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# A Review: Six Sigma Implementation Practices in Indian Manufacturing SMEs

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***Abstract***
At present competitive market is focusing on industrial efforts to produce high quality products with the lowest possible cost. To help accomplish this objective, various quality improvement philosophies have been put forward in recent years and of these Six Sigma has emerged as perhaps the most viable and efficient approach for process quality improvement. The objective of this paper is to review and examine the advancement and encounters of six sigma practices in Indian manufacturing SMEs and identify the key tools for each step in successful Six Sigma project execution. The paper also integrates the lessons learned from successful six sigma projects and their prospective applications in various manufacturing SMEs. Large scale organizations are expecting high quality products from their suppliers and are owners of Small and Medium Enterprises (SMEs). The vast range of products are manufactured in the SMEs, the nature of the export composition makes it amply clear that products from mostly smaller enterprises have hardly improved quality through supportive engrossments towards product/process modernizations, diversification and larger market access. In today scenario, many Indian SMEs' operate their processes at the two to three sigma quality levels. So there is Six Sigma implementation needs and have been appealing much attention.
**Keywords**:Indian Manufacturing SMEs, Review, Six Sigma, DMAIC

## I. INTRODUCTION

Since its origins in the mid-1980s, the Six Sigma approach for process improvement has become widely embraced and many Fortune 500 firms have adopted Six Sigma. Early successes in high profile companies such as Motorola, Allied Signal (now Honeywell), and General Electric helped to popularize the approach and dozens of books have been devoted to the topic.

The traditional quality management approaches, including Statistical Quality Control (SQC), Zero Defects and Total Quality Management (TQM), have been key players for many years, while Six Sigma is one of the more recent continuous quality improvement initiatives to gain popularity and acceptance in many industries across the globe.Six Sigma derives from Total Quality Management (TQM). Like its predecessor, Six Sigma relies on the use of statistical analysis and other quality tools to identify and eliminate defects but provides a framework for using them and extends its focus beyond quality to other strategic areas of the organization. Six Sigma on the other hand, is a continuous improvement plan that is intended to reduce variability. [1]

## II. Six Sigma Methodology

As it is well known, Six Sigma was developed in the 1986's by Motorola in an effort to improve their quality by reducing variability in their manufacturing operation as they competed in the semiconductor industry. This allowed Motorola to become the first American company to win the Malcolm Baldrige Quality Award, in 1988.

Though Fredrick Taylor, Walter Shewhart and Henry Ford played a great role in the evolution of Six-Sigma in the early twentieth century, it is Bill Smith, Vice President of Motorola Corporation, who is considered as the father of Six-Sigma. Fredrick Taylor came up with the methodology of breaking systems into sub systems in order to increase the efficiency of the manufacturing process. Henry Ford followed his four principles, namely continuous flow, interchangeable parts, division of labour and reduction of wasted effort, in order to end up in an affordable priced automobile. The development of control charts by Walter Shewhart laid the base for statistical methods to measure the variability and quality of various processes.[2]

### 2.1 Six sigma definition

Six Sigma is a data-driven structured problem solving methodology for solving enduring issues facing a business. It is a highly disciplined approach used to reduce the process variations to the extent that the level of defects are drastically reduced to less than 3.4 (DPMO). The approach relies heavily on advanced statistical tools. Sigma ($\sigma$) is Greek letter that is used to describe variability. In statistical quality control, this means "standard deviation". Six Sigma, like other approach to business improvement e.g. TQM and ISO9000, has a strong customer focus, and contains key concepts related to strategy, organizational change, training and setting stretch objectives. The central idea of the Six Sigma approach is to design processes or improve existing processes, to obtain very high process capability and hence defect rates that are close to zero.[3]

The origin of Six Sigma comes from statistics and statisticians and deliberates the six sigma methodology from a statistical, probabilistic, and quantitative point of view. From the statistical point of view, the term Six Sigma is defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997%. If an organization is operating at three Sigma level for quality control, this is taken as achieving a success rate of 93% or 66,800 defects per million opportunities. Therefore, the Six Sigma method is a very rigorous quality control concept where several organizations still performs at three Sigma level.[4]

The Six Sigma methodology includes measured and reported financial results, uses additional, more advanced data analysis tools, focuses on customer concerns, and uses project management tools and methodology. The Six Sigma approach summarized as follows:
Six Sigma = TQM (or CQI) + Stronger Customer Focus + Additional Data Analysis Tools + Financial Results + Project Management

