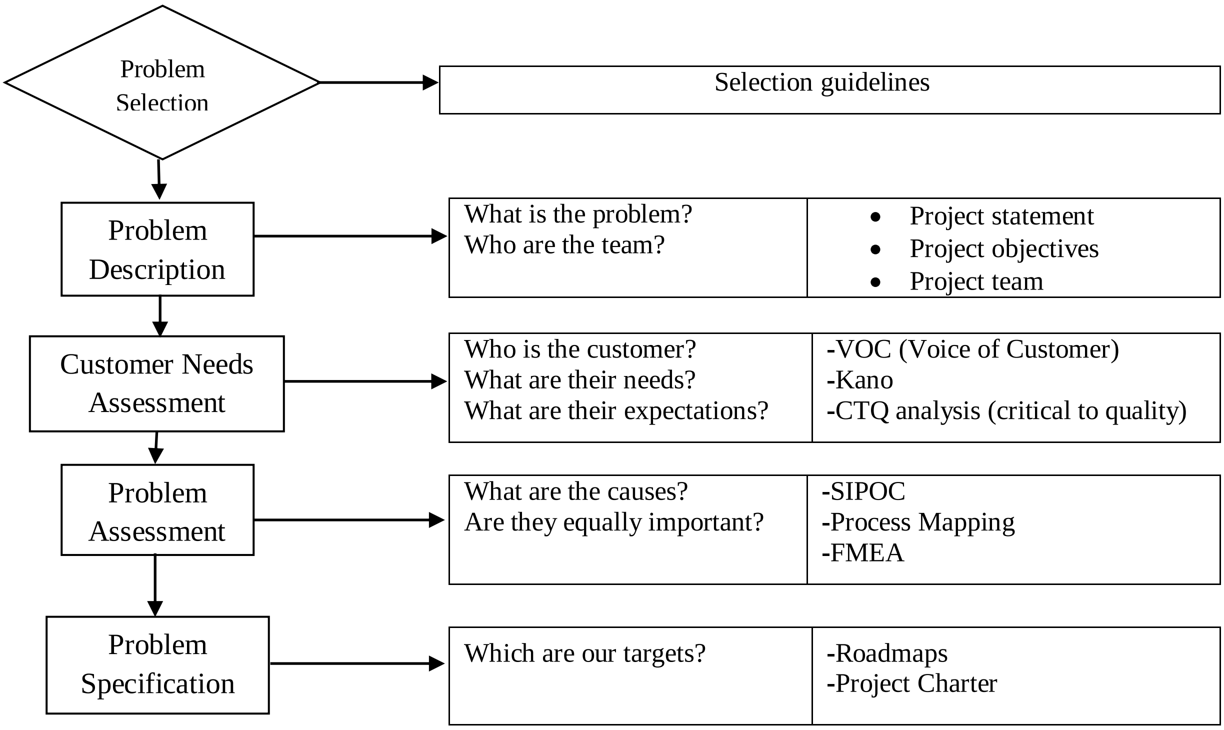


Figure 2- 1: Define Phase

2.5.2 Measure

The Measure phase aim at setting as take in the ground in terms of process performance (a baseline) through the development of clear and meaningful measurement systems. The Measure phase builds upon the existing data available (introducing new data collection and measurements, if necessary) in order to fully understand the historical `behavior´ of the process (Refer Figure 2-2).

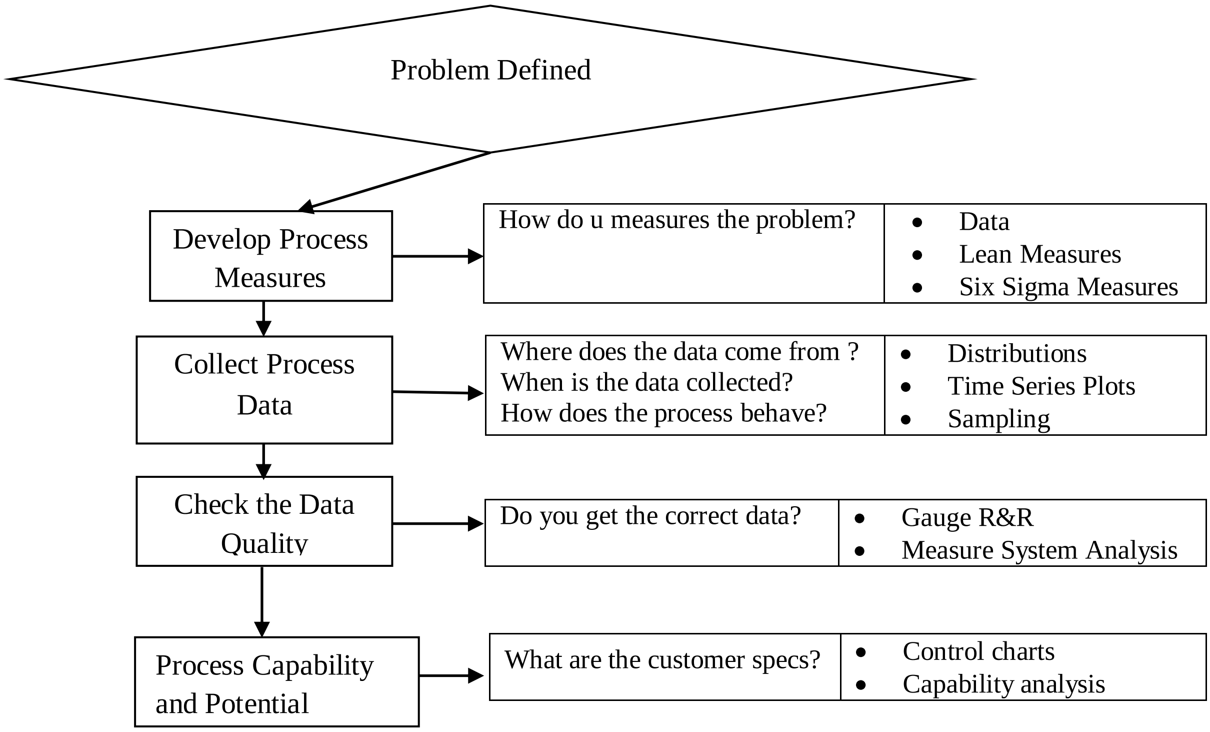


Figure 2- 2: Measure Phase

2.5.3 Analyse

The goal of the Analyse phase is to understand how the processes actually work, identify the root causes of the process variation and to confirm those causes using appropriate data analysis tools. The main issue is to clarify the hypothesis question that the analysis is going to answer is explained in Figure 2-3.

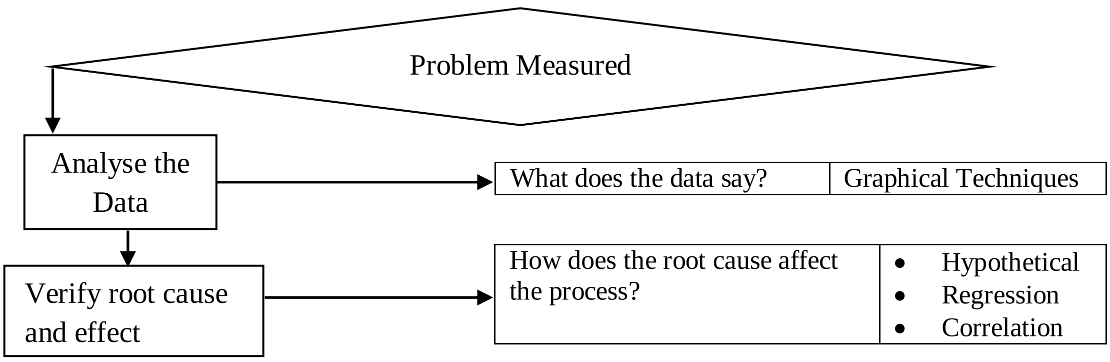


Figure 2- 3: Analyse Phase

2.5.4 Improve

On the basis that you have a clear knowledge of the root causes of the problem, you need to implement different improvement solutions and evaluate how these address the problem identified during the previous phase. The best solution needs to be verified (pilot trial) for its effectiveness (Refer Figure 2-4).

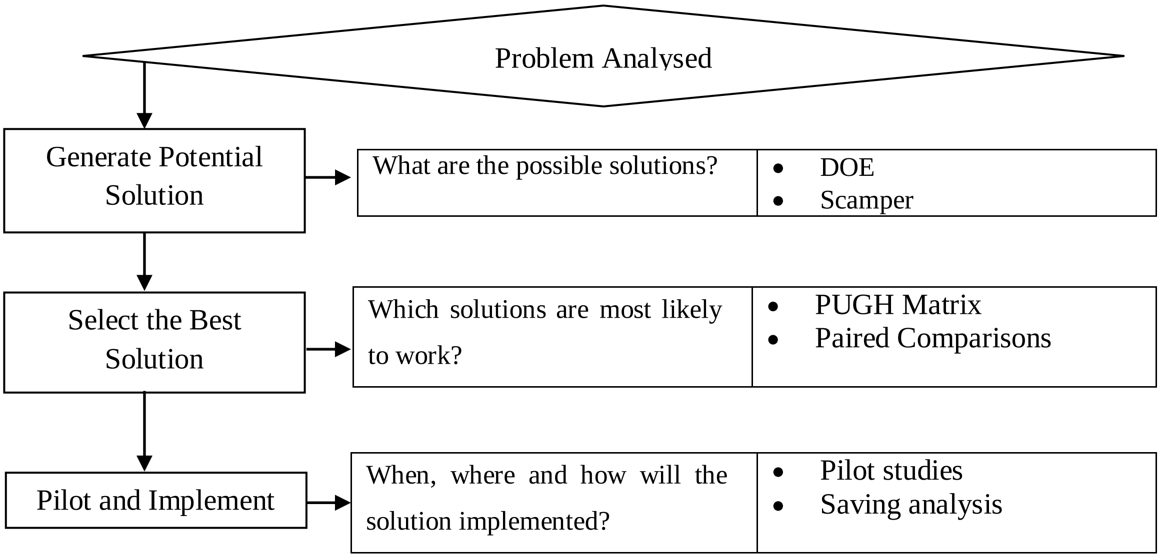


Figure 2- 4: Improve Phase

2.5.5 Control

The control phase aims at ensuring that the improvements achieved will be sustained in the long term. Certainly, we must make use of visual management to communicate the results of the project. Also, it would be useful to apply the lessons learnt from a specific project to different areas within an organization through appropriate knowledge management (Refer Figure 2-5).

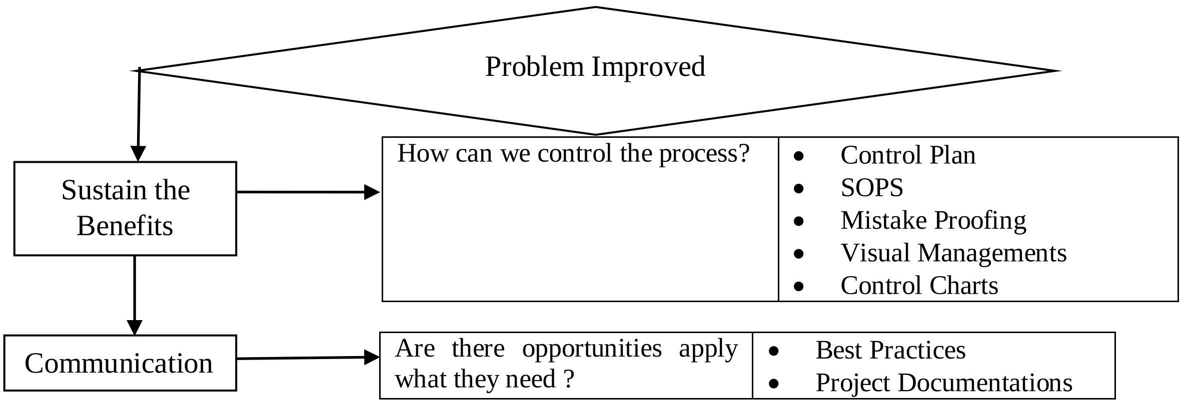


Figure 2- 5: Control Phase

2.6 DMADV Process

When to Use DMADV The DMADV methodology, instead of the DMAIC methodology, should be used when: A product or process is not in existence at your company and one needs to be developed The existing product or process exists and has been optimized (using either

DMAIC or not) and still does not meet the level of customer specification or Six Sigma level The application of DMADV is used when a client or customer requires product improvement, adjustment, or the creation of an entirely new product or service (Stuteville and Ikerd, 2009). The application of these methods is aimed at creating a high quality product keeping in mind customer requirements at every stage of the game. It consists of five phases

- **Define Phase:** Project leaders identify wants and needs believed to be considered most important to customers. Wants and needs are identified through historical information, customer feedback and other information sources. Teams are assembled to drive the process. Metrics and other tests are developed in alignment with customer information.
- **Measure Phase:** The second part of the process is to use the defined metrics to collect data and record specifications in a way that can be utilized to help drive the rest of the process. All the processes needed to successfully manufacture the product or service are assigned metrics for later evaluation. Technology teams test the metrics and then apply them.
- **Analyze Phase:** The result of the manufacturing process (i.e. finished product or service) is tested by internal teams to create a baseline for improvement. Leaders use data to identify areas of adjustment within the processes that will deliver improvement to either the quality or manufacturing process of a finished product or service. Teams set final processes in place and make adjustments as needed.
- **Design Phase:** The results of internal tests are compared with customer wants and needs. Any additional adjustments needed are made. The improved manufacturing process is tested and test groups of customers provide feedback before the final product or service is widely released.
- **Verify Phase:** The last stage in the methodology is ongoing. While the product or service is being released and customer reviews are coming in, the processes may be adjusted. (a) Metrics are further developed to keep track of ongoing customer feedback on the product or service. (b) New data may lead to other changes that need to be addressed so the initial process may lead to new applications of DMADV in subsequent areas. The applications of these methodologies are generally rolled out over the course of many months, or even years. The end result is a product or service that is completely aligned with customer expectations, wants and needs.

2.7 DMAIC VS DMADV

Below Table 2-2 shows the few difference between the basic DMAIC and DMADV processes as follows:

Table 2- 2: Difference between DMAIC VS DMADV

DMAIC	DMADV
Define-Determine Project Objectives, Scope, Resources, Constraints, Etc.	Define-Similar
Measure-Determine CTQ's, Gage R&R, Obtain Data To Quantify Process Performance	Similar Measure-Determine CTQ's, Gage R&R
Analyze-Analyze Data To Identify Root Causes Of Defects	Analyze-Develop Design Concepts, And High-Level Design
Improve-Intervene In The Process To Improve Performance	Design-Develop Detailed Design, And Control Plan
Control-Implement A Control System To Maintain Performance Over Time	Verify-Test Design With Pilot, Full Scale Implementation

2.8 Quality Management Tools and Methods

Within the individual phases of a DMAIC or DMADV project, Six Sigma utilizes many established quality-management tools that are also used outside Six Sigma. The following classifications show an overview of the main methods used under this category.

- 5 Whys
- Statistical and fitting tools
    - Analysis of variance
    - General linear model
    - ANOVA Gauge R&R
    - Regression analysis
    - Correlation
    - Scatter diagram
    - Chi-squared test
- Axiomatic design
- Business Process Mapping/Check sheet
- Cause & effects diagram (also known as fishbone or Ishikawa diagram)
- Control chart/Control plan (also known as a swim lane map)/Run charts
- Cost-benefit analysis
- CTQ tree

- Design of experiments/Stratification
- Histograms/Pareto analysis/Pareto chart
- Pick chart/Process capability/Rolled throughput yield
- Quality Function Deployment (QFD)
- Quantitative marketing research through use of Enterprise Feedback Management (EFM) systems
- Root cause analysis
- SIPOC analysis (Suppliers, Inputs, Process, Outputs, Customers)
- COPIS analysis (Customer centric version/perspective of SIPOC)
- Taguchi methods/Taguchi Loss Function
- Value stream mapping

2.9 Benefits of Six Sigma Implementation

Since the introduction of Six Sigma in Motorola, Six Sigma has been implemented in a wide range of industries. The successful financial returns have encouraged different organizations to take Six Sigma initiative (Thampapillai, 2010; Tomkins, 1997). The Table 2-3 summarizes the reported benefits from manufacturing sectors.

Table 2- 3: Reported Benefits from Six Sigma in Manufacturing

Company/project	**Metric/measures**	**Benefit/savings**
Motorola	In-process defect levels	150 times reduction
Raytheon/aircraft integration systems	Depot maintenance inspection time	Reduced 88% as measured in days
GE/Railcar leasing business	Turnaround time at repair shops	62% reduction
Allied signal (Honeywell)/ Iaminates plant in South Carolina	Capacity Cycle time Inventory On-time delivery	Increased to near 100%
Allied signal (Honeywell) /bendix IQ brake pads	Concept-to-shipment cycle time	Reduced from 18 months to 8 months
Hughes aircraft's missiles systems group/wave soldering operations	Quality/productivity	Improved 1,000%/Improved 500%
General electric	Financial	$2 billion in 1999
Motorola	Financial	$15 billion over 11 years
Dow chemical/rail delivery project	Financial	Savings of $2.45 million in capital expenditures
DuPont/Yerkes plant in New York	Financial	Savings of more than $25 million
Telefonica de espana	Financial	Savings and increases in revenue 30 million euro in the first 10 months
Texas instruments	Financial	$600 million
Johnson and Johnson	Financial	$500 million
Honeywell	Financial	$1.2 billion

2.10 Six Sigma and Sustainability

The six sigma method is a project-driven management approach to improve the organization's products, services, and processes by continually reducing defects in the organization. It is a business strategy that focuses on improving customer requirements and needs understanding, business systems process, productivity, and financial performance. Dating back to the mid-1980s, applications of the six sigma methods allowed many organizations to sustain their competitive advantage by integrating their knowledge of the process with statistics, engineering, and project management (Anbari, 2002).

Sustainability is and will be a crucial issue for the present and future generations. The current assumption that natural resources are infinite and that the regenerative capacity of the environment is able to compensate for all human action is no longer acceptable. Hence, sustainability issues will influence all organizational aspects of the human life, from the economic, political, social and environmental points of view. The reason is simple: until now, all human activities have been based on the paradigm of unlimited resources and unlimited world's capacity for regeneration; from now on, the awareness of the termination of this assumption means that all related behavioral models must be changed. This is a very impressive objective embracing all fields of culture, economy, technology and much more. A continuing effort, together with a reasonable time span, will be required to pursue this goal. Fortunately, nature and the environment are capable of self-regulation and will give man a chance to recover from the damage he is causing to the earth mother, provided that the will to do so is firmly established. Manufacturing, as the main pillar of the civilized lifestyle, will be strongly affected by the sustainability issues and it will play an important role in establishing a sustainable way ahead. Today, nearly all manufacturing models are based on the old paradigm. Technology, on which the manufacturing is largely based, is asked, together with culture and economy, to give the tools and options for building new solutions towards a sustainable manufacturing concept. Generally speaking, new technology, new business models and new lifestyle models will be the cornerstones of the new sustainable world and this will be particularly true for what concerns the manufacturing sector. Impressive constraints and requirements will affect the industrial sector on the way ahead towards sustainability.

2.11 Sustainability Achieved Through Six Sigma

Multinational companies have adopted Six Sigma for variety of purposes however; the main goal was to attain financial and social sustainability through improved processes and better flow of work (Pintellon et al., 2006). However, the financial success is achieved through multi-dimensional quality improvements processes and technique (Pereira, 2007).

General Motors reduced its disposal costs by $12 million by using kanban system; an integral part of Six Sigma. Similar like, Robins Air Force Base, C-130 paint shop has been reduced tools material and equipment by 39% and $373,800 in direct operating savings (Reynard, 2007). 3M was among few companies which initiated to adoption of Six Sigma. 3M upgraded to lean Six Sigma and its purpose was to attain environmental and social stability. The company is pioneer in use of lean Six Sigma methods and tools to improve operations and quality. In first phase, the company trained its 100,000 employees for Six Sigma in order to attain the operational sustainability. 3M achieved multi side results such as improvement in energy efficiency from 20% to 27% and reduction in waste index to net sales from 25% to 30%. All these achievements are aimed toward attaining environmental sustainability and operational sustainability (Paulk et al., 1993). Till 2005, savings from the lean Six Sigma project was amounted to $1 billion which was made possible by reducing pollution, improving work flow, equipment redesign, process consequence and product reformulation.