**2.2 DMAIC process**

As shown in figure 1. DMAIC is a closed-loop process that eliminates unproductive steps, often focuses on new measurements and spread over technology for continuous improvement. Some papers focus on explaining the DMAIC contents, with some authors discussing each phase of DMAIC in detail. This paper helps the readers to learn how to carry out a small scale Six Sigma project with guidance on the application of tools. It indicates a perceived need for training material and suggests that an avenue for further research is to develop training material to cover a wider range of applications and larger scale projects. Table 1 presents the key steps of Six Sigma using DMAIC process. [1]

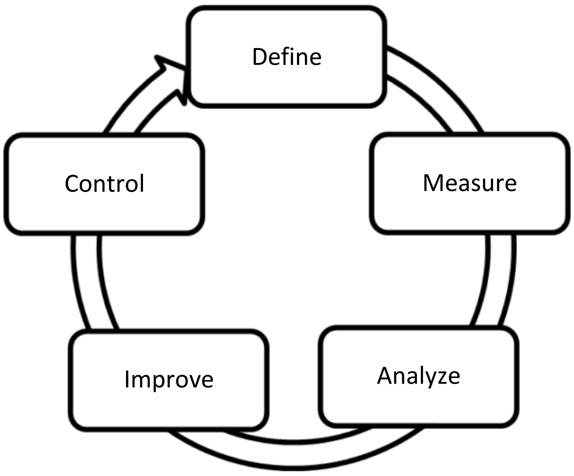


Figure 1. DMAIC Cycle

| Steps | Key Processes |
|---|---|
| Define | • Define the requirements and expectation of the customers<br>• Define the project boundaries<br>• Define the process by mapping the business flow |
| Measure | • Measure the process to satisfy customer's need<br>• Develop a data collection plan<br>• Collect and compare data to determine issues and shortfalls |
| Analyse | • Analyse the causes of defect and sources of variation<br>• Determine the variation in the process<br>• Prioritize opportunities for future improvement |
| Improve | • Improve the process to eliminate variation<br>• Develop creative alternatives and implement enhanced plan |
| Control | • Control process variations to meet customer requirements<br>• Develop a strategy to monitor and control the improved process<br>• Implement the improvements of systems and structures |

Table 1.Key Steps of Six Sigma DMAIC Process [1]

**2.3 DFSS Process**

As shown in figure 2. Design for Six Sigma (DFSS) is a systematic methodology utilizing tools, training and measurements to enable the organization to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels. DFSS is potentially far more effective than DMAIC as its application is in the early stage of new product/process development. The goal of DFSS is to achieve minimum defect rates, six sigma level, and maximize positive impact during the development stage of the products. It is used to develop new products or services with a six sigma criteria, capability, and performance. [5]

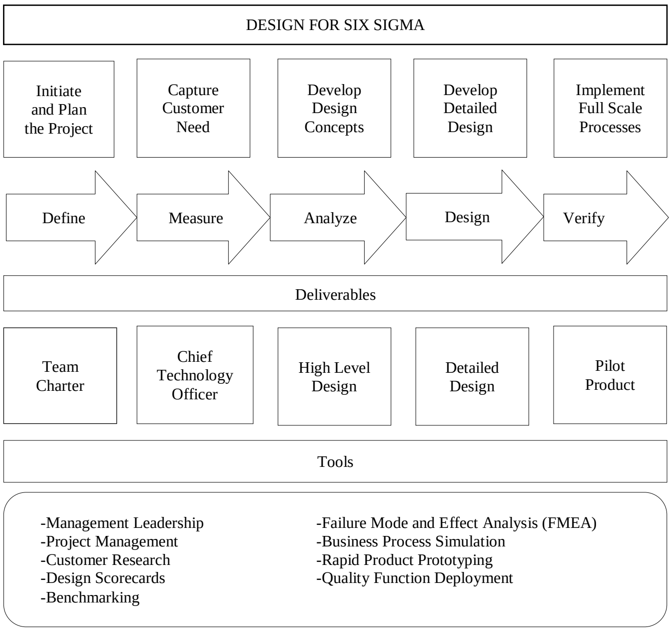


Figure 2.Five Step DFSS Process [3]

## III. Role of Six Sigma in SMEs

Rapid changes are taking place in the industry globally. It is make companies to think about adopting the Six Sigma approach such that they can improve their effectiveness in all the realistically feasible ways and to the maximum extent possible. The ongoing industrial changes indicate that more SMEs are becoming serious about Six Sigma approach for improving bottom-line of their business. It is very vital for SMEs in the manufacturing sector to employ Six Sigma methodologies for defects free production and be globally cost effective.[9]

It does not matter what type or size of business Six Sigma methodology is applied to, no matter whether it is a 300 employee company or a 10 employee family business, Six Sigma will work as long as you follow the process effectively.[6] Six Sigma is very appropriate for smaller companies too. The Six Sigma strategy works well in billion dollar corporations as well as $50 million privately held companies. In fact, it has been experienced that the results are usually quicker and more visible in smaller companies.[10]

The greatest barrier to implementation of Six Sigma in SMEs to date has been the way the major Six Sigma training providers have structured their offerings [4]. SMEs may have to adopt Six Sigma slightly differently compared to large companies with plenty of resources. Resources used for the Six Sigma projects by SMEs should be optimized at the same time target should be attaining maximum organizational effectiveness. This is possible by customization of the implementation process [5].

## IV. Literature review: Implication of Six sigma implementation in SMEs

In order to enhance the quality of the output of manufacturing sector to the world class organizations, there is a need to use continuous improvement strategies such as Six Sigma. Especially large concerns have successfully tried this breakthrough improvement strategy to get solutions in many of their ongoing problems. But small and medium enterprises are still ignorant regarding strengths of this improvement drive, of course there may be few exceptions. Sparing some sporadic articles and case studies in the corporate publications and magazines, the research publications illustrate wide ranging studies regarding saturation of Six Sigma among Indian industries [8].

Jiju Antony [9], provides an excellent resource for those people who believe that Six Sigma is primarily meant for large organization and also makes an attempt to remove one of the common myths of Six Sigma. The results of his study clearly indicate that Six Sigma is equally applicable to both large corporations and small companies. In fact, the results are quicker and much more visible in smaller companies than in larger corporations.

### 4.1 Six Sigma practices in non-Indian SMEs

Jonny *et al*., 2012 [13] In Indonesia, the quality issue of asbestos roofing has been one of its key success factors in winning its customers loyalty. Therefore, PT BBI has set its strategic initiative to improve the quality of this product. By implementing Six Sigma, the team found that this condition was mainly caused by side flat as its dominant defect type due to speeding up the curing time without simultaneously increasing its temperature. To solve this problem, the team has proposed that the company should increase its temperature up to 350°C by DOE (Design of Experiment) if it needs to speed up the curing time from normally 5 hours to 4 hours. Before the initiative was conducted, the sigma level was at 4.91 sigma with defect per million (DPMO) at 200 units. After implementation the quality figure was better with improved sigma level to 5.02 sigma and DPMO level at 180.

PloytipJirasukprasert*et al*., 2012 [14]Thai rubber gloves manufacturing organization studied that Six Sigma and the DMAIC problem solving methodology are effective approaches capable of improving its gloves manufacturing process by reducing the amount of defects. The design of experiments (DOE) and two-way analysis of variance

(ANOVA) techniques were combined to statistically determine the correlation of the oven's temperature and conveyor's speed with defects as well as to define their optimum values needed to reduce/eliminate the defects. As a result, a reduction of about 50% in the "leaking" gloves defect was achieved, which helped the organization studied to reduce its defects per million opportunities (DPMO) from 195,095 to 83,750 and thus improve its Sigma level from 2.4 to 2.9.

AdanValles *et al*., 2009 [15] presents a Six Sigma project conducted at a semiconductor company dedicated to the manufacture of circuit cartridges for inkjet printers. It is tested electrically in the final stage of the process measuring electrical characteristics to accept or reject it. Electrical failures accounted for about 50% of all defects. Therefore, it is crucial to establish the main problems, causes and actions to reduce the level of defects. The implementation of this project has been considered as successful because the critical factor for the process were found and controlled. The base line of the project was 3.35 sigma level and the gain 0.37 sigma that represents the elimination of 1.88% of nonconforming units or 18,788 PPM's.

A.K. Sahoo*et al*., 2007 [16] focuses on implementing the DMAIC based Six Sigma approach in order to optimize the radial forging operation variables. They have kept their prime focus on minimizing the residual stress developed in components manufactured by the radial forging process. Analysis of various critical process parameters and the interaction among them was carried out with the help of Taguchi's method of experimental design. To optimize the results obtained and to make the analysis more precise and cost effective, response surface methodology (RSM) was also incorporated. It has substantiated the fact that the efficiency and performance level of the radial forging operation can be improved by adopting a Six Sigma approach.