Hellstorm et al., (2007) also asserts that companies implement Six Sigma to drive the innovation. The first five years of lean Six Sigma helped many companies to improve their results such as attained by Caterpillar. Mccarty and Fisher (2007) also quote Caterpillar as achiever from Six Sigma. In September 2004, Caterpillar was $20 billion Company and Caterpillar was aimed to increase the revenues by $10 billion in first decade of lean Six Sigma implementation. Weber et al., (2004) contrasts with Byrne (2007) in the context that caterpillar wanted to attain the innovation sustainability. According to Snee, (2004), caterpillar was focused on achieving financial stability. The company’s top management has highlighted that Caterpillar management such as CEO has claimed that Six Sigma was the important contribution toward increase in sales of caterpillar. Six-Sigma is also driving the continuous improvement culture in the company and business is gaining efficiency in all respects (Weber et al., 2004).

Hilton (2008) identifies several companies such as Motorola, General Electric, Dell Computer, Dow Chemicals, Wal-Mart and Honeywell who implemented Six Sigma and attained measurable results. General electric saved $8 billion after implementing Six Sigma in three years and Wall-Marts is looking for savings of $1 billion from lean Six Sigma (Leahy, 2000).

2.12 Scope of the Dissertation

Six-Sigma is focusing on reducing defects to improve product quality and consistency, which relates with sustainable manufacturing's emphasis on reducing waste. When defect rates are very high in a production line, the defective products, if not recyclable, are generally sent to landfill. Through limiting defects to improve production process efficiency, the Six Sigma approach can improve a company's sustainable impact through reducing defects and wasted resources. Six Sigma analyses can also uncover waste throughout the production process. Through monitoring the two values, equipment was tuned to reduce both energy consumption and defect rate. Six-Sigma can also be applied directly to sustainable manufacturing concepts. Through identifying that all resources and emissions leaving production facilities are products, companies can identify negative environmental impacts that do not meet regulatory standards as "defects" that must be reduced to limit operating costs and improve production efficiency and quality. Through using the statistical approach that traditional products are evaluated with, Six Sigma companies are able to monitor the environmental quality of their production processes to improve the product's sustainable qualities and avoid regulatory action. Because Six Sigma is led and implemented by a small team of experts to specifically address production line issues, employees are not incorporated into the improvement processes. This exclusive environment is the most removed from addressing social sustainability both within and outside of the organization. A company using Six Sigma would need other measures in place to address social issues. Many projects that are related to sustainability development have been conducted using Six Sigma approach. As a leading global supplier of high performance specialty chemicals and coatings. Enthone (2013) has demonstrated good examples of the applications of Six Sigma in Sustainability development. The project of Reduction of Plastic Packaging has resulted in a 20% reduction in plastic packaging while providing environmental benefits. Additionally, the project of Reduction in Energy Usage resulted in a significant annual cost savings, primarily by consolidating into larger batches being manufactured. This has resulted in less waste treatment and has resulted in a 10% reduction in energy usage. What's more, 3M as a pioneer in corporate pollution prevention, it has implemented sustainability development with the help of Lean Six Sigma.

Another technique that is widely discussed is Lean Six Sigma. It evolves from Six Sigma with DMAIC framework but also involves green concepts (Park, et al., 2008). While it has been implemented in different organizations, the focus of Lean Six Sigma is mostly to reduce waste and environmental impact. It lacks of emphasis on social impact which is becoming more and more crucial in developing countries, especially in Asia and Latin America which is the hubs for production activities.

Chapter 3 Research Methodology

3.1 Company Profile

Bosch limited (formerly Motor Industries Co. Ltd.)

Bosch has been present in India for over 50 years, through its subsidiary, Motor industries company limited (MICO), the name of which was recently changed to Bosch Ltd. In 1951, when Bosch Ltd. (then MICO) began operations with a two man team in Chennai, its activities were importing and marketing Bosch automotive products. Soon after, the companies setup a manufacturing plant for spark plugs for petrol engines and fuel injection equipment for diesel engines in Bangalore. Bosch limited today is the country's largest auto component manufacturer and also one of the largest Indo-Germen companies in India. The Bosch Group holds close to 70% stake in Bosch Ltd. The company is headquartered in Bangalore with manufacturing facilities in Bangalore, Nasik, Naganathapura, Jaipur and the recently opened facility in Goa. The plans are TS 16949 and ISO14001 certified. Bosch manufactures and trades products as diverse as diesel and gasoline fuel injection systems, Blaupunkt car multimedia systems, auto electrical, industrial equipment, special purpose machine, packaging machines, electric power tools and security systems.

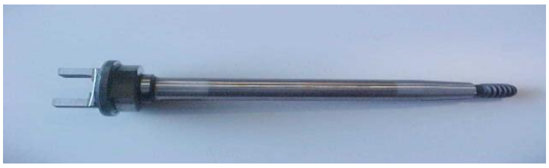
JAIPUR (JaP):

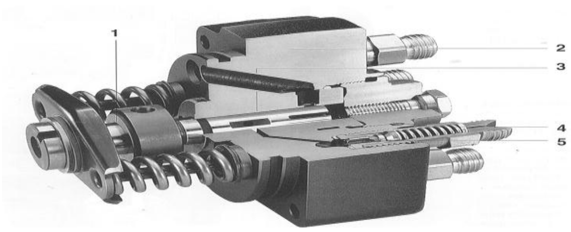
Jaipur is the fourth location of Motors Industries Company Ltd., commissioned in1999 with a state-of-the-art manufacturing facility to FIP's. A TS16949 certified company; it is a technological oasis in the developing state of Rajasthan. A young team of enthusiastic & dedicated professionals work single-mindedly to make BOSCH, Jaipur world class. Jaipur plant manufactures VE (Mechanical) pumps for domestic market and export purposes. The VE pump (Distributor fuel injection pump) is designed to Bharat Stage II and Euro II emission norms. These pumps are used in 3-6 cylinder vehicles.

3.2 Major Products

Below Table 3-1 shows the product delivered by the BOSCH Ltd. and these product are very useful in the VE pump manufacturing.

Table 3- 1: Product range of BOSCH Ltd

Drive Shaft 	Drive Shaft forms a part of drive chain in VE Pump. Its threaded end forms the mounting part to the engine. It provides positive drive inside the pump by Drive Shaft claws. The gear is mounted on Drive Shaft for running governor cage.
Roller ring 	Roller Ring influences timing of Fuel Delivery. It is provided with a slot which Connect with TD Piston. Due to high pressure at TD Piston, TD Piston moves the roller ring and timing parameters change.
Cam plate 	Cam Plate forms a part of the Drive Chain mechanism. It controls delivery writ to its Cam Profile & Shim Face. It provides reciprocating movement of plunger due to its cam profile.
Pump Housing 	Pump Housing is a very critical component & works as a house of all pump components. It facilitates functions like cold starting & also load dependent functions in a pump & enables pump mounting on the engine.
Cross-Disc 	The Cross-Disc works as a coupling in the VE Pump. It has 4 slots at right angles to each other. It holds the claws of Drive Shaft in 2 slots& Cam Plate in the other 2. In this way it transfers the rotary motion from the Drive Shaft onto the Cam Plate.
Support Ring 	The basic raw material used in the Support Ring is Steel. It is a cold forged component. The main function of the Support Ring is to support the Roller Ring & house the Feed Pump.

Connecting Flange 	Connecting Flange houses the valve bush & delivery valve. The fuel is passed on through the flange to the valve bush. A solenoid is fitted on to the connecting flange to shut off the fuel flow. It also has outlet holes equal to that in the valve bush & they are connected.
Plunger 	It is driven by the cam plate which gives it a rotating& reciprocating movement. Due to this, it develops the pressure required & delivers it through the outlet holes of the valve bush one at a time.
Fulcrum Lever 	The Assembly of the Starting lever, Tensioning Lever & Control Lever forms the Fulcrum Lever. The major function is to determine the quantity of fuel delivery by the Distributor Plunger.

3.3 VE Pump

VE means "**Verteiler Einspritz**" in **German and** in English **Distributor Injection Pump**. The purpose of the fuel injection pump is to deliver an exact metered amount of fuel, under high pressure; at the right time to the injector. The injector injects the fuel directly into the cylinder or a pre chamber connected to the cylinder. Distributor pumps are mainly used in passenger cars, commercial vehicles, agricultural tractors and stationary engines. Small high speed diesel engines demand a lightweight and compact fuel-injection system.

The distributor fuel-injection pump fulfills these requirements by combining the fuel-supply pump, high-pressure pump, governor and timing device in a compact unit. For every power stroke, the fuel-injection system supplies the required quantity of fuel at high pressure and at a precisely determined crankshaft position. The nozzle sprays the atomized fuel into the combustion chamber. The injection timing is exactly determined according to the engine speed and load. VE pump consists of eight major components, what are manufactured in main parts in house.

- Drive shaft
- Roller ring
- Pump housing
- Support plate
- Fulcrum lever
- Feed pump
- Cam disc
- Hydraulic head

Figure 3-1 shows the assembly figure of VE pump showing all main parts.

Figure 3- 1: VE Pump

3.4 VE-Pump Working

Pump is divided into four main steps. It starts with the pre-manufacturing and sub-assembly of all components. Several items are imported from or delivered from local suppliers in India and some parts are manufactured or finished in the Jaipur plant. Imported parts which can be used directly after un-packing and cleaning are stored and organized by the Kardex. Parts which are finished or sub-assembled in house like e.g. housing, head, fulcrum lever, vane pump will be shifted from the manufacturing shop to the assembly line organized by the Kardex as well. All components which are required for calibrating the pump will be assembled in the assembly line. After the 42 assembly station the pump is checked for leakage defects and cleaned by a running-in. The next step is the calibration of all adjustable functions. After the pump is adjusted to its optimum setting the pump will be finished in the post-calibration and packed to send it to the customer.

The distributor pump helps to achieve the basic purpose of injecting the fuel (high speed diesel oil) into the engine at accurately metered quantities. For the best performance of the engine, the pump needs to the following basic needs of the engine:

- **Correct volume of fuel:** This is achieved by the working of the governor system. The governor mechanism moves the valve spool in the distributor towards the connecting flange to increase the fuel delivery. This results in the plunger spill port to close and reduce leakage into the pump cavity. Similarly, to reduce delivery of fuel, the reverse is applicable.
- **Dynamic fuel timing:** In internal combustion engines, the piston reciprocates to and fro in the cylinder. The extreme front position of the piston, where the entrapped volume between the piston and cylinder is minimum is called Top Dead Centre or TDC. The extreme back position of the piston, where the entrapped volume between the piston and cylinder is maximum is called Bottom Dead Centre or BDC.

3.5 Methodology

Following in the previous chapters, we realize the importance of maintenance as a critical factor in the establishment of competitive advantage. For this reason, a case study regarding the maintenance performance was developed in BOSCH manufacturing company Jaipur. Our research is a part of a wider project that is conducted in the company and is related to the implementation of world class performance (WCP) concepts to all our activities e.g. safety, production, maintenance etc.

Our research is of experimental type since we tried to discover cause – and – effect relationships between maintenance activities and various kinds of defects. We applied Six Sigma and, specifically, the methodology followed was the DMAIC in which each one of the five phases is a combination of both qualitative and quantitative techniques. The study population is the total occurrence of defects and we set out objectives to attain through the implementation of improving actions based on the findings. It is the belief of the author that our research will add a scientific approach to the existing maintenance function in the plant.

As far as literature review is concerned, we focused our interest on journals and articles of relevance in our research topic. Regarding data, we established a primary data collection system through observations and individuals interviewing, so some ethical issues in relation to the participants and the researcher may have risen.

The tools from Six Sigma management are integrated into these five phases as shown below in Figure 3-2 and Figure 3-3 demonstrates the high rejection in fouling by using the cause and effect diagram.

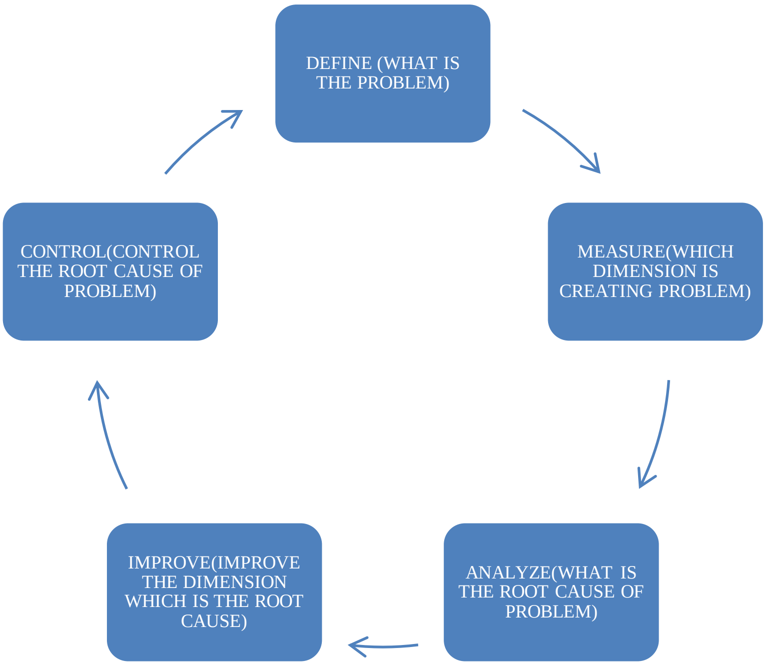


Figure 3- 2: Different phases of DMAIC

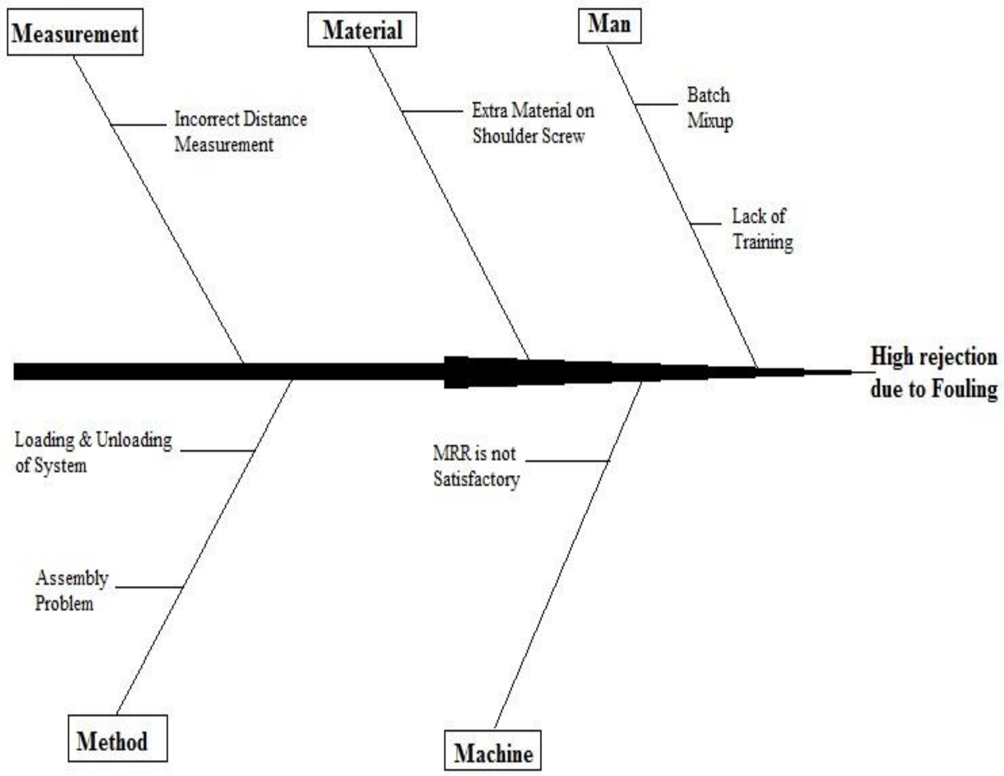


Figure 3- 3: Cause and effect diagram for VE pump assembly

Chapter 4 Case Study

4.1 Background

In order to test the framework and illustrate how the framework can be customized in different situations, a BOSCH manufacturing company Jaipur, has been selected for case study. This company designs and manufactures mainly for VE pumps. It has short history in the same industry, but it's been known for its cost effective products. The company is still under new technology and new customers' accumulation phase, which is focusing on developing new customers and selling more products in order to grow into a stronger player in the industry. There are some quality management systems that have been developed. But the system is still in its developing phase. Sustainability as part of their lean production vision starts to get credits from senior management and direct labour workers, though the understanding of sustainability and lean production is still not very clear for the company. Figure 4-1 shows the strategy followed implementing DMAIC approach in this case study for achieving sustainability in the BOSCH manufacturing for the VE pump is demonstrated.

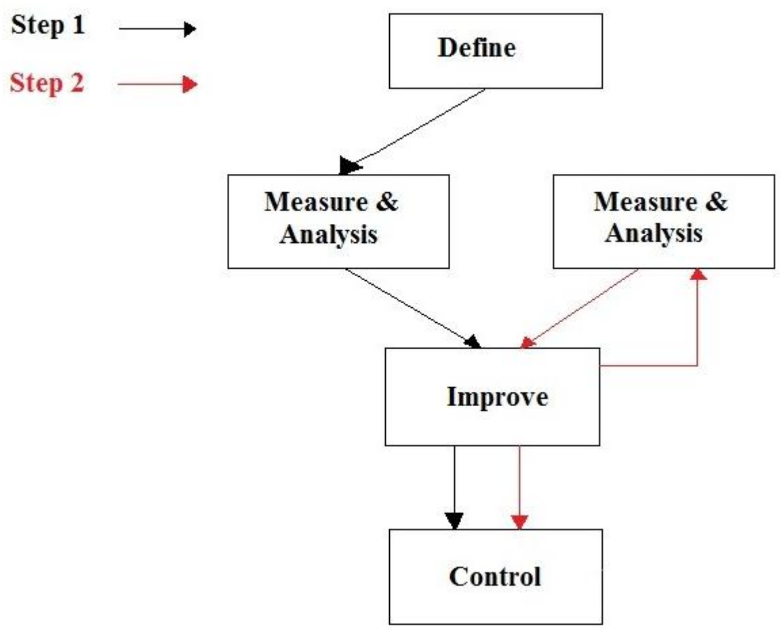


Figure 4- 1: Strategy followed for Implementing DMAIC

Figure 4-1 shows the flow of DMAIC where in step 1 after defining problem measure and analysis phase come in to picture where some dimensions improved but cannot eliminate the problem after step 2 some other dimensions also required improvement after these two steps control of these dimensions will take place.

4.2 Phase 1 Analysis for Problem

4.2.1 Define

The Define phase of DMAIC is defining the goals of the improvement activity. This phase typically involves meets with management defining the goals of a project and coordinating what will be specifically looked at during the duration of the project. This step of the cycle is necessary in order to have a solid definition of the project outcomes. Lacking this step has the potential to not include or include too much information.

- **Problem definition:** Bosch manufacturing company producing distribution pump they got the complaint from costumer side they are facing hunting (change in speed frequently) which is called as Fouling. Fouling means it may be an extra part on shoulder screws or it may be an additives during assembly due to this hunting (change in speed frequently due to this a lot of problems occurring). So our objective is to find out the problem and elimination of problem with the help of six sigma methodology.
- **Selection of Problem:** Part number selected for study
    - Pump type: **0 460 426 396.**
    - Good Pump: **Sr.no. 886 35142**
    - Bad Pump**: Sr.no. 886 31207**

Other similar part numbers having the problem.

- **Location of Problem and Rejection Quantity:** Last manufacturing process stages where the Problem is generated in assembly and current average rejection for last 6 months is 0.6 %.

Maximum and Minimum rejection in last 6 months:

- Maximum rejection in a month - 0.84 %
- Minimum rejection in a month - 0.68 %

This problem is solved on the two lines/presses/machines which used for processing the part for the purpose of manufacturing.