M. Soković *et al*., 2006 [17] presented a Six Sigma project, undertaken within company for production automotive parts, which deals with reduction of production cost in the deburring process for gravity die castings and improvement of quality level of produced parts. Systematic application of Six Sigma DMAIC tools and methodology within an automotive parts production results reduced tool expenses for 40 %, reduced costs of poor quality (COPQ) for 55 %, and reduced labours expenses for 59% which annually benefits of $ 72000.

J. P. C. Tong *et al*., 2004 [18] Applying statistical quality techniques especially in the manufacture of surface mounted printed circuit boards (PCB). As any defect in the solder joint can lead to circuit failure, the screening process is regarded as the most critical process in PCB manufacturing. The comparison of the printing performance before and after using the optimal settings, the sigma level of the screening process can be improved from 1.162 to 5.924. This shows that a nearly six sigma level performance can be achieved.

**4.2 Six Sigma practices in Indian SMEs**

Indian manufacturing SMEs has strong foundation in the form of ISO 9000. But except a few, many have not yet adopted advanced breakthrough quality improvement strategy like Six Sigma and other continuous process improvement techniques. Probably this can be one of the important reasons for companies not able to gain access to the international market and contribute significantly to the Indian economy. Thus, Indian SMEs are required to build their capability in respect of knowledge of global products, and global quality and technical standards [7].

Desai, D. A. *et al.* [10], pinpointed the results obtained from a cross-sectional study accomplished for the rate of response and benefits of Six Sigma implementation from different key sectors of the Indian industries. The manufacturing sector is on the top in implementing Six Sigma with 69% contribution in India.

AnupamaPrashar, 2014[19] deals with high warranty claims due to field failures of relief valves resulting in higher customer dissatisfaction. Thus, by decreasing field failures at various stages, we can reduce the cost of warranty claims & anticipate an increase in customer satisfaction levels". The implementation of remedies reduced the COPQ from INR 4.385 million to INR 19,000 (field failures from 111,810 ppm to 478 ppm). The sigma level enhanced from 2.32 to 4.8. The rolled throughput yield (RTY) at supplier end improved from 0.49% to 0.99%. All this ultimately contributed to improved customer satisfaction.

Vikas Kumar *et al*., 2013[20] finding the implication of applying six-sigma methodology in SSI, taking a specific case of Hydraulic jack manufacturing industry. DMAIC Methodology adopted which is help to reduce the rejection rate of pump head of hydraulic jack set by removing error in process & method of operation. This paper justify the successfully application of six-sigma in Hydraulics jack set manufacturing industry a small scale industry improve the sigma level from 2.21σ to 5.64σ and it help in the cost saving of Rs. 0.01929 million/annum. SSI is a very important sector for Six Sigma to grow over the last two to three years. A small number of studies have been reported about the successful applications of Six Sigma in SSI. In the small companies is much easier to buy in management support and commitment, as opposed to large organizations.

Sunil Dambhare*et al*., 2013 [21] reports a case study of an engine manufacturing industry. Variation in depth of an engine bore was observed with unknown reasons as the pattern of variation in size was different. The problem faced on the production line was, that in 18% of the bores produced per month the depth of this critical liner bore was not within the designated tolerance limits and varied non-uniformly. By using Six Sigma , DMAIC and fault tree analysis the probable reasons for variation were listed and experimentation were carried out to understand the effect of the variation in parameters on process output. After successful implementation it was observed that the engine bore rework was reduced from 18 % per month to 2.2 % per month. Man hours required for rework was brought down to 43 hours per month thus increasing productivity.

SalilDey*et al*., 2013[22] pinpointed the case study of electronics industry, existing process could not able to provide appreciable first time pass (FTP) of assembled Pcb during testing cycle. Systematic analysis of data along with the process parameter able to focus on the correct identification of problem and then gradually arrives at the optimum solution of the problem which resulted into considerable improvement of First time pass of assembled Pcbs after testing. Before starting of the project, the process yield was at 3.87 sigma level. In other word the process was generating 8890 defects in 1 million of opportunities. By applying Six Sigma techniques the process yield is improved to 5.14 Sigma level means defect rate is reduced to 54 defects per 1 million of opportunities.

MehdiuzZaman*et al*., 2013 [23] discusses the implementation of Six Sigma methodology on the problem of rejection of welding electrodes due to the variations in diameter of the manufactured units and explains the step-by-step approach of Six Sigma implementation in this manufacturing process for improving quality level. The Six Sigma methodology including Taguchi methods has proved to be an effective approach for improving the quality of the welding electrodes that are manufactured in the concerned industry. This resulted in reduction of rejection from 28356.96 to 1666.67 DPMO. This had resulted in increasing the sigma level from 3.41 to 4.43, without any huge capital investment. Implementation of Six Sigma methodology has resulted in large financial savings for the industry.