- **Objective of the Project:**
    - To eliminate fulcrum lever fouling.
    - Increase annual Savings by reducing the defect.
    - Reduce the waste to protect our environment from the pollution.
- **Process Mapping:** Figure 5-2 shows the process mapping for the VE pump assembly in

which how the detection of problem takes place.

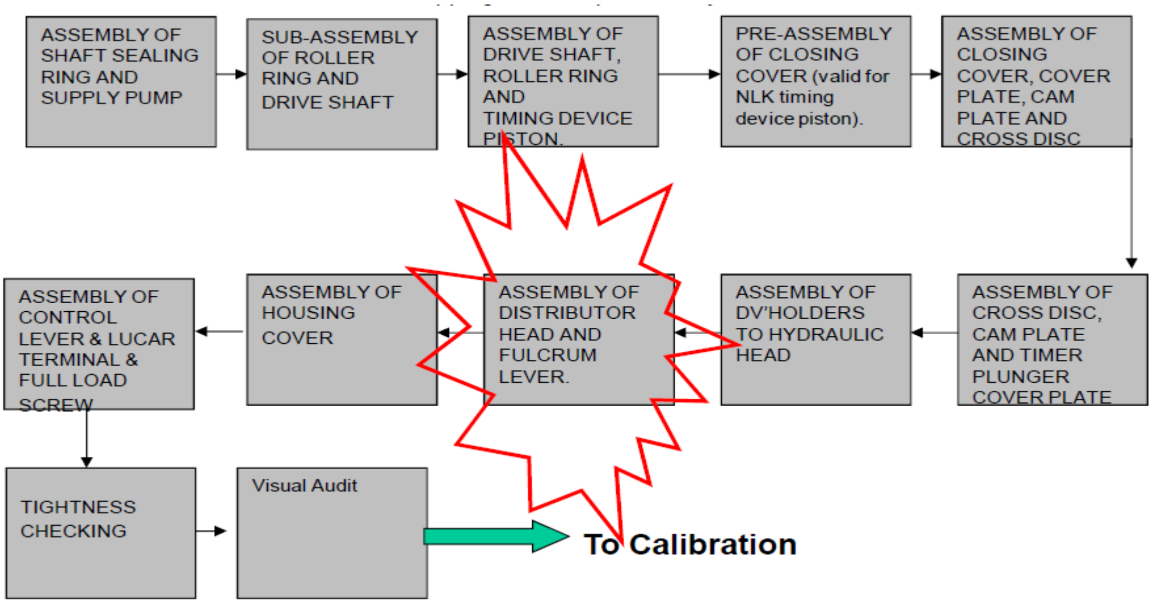


Figure 4- 2: Process Mapping: VE Pump Assembly

Figure 4-3 shows the phase diagram for the DMAIC implementation schedule on the assembly for reducing defects shown in Table 4-1.

Table 4- 1: Phase diagram for DMAIC implementation

Phase	Month-Nov				Month-Dec				Month-Jan			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
Define												
Measure & Analyze												
Improve												
Control												

Figure 4- 3: Defects in VE pump assembly

- **Pareto analysis:** Based on last 6 months data Defect wise pareto analysis for VE pump assembly is collected which is shown in the Figure 4-4.

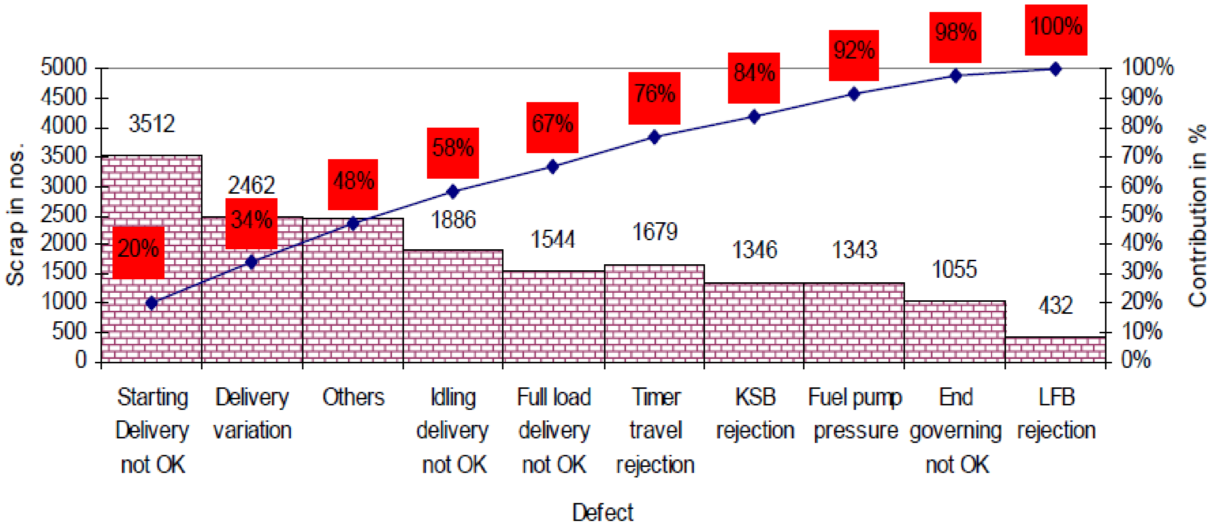


Figure 4- 4: Pareto analysis for last six month data

- **COPQ (Cost of Poor Quality) Calculation:** Table 4-2 shows the COPQ for the assembly and it shows the total expended cost of scrap for one year is 96, 00, 000 which is too high.

Table 4- 2: COPQ calculation

Number of pieces rejected last month (for the part number identified for study)	87
Number of pieces scrapped last month	87
Number of pieces reworked last month	NA
Scrap cost/piece	800 Rs.
Rework cost/piece	NA
Total scrap cost (Rs. Lakhs) for last Month	8 00 000 Rs.
Total rework cost (Rs. Lakhs) for last Month	NA
Total Rejection cost (Rs. Lakhs) for last Month	8 00 000 Rs.
Extrapolated Total rejection cost (Rs. Lakhs) for one year)	96 00 000 Rs.

4.2.2 Measure

The Measure phase of DMAIC is measuring the existing systems that are in place. During the measure phase, data acquisition is done. This data then is used to create an overall baseline of a system to measure its performance based on the necessary improvement areas established in the define phase.

4.2.3 Analyze

The Analyze phase of DMAIC is the analysis of data collected during the measure phase to eliminate gaps between the current system and the desired performance level. This data is viewed in detail determining root causes of problems. This can be done via analog methods or digital. Often analysis is done via a computer based system (digital) to reduce the analysis time. Once these problems are found it is determined whether or not these root causes can be improved.

- **Objective 1:** To identify whether assembly process or components are cause of problem
- **Technique/Tool used:** Modified component search

Y = fouling of fulcrum lever with shoulder screws

X's = Components or Assembly process

Table 4-3 shows the component searching after some modifications like assembling and disassembling.

Table 4- 3: Modified component Search

	Good Pump Sr. no. 886 35142	**Bad Sr. no. 886 31207**
Initial Value	Good	Bad
First disassembly and reassembly	Good	Bad
Second disassembly and reassembly	Good	Bad

- **Conclusion:** As there is no changeover after assembly and reassembly, assembly process and replaced component (Washer) are not the cause of problem. Other component (s) used in the assembly are the cause of problem.
- **Ranking of other components by importance:** Table 4-4 shows the ranking of the component for analysis of the defect.

Table 4- 4: Defect ranking for various assembly parts

Rank	**Components**	**Label**
1	Fulcrum lever	A
2	Shoulder screw	B
3	Distributor head	C
4	Pump housing	D

- **Component Testing**: According to the ranking defined in Table 4-4 testing of the components has been done for finding good or bad assembly conditions (Refer Table 4-5). Below Figure 4-5 shows the various components to be test.

Fulcrum Lever (A)

Pump Housing (D)

Distributor Head (C)

Shoulder Screw (B)

Figure 4- 5: Components to be test

Table 4- 5: Assembly testing results

No.	Good Assembly	Result	Bad Assembly	Result
1	A-R+	Good	A+R-	Bad
2	B-R+	Good	B+R-	Bad
3	C-R+	Good	C+R-	Good
4	D-R+	Bad	D+R-	Good

- **Objective 2:** To find out the dimension (s) in pump housing which is the root cause of problem?
- **Technique used:** The following steps were used to identify root causes which are major contributors to the variation in VE pump assembly using the Paired Comparison tool.
  - ➢ Ideally 6 Good and 6 Bad Parts were selected on the based on Response (Y).

- When selecting Good and Bad, Best of Best (BOB) and Worst of Worst (WOW) should be selected. And Part should be marked from 1 to 12.
- From the Top row of the derived table, check where for first time transition in response is happening i.e. 'BOB' changes to 'WOW' or 'WOW' changes to 'BOB'. Draw a line at the point of transition.
- Similarly, check from the bottom also and draw a line at the first transition from bottom. Count the number of data above the Top Transition line. This is called 'Top count'.
- Count the number of data below the Bottom Transition line. This is called 'Bottom count'
- Add both Top and Bottom count, this is called 'Total count'.
- Check the Total Count. If Total count ≥5 in any table, then that root cause is the Reason of the problem and If Total count is <5, then that root cause is not the reason of the problem.

These are the main steps of Paired Comparison tool by which we found the root cause which produce the variations in the VE pump. We followed the above steps and found the root cause which produces the defect in VE pump assembly.

- **Suspected dimensions in pump housing:**
  - Distance from Shoulder screw center to flange face Specification: 116.5 ±0.2 mm
  - Distance from pump axis of bore dia. to center of shoulder screw Specification: 34 ±0.15 mm
  - Distance from Shoulder screw outer face to pump axis Specification: 33 ±0.1 mm
  - Distance between shoulder screw Specification: 66 ±0.2 mm
  - PCD of flange mounting Screw Specification 82 ±0.1mm
  - Concentricity of Dia. 82 w.r.t Dia. 67.5 Specification: 0.1 mm
  - Internal distance Specification: 36 ±0.2 mm
  - Symmetry of shoulder screw Specification: Max. 0.6 mm
  - Run out of shoulder screw Specification: Max. 0.03 mm

Figure 4-6 shows the suspected assembly with numbered dimensions for the testing.

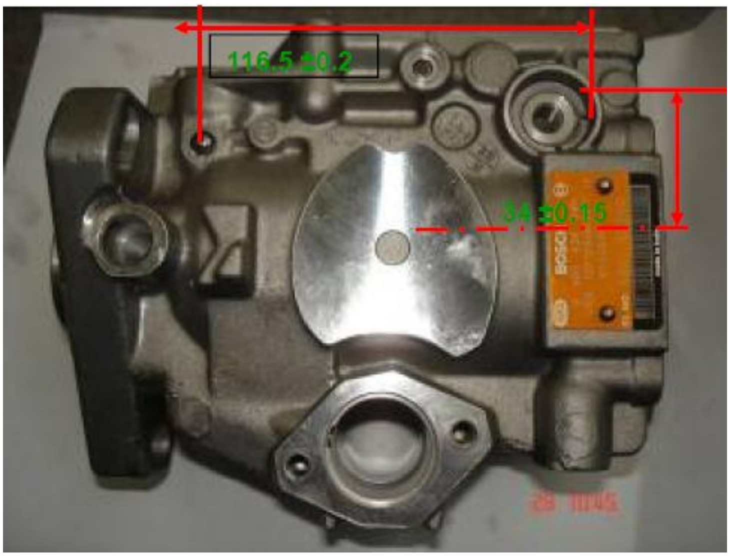


Figure 4- 6: Suspected Assembly

- All the four components are assemble to each other and we are observing the root cause for the problem where we have selected 6 bed parts and 6 good parts first we will check is there any mistake in assembly after this we will assemble some parts of good with bed and then check and there is some specification if they will deviate then problem may occur all the possibilities we will check Ideally 6 Good and 6 Bad Parts were selected on the based on Response.
- When selecting Good and Bad, Best of Best (BOB) and Worst of Worst (WOW) should be selected. And Part should be marked from 1 to 12. Similarly, check from the bottom also and draw a line at the first transition from bottom. Count the number of data above the Top Transition line. This is called 'Top count'. Count the number of data below the Bottom Transition line. This is called 'Bottom count' Add both Top and Bottom count, this is called 'Total count'.

- **Component Testing 1**

Distances from Shoulder screw center to flange face 05 Specification: 116.5 ±0.2 mm.

Table 4- 6: Component Testing 1

Distance from Shoulder screw center to flange face			Count
Sr.no	**Category**	**Spec.(116.5 ±0.2) Face 05**	**0**
5	WOW5	116.5124	
9	BOB3	116.5458	
4	WOW4	116.5487	
2	WOW2	116.5507	
10	BOB4	116.5901	
7	BOB1	116.6099	
1	WOW1	116.6175	
12	BOB6	116.6294	
11	BOB5	116.6684	
6	WOW6	116.6904	
8	BOB2	116.6977	
3	WOW3	116.7426	

6 good and 6 bad parts were selected and arranged in the increasing order for Distance from Shoulder screw center to flange face 05 and total count was calculated. In this the Top count is 1 and Bottom Count is 1. The total count came out to be 2. Thus it was concluded that flange face 05 was not the reason for the problem in assembly of VE pump shown in Table 4-6.

- **Component Testing 2**

Distances from Shoulder screw center to flange face 06 Specification: 116.5 ±0.2 mm.

Table 4- 7: Component Testing 2

Distance from Shoulder screw center to flange face			**Count**
Sr.no	**Category**	**Spec.(116.5 ±0.2) Face 06**	**4**
5	WOW5	116.4494	
4	WOW4	116.4673	
9	BOB3	116.4843	
2	WOW2	116.5211	
12	BOB6	116.5938	
11	BOB5	116.6354	
1	WOW1	116.6394	
10	BOB4	116.6427	
6	WOW6	116.6517	
3	WOW3	116.6598	
7	BOB1	116.6758	
8	BOB2	116.6959	

6 good and 6 bad parts were selected and arranged in the increasing order for Distance from Shoulder screw center to flange face 06 and total count was calculated. In this the Top count is 2 and Bottom Count is 2. The total count came out to be 4. Thus it was concluded that flange face 06 was not the reason for the problem in assembly of VE pump shown in Table 4-7.

- **Component Testing 3**

Distance from pump axis of bore dia. to center of shoulder screw Specification: 34 ±0.15 mm.

Table 4- 8: Component Testing 3

Distance from pump axis of bore Dia. to center of shoulder screw.			**Count**
Sr.no	**Category**	**Spec.(34 ±0.15) Face 05**	**3**
6	WOW6	32.9103	
4	WOW4	33.6693	
12	BOB6	33.6981	
9	BOB3	33.7096	
5	WOW5	33.7595	
2	WOW2	33.8172	
3	WOW3	33.9216	
11	BOB5	34.0044	
8	BOB2	34.0271	
10	BOB4	34.0667	
1	WOW1	34.0712	
7	BOB1	34.0792	

6 good and 6 bad parts were selected and arranged in the increasing order for Distance from pump axis of bore Dia. to center of shoulder screw and total count was calculated. In this the Top count is 2 and Bottom Count is 1. The total count came out to be 3. Thus it was concluded that Distance from pump axis of bore Dia. to center of shoulder screw Face 05 was not the reason for the problem in assembly of VE pump shown in Table 4-8.

- **Component Testing 4**

Distance from pump axis of bore dia. to center of shoulder screw Specification: 34 ±0.15 mm.

Table 4- 9: Component Testing 4

Distance from pump axis of bore Dia. to center of shoulder screw.			**Count**
Sr.no	**Category**	**Spec.(34 ±0.15) Face 06**	**3**
5	WOW5	33.7732	
12	BOB6	33.7825	
4	WOW4	33.7878	
9	BOB3	33.7903	
2	WOW2	33.8146	
6	WOW6	34.04	
11	BOB5	34.0454	
3	WOW3	34.0683	
8	BOB2	34.0766	
1	WOW1	34.078	
10	BOB4	34.0949	
7	BOB1	34.1069	

6 good and 6 bad parts were selected and arranged in the increasing order for Distance from pump axis of bore Dia. to center of shoulder screw and total count was calculated. In this the Top count is 1 and Bottom Count is 2. The total count came out to be 3. Thus it was concluded that Distance from pump axis of bore Dia. to center of shoulder screw Face 06 was not the reason for the problem in assembly of VE pump shown in Table 4-9.

- **Component Testing 5**

Distance from Shoulder screw outer face to pump axis Specification: 33 ±0.1 mm.

Table 4- 10: Component Testing 5

Distance from Shoulder screw outer face to pump axis.			**Count**
Sr.no	**Category**	**Spec.(33 ±0.1) Face 05**	**2**
11	BOB5	32.886	
6	WOW6	32.9103	
3	WOW3	32.9225	
8	BOB2	33.0033	
10	BOB4	33.0614	
2	WOW2	33.0747	
7	BOB1	33.0754	
1	WOW1	33.0822	
4	WOW4	33.0935	
12	BOB6	33.0942	
9	BOB3	33.1108	
5	WOW5	33.1222	

6 good and 6 bad parts were selected and arranged in the increasing order for Distance from Shoulder screw outer face to pump axis and total count was calculated. In this the Top count is 1 and Bottom Count is 1. The total count came out to be 2. Thus it was concluded that Distance from Shoulder screw outer face to pump axis Face 05 was not the reason for the problem in assembly of VE pump shown in Table 4-10.

- **Component Testing 6**

Distance from Shoulder screw outer face to pump axis Specification: 33 ±0.1 mm.

Table 4- 11: Component Testing 6

Distance from Shoulder screw outer face to pump axis.			Count
Sr.no	**Category**	**Spec.(33 ±0.1) Face 06**	**4**
4	BOB4	32.8347	
5	WOW5	32.8423	
4	WOW4	32.8531	
1	BOB1	32.8558	
2	BOB2	32.8563	
6	BOB6	32.8607	
2	WOW2	32.8643	
3	BOB3	32.9374	
5	BOB5	32.9565	
6	WOW6	33.0003	
3	WOW3	33.0937	
1	WOW1	33.883	

6 good and 6 bad parts were selected and arranged in the increasing order for Distance from Shoulder screw outer face to pump axis and total count was calculated. In this the Top count is 1 and Bottom Count is 3. The total count came out to be 4. Thus it was concluded that Distance from Shoulder screw outer face to pump axis Face 06 was not the reason for the problem in assembly of VE pump shown in Table 4-11.

- **Component Testing 7**

Distance between shoulder screw Specification: 66 ±0.2 mm.

Table 4- 12: Component Testing 7

Distance between shoulder screws			Count
Sr.no	**Category**	**Spec.(66 ±0.2) Face 05**	**0**
11	BOB5	65.8425	
8	BOB2	65.8597	
10	BOB4	65.8961	
6	WOW6	65.9106	
7	BOB1	65.931	
2	WOW2	65.939	
4	WOW4	65.9466	
12	BOB6	65.9548	
5	WOW5	65.9645	
1	WOW1	65.966	
3	WOW3	66.0161	
9	BOB3	66.0482	

6 good and 6 bad parts were selected and arranged in the increasing order for Distance between shoulder screws and total count was calculated. In this the Top count is 0 and Bottom Count is 0 because top and bottom status is same. The total count came out to be 0. Thus it was concluded that Distance from Shoulder screw outer face to pump axis Face 05 was not the reason for the problem in assembly of VE pump shown in Table 4-12.

- **Component Testing 8**

PCD of flange mounting Screw Specification 82 ±0.1mm suspected dimensions in pump housing.

Table 4- 13: Component Testing 8

PCD of flange mounting Screw.			**Count**
Sr.no	**Category**	**Spec.(82 ±0.1) Face 05**	**0**
8	BOB2	81.9286	
6	WOW6	81.9287	
11	BOB5	81.9384	
10	BOB4	81.9438	
12	BOB6	81.9438	
5	WOW5	81.9539	
1	WOW1	81.9555	
2	WOW2	81.9647	
7	BOB1	81.9858	
3	WOW3	81.9876	
4	WOW4	82.0089	
9	BOB3	82.0168	

6 good and 6 bad parts were selected and arranged in the increasing order for PCD of flange mounting Screw and total count was calculated. In this the Top count is 0 and Bottom Count is 0 because top and bottom status is same. The total count came out to be 0. Thus it was concluded that PCD of flange mounting Screw Face 05 was not the reason for the problem in assembly of VE pump shown in Table 4-13.

- **Component Testing 9**

Concentricity of Dia. 82 w.r.t Dia. 67.5 Specification: 0.1 mm.

Table 4- 14: Component Testing 9

Con. Dia. 82 w.r.t Dia. 67.5			**Count**
Sr.no	**Category**	**Spec.(±0.1)**	**7**
11	BOB5	0.0556	
7	BOB1	0.0597	
10	BOB4	0.0639	
9	BOB3	0.0817	
3	WOW3	0.0819	
6	WOW6	0.1137	
1	WOW1	0.1347	
12	BOB6	0.1486	
8	BOB2	0.1722	
4	WOW4	0.1818	
5	WOW5	0.1956	
2	WOW2	0.2923	

6 good and 6 bad parts were selected and arranged in the increasing order for Concentric diameter and total count was calculated. In this the Top count is 4 and Bottom Count is 3 because top and bottom status is same. The total count came out to be 7. Thus it was concluded that Concentric diameter 82 w.r.t. 67.5 was the reason for the problem in assembly of VE pump shown in Table 4-14.

- **Component testing 10**

Internal distance Specification: 36 ±0.2 mm

Table 4- 15: Component Testing 10

Internal distance			Count
Sr.no	**Category**	**Spec.(36 ±0.2)**	**5**
10	BOB4	36.9794	
12	BOB6	37.011	
11	BOB5	37.2088	
6	WOW6	37.4475	
5	WOW5	37.4641	
8	BOB2	37.6205	
9	BOB3	37.6233	
2	WOW2	37.6286	
4	WOW4	37.6635	
7	BOB1	37.7079	
3	WOW3	37.7123	
1	WOW1	37.7244	

6 good and 6 bad parts were selected and arranged in the increasing order for Internal distance and total count was calculated. In this the Top count is 3 and Bottom Count is 2. The total count came out to be 5. Thus it was concluded that Internal distance was the reason for the problem in assembly of VE pump shown in Table 4-15.

- **Component testing 11**

Symmetry of shoulder screw Specification: Max. 0.6 mm.

Table 4- 16: Component Testing 11

Run out of shoulder screw.			Count
Sr.no	**Category**	**Spec. 0.03 face 06**	**0**
2	WOW2	0.0204	
12	BOB6	0.0261	
7	BOB1	0.0411	
9	BOB3	0.0445	
4	WOW4	0.0474	
10	BOB4	0.0517	
11	BOB5	0.0565	
5	WOW5	0.0576	
8	BOB2	0.0595	
1	WOW1	0.0611	
3	WOW3	0.0651	
6	WOW6	0.0735	

6 good and 6 bad parts were selected and arranged in the increasing order for Run out of shoulder screw and total count was calculated. In this the Top count is 0 and Bottom Count is 0 because top and bottom status is same. The total count came out to be 0. Thus it was concluded that Run out of shoulder screw face 06 was not the reason for the problem in assembly of VE pump shown in Table 4-16.

- **Component testing 12**

Run out of shoulder screw Specification: Max. 0.03 mm.

Table 4- 17: Component Testing 12

Run out of shoulder screw.			**Count**
Sr.no	**Category**	**Spec. 0.03 face 05**	**4**
3	WOW3	0.0091	
6	WOW6	0.0115	
1	WOW1	0.0143	
10	BOB4	0.0202	
5	WOW5	0.0208	
9	BOB3	0.0218	
11	BOB5	0.0223	
8	BOB2	0.0235	
2	WOW2	0.0237	
12	BOB6	0.0396	
4	WOW4	0.0484	
7	BOB1	0.0524	

6 good and 6 bad parts were selected and arranged in the increasing order for Run out of shoulder screw and total count was calculated. In this the Top count is 3 and Bottom Count is 1. The total count came out to be 4. Thus it was concluded that Run out of shoulder screw face 05 was not the reason for the problem in assembly of VE pump shown in Table 4-17.

4.2.4 Improve

The Improve phase of DMAIC is improving the system. These improvements are the chosen root causes to be addressed from the analyze phase. These modifications can be a simple change in a way someone walks, how a process is performed, or a change in a piece of equipment. The improvement phase itself varies from facility to facility depending on what type of process is being used.

- **Tool used:** Better VS Current condition (shoulder screw VS distribution head) where we are trying to find out the BED and GOOD parts from (1-6) parts as shown in Table 4-18 and 4-19.

Table 4- 18: Improvement analysis B

Better Condition				
Pump Nr.	**Housing**	**Concentricity < 0.1mm**	**Flange**	**Concentricity ≤0.1mm**
Pump 1	B1	0.0347	G6	0.0714
Pump 2	G5	0.0556	G1	0.0966
Pump 3	G1	0.0597	G4	0.0974
Pump 4	G4	0.0639	B1	0.1065

Table 4- 19: Improvement analysis C

Current Condition				
Pump Nr.	**Housing**	**Concentricity > 0.1mm**	**Flange**	**Concentricity > 0.1mm**
Pump 5	B4	0.1818	B6	0.2118
Pump 6	BP	0.1892	B3	0.6376
Pump 7	G2	0.1722	G5	0.3049
Pump 8	B2	0.2923	B5	0.221

- **Validation data for Root cause(s)**

Table 5-20 shows the comparison between the B VS C conditions for identifying the root cause identification for the improvement.

Table 4- 20: B VS C Comparison

Better Condition	
Pump nr. 1	BAD
Pump nr. 2	BAD
Pump nr. 3	BAD
Pump nr. 4	BAD
Current Condition	
Pump nr. 4	BAD
Pump nr. 5	BAD
Pump nr. 6	BAD
Pump nr. 7	BAD

- **Data Validation**

Fulcrum lever is still fouling in better as well as current condition due to the internal dia. was not improved in this phase.

- **Conclusion**

So one additional dimension (Internal distance) to be checked for the root cause. Go back to Measure and Analyze Phase.

4.3 Phase 2 Analysis for Problem

- **Objective**

➢ To find out the dimension (s) in pump housing which is the root cause of problem?

- To achieve the sustainability by reducing the waste in the process.

4.3.1 Measure and Analyze

- Suspected dimensions in pump housing
- Internal distance (measured 28.5 mm above the main bore axis Specification: 36.1±0.3 mm)
- **Component testing**

Internal distance (Measured 28.5 mm above the main bore axis) Specification: 36 ±0.2 mm is the root cause of problem.

Table 4- 21: Component testing phase 2

Internal distance (measured 28.5 mm above the main bore axis.)			Count
Sr.no	**Category**	**Spec.(36±0.2)**	**12**
11	BOB5	36.4	
7	BOB1	36.5	
9	BOB3	36.5	
8	BOB2	36.6	
12	BOB6	36.6	
10	BOB4	36.7	
3	WOW3	37	
6	WOW6	37.3	
1	WOW1	37.5	
2	WOW2	37.7	
4	WOW4	37.8	
5	WOW5	37.8	

6 good and 6 bad parts were selected and arranged in the increasing order for Internal distance and total count was calculated. In this the Top count is 3 and Bottom Count is 1. The total count came out to be 4. Thus it was concluded that Internal distance was the reason for the problem in assembly of VE pump shown in Table 4-21.

4.3.2 Improve

After doing assembly again we find the housing with internal distance have a root cause for problem which is shown in Table 4-22.

Table 4- 22: Phase 2 Testing of Assembly

After assembly		
Housing	**Spec.(36±0.2)**	**Result**
Housing with internal distance less than 36.7 mm		
BOB5	36.4	Good
BOB1	36.5	Good
BOB3	36.5	Good
BOB2	36.6	Good
BOB6	36.6	Good
BOB4	36.7	Good
Housing with internal distance more than 36.7 mm		
WOW3	37	Bad
WOW6	37.3	Bad
WOW1	37.5	Bad
WOW2	37.7	Bad
WOW4	37.8	Bad
WOW5	37.8	Bad

From Table 4-22 it can be easily said that housing with internal distance less than or equal to 36.7 mm are giving good results and more than this are giving bad results.

4.4 Control

The Control phase of DMAIC is the control of the new system. This control phase establishes whether or not the improve phase did in fact work as intended and root causes were corrected. If root causes were not corrected through this process, another cycle of DMAIC must be done in order to address the additional issue.

The last step of DMAIC is called control. Now that the solutions have been found and validated they need to be implemented and maintained. This means that the critical inputs need to be set under control and process outputs monitored. Monitoring will ensure that the process does not drift back to the old performance. The goal of the control phase is to ensure that the improvements stick and become part of the normal way of doing things. Only reason why the improvements should be revoked is if an even better way of doing things is found and validated.

When we control our dimensions then we have removed problem from the device and getting good results from the distribution pump. As a result of the previous steps, the recommended solutions are now known as well as the positive and negative effects these solutions bring to the system. During the last step of the DMAIC process, the implementation responsibilities are given to the key personnel. Housing with internal distance more than 36.7 mm .internal distance which is more than 36.7mm are giving good results. With changing technologies, it is often found that newer technologies may be more efficient and more practical for corporations allowing them to reduce their waste, energy, and productivity usage further than at the time of the initial assessment.

Chapter 5 Discussion and Conclusions

5.1 Discussion

The project described in this work is one of those projects that benefited from the use of Lean tools inside the DMAIC structure. Lean offered some of the basic principles behind optimal production flow. These principles guided the direction of the project in many of its phases. At the same time the tools of Six Sigma enabled the scientific analysis of the data and accurate estimations of process improvement potential. In addition, the DMAIC process gave a clear framework through which the project was easy to systematically execute. Based on the experiences from this manufacturing improvement project, it can be said that the Six Sigma improvement process DMAIC can benefit considerably from the incorporation of Lean tools to its different phases. The DMAIC process itself worked well in this type of project, guiding the project through the different phases and ensuring that no shortcuts were taken. For example, the second phase "Measure" includes the evaluation of the measurement system accuracy, which is easily to forgotten. If such an important step would be skipped, then the project team cannot be certain of the actual performance of the system and the conclusions would be based on possibly false data.

This research is a practical application of Six Sigma methodology in the evaluation of maintenance performance of automobile parts, BOSCH Jaipur plant. It is worth mentioning that our project is the starting point of a continuous effort, to not only change the way we do maintenance but, also, the way we manage our operations since Six-Sigma is a philosophy of life. During the implementation of the DMAIC approach, it became obvious that a six Sigma project needs resources and top management commitment. Although, support from top management is critical, the role of line management employees is vital, too. For this reason, training on World Class Performance concepts needs to be provided as well as appropriate visual management has to take place e.g. display boards indicating can lines defects, etc. in order to encourage employees' involvement and participation. The most difficult part is (and will be) having the commitment to the project been spread all over the organization. In this way, we will succeed in sharing the knowledge gained from the project and in eliminating the waste in our operations.

Sometimes, it is possible for a Green Belt trainee to feel like a \`lonely rider´ when he returns to the plant wishing to generate financial returns through successful projects. However, whilst there may be a significant amount of \`push´ created by a newly trained Green Belt employee, it is important to create a \`pull´ for Six Sigma led by the senior management. It is suggested that a meeting takes place prior to high season in order to present the potentials of the method to the shift leaders based on the findings of this dissertation.

5.2 Conclusions

According to our experience, both the Define and Measure phases are being proved to be the most demanding. For instance, our project could be held at the Define phase for a couple of reasons such as either unclear problem statement and project objectives or low potential returns. As far as the Measure phase is concerned, the problem has been found to lie in the way the breakdown time is being measured in addition to convincing people of recording all the occurrences of defects. As a result of the previously mentioned limitations came up the small sample sizes thus affecting the Normality of data since the values tend to group in exactly the same number. The statistical processing of data revealed that a relationship does exist between number of defects and total breakdown time and that 76.4% of defects are related to maintenance practices and wear issues. This can happen if, for instance, we produce both work orders and job guidelines of improvement type during the implementation of the Improve and Control phases. Another interesting aspect of the data is the fact that 7.3% of causes of defects are assigned to employee skills. This is quite controversial since it is not easy to distinguish if a defect is related to a badly maintained machine and is linked to a number of issues like lack of training, limited resources etc.

As far as the implementation of preventive maintenance policy is concerned, we consider it to be a highly challenging goal for achieving sustainable development. This is happening due to the fact that we need to provide good feedback to the system; otherwise, maintenance reporting is neither able to support alternative maintenance strategies nor appropriate to support capital expenditures, e.g. new machinery; however it is essential to be able to produce good reports since maintenance is a service function for production and it has the potential to provide an organization with competitive advantage thus making influence to the plant performance.

Finally, it is well understood that a lot of the concepts of sustainability from the relevant literature have application to our case study and that the establishment of valid sustainable development results based on the reduction in the waste will allow the improvement of plant performance.

5.3 Future Scope

The work done can be further extended in the reduction in waste for various departments in the organizational processes as waste in the activities for various alternative departments at a very fast rate without actually implementing it in reality. As the company is growing very fast, it becomes relevant for the company to standardize this process to carry out various assembly jobs.

References

- Avila, M. C., Gardner, J. D., Reich-Weiser, C., Vijayaraghavan, A., and Dornfeld, D. (2006). Strategies for burr minimization and cleanability in aerospace and automotive manufacturing. *Journal of Aerospace, SAE Transactions*, 114(1), 1073-1082.
- Anbari, F.T. (2002). Six Sigma Method and Its Applications in Project Management, Proceedings of the Project Management Institute Annual Seminars and Symposium [CD], San Antonio, Texas. Oct 3–10. Project Management Institute, Newtown Square, PA.
- Barber, J. (2007). Mapping the movement to achieve sustainable production and consumption in North America. *Journal of Cleaner Production*, *15*(6), 499-512.
- Brady, J. E., and Allen, T. T. (2006). Six Sigma literature: a review and agenda for future research. *Quality and reliability engineering International*, *22*(3), 335-367.
- Bonn, I., and Fisher, J. (2011). Sustainability: the missing ingredient in strategy. *Journal of business strategy*, *32*(1), 5-14.
- Clark, G. (2007). Evolution of the global sustainable consumption and production policy and the United Nations Environment Programme's (UNEP) supporting activities. *Journal of Cleaner Production*, 15(6), 492–498
- Deif, A. M. (2011). A system model for green manufacturing. *Journal of Cleaner Production*, *19*(14), 1553-1559.
- Enthone (2013). Six Sigma Sustainability Report [Online]. http://www.enthone.com/Sustainability/Six_Sigma_Sustainability.aspx. [Accessed May 10, 2015].
- Fricker, A. (1998). Measuring up to sustainability. *Futures*, *30*(4), 367-375.
- Giardina, A. (2006). Sustainability and Lean Six Sigma. [Online] http://proceedings.ndia.org/JSEM2006/Wednesday/Giardina.pdf [Accessed May 10, 2015].
- Goldstein, M. D. (2001) Six Sigma Programme Success Factors, *Six Sigma Forum Magazine*, 1(2), 36–45.
- Hui, I. K., He, L., & Dang, C. (2002). Environmental impact assessment in an uncertain environment. *International Journal of Production Research*, *40*(2), 375-388
- Jackson, A., Boswell, K., & Davis, D. (2011). Sustainability and triple bottom line reporting- what is it all about? *International Journal of Business, Humanities, and Technology*, 1(11), 55-59.

- Jovane, F., Koren, Y., & Boer, C. R. (2003). Present and future of flexible automation: towards new paradigms. *CIRP Annals-Manufacturing Technology*, 52(2), 543-560.
- Leahy, T. (2000). In search of perfection with Six Sigma, *Business Finance*, 5(1), 72-74.
- Linton, J. D., Klassen, R., & Jayaraman, V. (2007). Sustainable supply chains: An introduction. *Journal of Operations Management*, 25(6), 1075-1082.
- Wang, L., and Lin, L. (2007). A methodological framework for the triple bottom line accounting and management of industry enterprises. *International Journal of Production Research*, 45(5), 1063-1088.
- McClusky, R. (2000). The rise, fall and revival of Six Sigma quality. Measuring Business Excellence, 4(2), 42-48.
- Mefford, R. N. (2011). The economic value of a sustainable supply chain. *Business and Society Review*, 116(1), 109-143.
- McCarty, T. D., and Fisher, S. A. (2007). Six Sigma: it is not what you think. *Journal of Corporate Real Estate*, 9(3), 187-196.
- Munier, N. (2006). Economic growth and sustainable development: Could multicriteria analysis be used to solve this dichotomy? *Environment, Development and Sustainability*, 8(3), 425-443.
- Kumar, V., Mohanty, S., Kumar, A., Misra, R. P., Santosham, M., Awasthi, S., ... & Saksham Study Group. (1998). Effect of community-based behaviour change management on neonatal mortality in Shivgarh, Uttar Pradesh, India: a cluster-randomised controlled trial. *The Lancet*, 372(9644), 1151-1162.
- Naderi, A. (1996). Productive design: a new design attitude. *APO World Conference on Green Productivity. – Manila*, 178-182.
- Pepper, M.P.J., and Spedding, T.A. (2010). The evolution of lean Six Sigma, *International Journal of Quality & Reliability Management*, 27(2), 138- 155.
- Pintellon, L., Pinjala, S.K. and Vereecke, A. (2006). Evaluating the effectiveness of maintenance strategies. *Journal of Quality in Maintenance Engineering*, 12(1), 7-20.
- Paulk, M. C., Curtis, B., Chrissis, M. B., and Weber, C. V. (1993). Capability Maturity Model, Version 1.1. *IEEE Software*, 10(4), 18-27.
- Pereira, R. (2007). *Descriptive Statistics*, LSS Academy. [Online] http://lssacademy.com/2007/08/20/descriptive-statistics-part-1 (Accessed June 18, 2015)

- Reynard, S. (2007). Motorola Celebrates 20 Years of Six Sigma.19-27. What is Six Sigma? [Online] http://www.sdands.com/knowledge/whatis-six-sigma.html. (Accessed June 18, 2015).
- Reiling, J. (2008). Lean Versus Six Sigma: What's the Controversy? What the Difference? [Online] http://www.articlesbase.com/business-articles/lean-versus-six-sigma-whats-the-controversy-what-the-difference-595677.html#ixzz17Y3zDWRW (Accessed May 5, 2015).
- Salonen, A., and Deleryd, M. (2011). Cost of poor maintenance, *Journal of Quality in Maintenance Engineering*, 17(1), 63-73.
- Snee, R. D. (2004). Six–Sigma: the evolution of 100 years of business improvement methodology. *International Journal of Six Sigma and Competitive Advantage*, *1*(1), 4-20.
- Stuteville, R., and Ikerd, J. (2009). Global sustainability and service-learning: paradigms for the future. *International Journal of Organizational Analysis*, *17*(1), 10-22.
- Szekely, F., and Knirsch, M. (2005). Responsible leadership and corporate social responsibility: Metrics for sustainable performance. *European Management Journal*, *23*(6), 628-647.
- Taghizadegan, S. (2010). *Essentials of lean six sigma*. Butterworth-Heinemann.
- Thampapillai, D. J. (2010). Perfect competition and sustainability: a brief note. *International Journal of Social Economics*, *37*(5), 384-390.
- Tomkins, R. (1997). *GE Beats Expected Rise.* Financial Times, 22.
- World Commission on Environment and Development (WCED) (1987). *Our Common Future*. Oxford University Press, London.
- Wyckoff, A. (2014). OECD: About sustainable manufacturing and the toolkit [Online]. http://www.oecd.org/innovation/green/toolkit/aboutsustainablemanufacturingandthetoolkit.htm. (Accessed May 15, 2015).

List of Conferences

1. **Pradeep Kumar**, Adarsh Kumar, Rahul Jain, M. L. Meena, (2015) "Fit Six Sigma to Achieve Sustainable Manufacturing." In Proceedings of International Conference on Production and Automation (ICPA-2015) held at GIT Jaipur, 17th-18th April, 2015**.**
2. **Pradeep Kumar**, M. L. Meena, (2015) "Six Sigma to Achieve Sustainable Manufacturing." In Proceedings of National Conference on Sustainable Manufacturing for a Brighter Future held at MNIT Jaipur, 2nd- 3rd January, 2015.