Kumaravadivel*et al*., 2013 [24] deals with the application of Six Sigma methodology to the flywheel casting process in foundry to minimize the defects in this process. The present study proposes to measure the performance criteria of the process through investigating the effect of working parameters, namely, moisture content, green strength, permeability, and loss on ignition on sand preparation. Based on the findings, the optimized process parameters were taken for experiment and better performance obtained in the production process was confirmed. This paper has substantiated the fact that the efficiency and performance level of the sand-casting process can be improved by adopting the Six Sigma approach.

Dr.Rajeshkumar U. Sambhe, 2012 [25] focus on a case of provoked mid-sized auto ancillary unit consisting of 350-400employee and employed Six Sigma methodology to elevate towards the dream of Six Sigma quality level. The methodology is executed on one of product assembly for trimming down defects level which are critical to customers and its implementation has had a significant financial hit on the bottom-line of the enterprise. This Six Sigma quality management practice exhibits to improve stratum as well elevate internal and external customers atonement; redesign manufacturing processes in perspective of curtailing or eliminating defects; creating culture of perpetual improvement, but it needs right focus and commitments.

ShashankSoni*et al*., 2013 [26] discusses the quality and productivity improvement in a manufacturing enterprise and Identifies the root causes of failure for a welding defect at a manufacturing plant and proposes to use Operational Six Sigma technique to eliminate the problem. The paper deals with an application of Six Sigma DMAIC methodology in an industry which provides a framework to identify quantify and eliminate sources of variation in an operational process to optimize the operation variables, improve quality and performance with well executed control plan. By implementing Six Sigma the Benefits they get are as below: Production efficiency increase by section/day

- Reduction in COPQ by 50%.
- Saving of INR 8,43,000
- TPT reduced by 2 days
- Rework of defect 4.8 defects/section.

AnupA.Junankar*et al*., 2011 [27] discusses the quality and productivity improvement in a Raw Edge Cog Belt Manufacturing enterprise through a case study. The Six Sigma based methodology has been used to optimize the variables of cord wastage. The results obtained are in the form of improvement for fabric Rough in Sigma level (Previous =2.7, Improved=3.2). It has been found that organization achieved breakthrough in reducing fabric rework due to Six Sigma DMAIC Methodology.

PrabhakarKaushik*et al*., 2008[28] review the implications of applying Six Sigma methodology over the SMEs, taking a specific case of a bicycle chain manufacturing unit. The methodology has been applied to reduce the bush rejection rate (bush is an important component of a cycle chain) by reducing defects inherent in the processes. The statistical techniques such as two sample t-test and process capability analysis have been used to establish the process capability before and after the Six Sigma application. Application of Six Sigma project recommendation brought up the process sigma level to 5.46 from 1.40 by reduction in bush diameter variation in the process of bicycle chain bush manufacturing. This increase in sigma level is equivalent to monetary saving of Rs 0.288 million per annum, which is a noteworthy figure for an industry of such level.

Chethan Kumar C S *et al*.[29] develop an application guideline for the assessment, improvement, and control of wastes in garment industry using six-sigma improvement methodology. An attempt is made to introduce and implement DMAIC methodology in Sun garment industry located in Coimbatore. The garment industry in focus was exporting the final product to European countries. It was operating at a percentage defective of 4.42. After implementing the DMAIC methodology the percentage defective is reduced to 1.95.the sigma level increase from 3.2 to 3.56. If the quantum of defectives are reduced and converted into cash flows, the company will benefit through increased revenues.

## V. CONCLUSION

India is emerging as one of the key components manufacturing Centre in Asia and is projected to play a significant role in the global supply chain in the near future. Manufacturing competence of the Indian manufacturing SMEs is much higher than that of electronics, machinery, and process industries. Some researches hints on this subject by stating that Six Sigma promote many SMEs as identical benefits as larger companies and there is nothing inherent in Six Sigma that makes it incompatible for smaller companies. So, this would allow for constructing a potent immoral for Six Sigma implementation in SMEs, which will lead the enterprises to yield generous results and confront customer satisfaction.

Lastly, this research provides effective guideline for selecting an appropriate tool in each stage of DMAIC Six Sigma programs to reduce variation or waste from the processes and encourage for successful implementation of Six Sigma methodology in various Indian manufacturing SMEs. This is particularly significant because today's competitive environment demands that companies reduce variation (waste) to meet or exceed efficiency and responsiveness requirements of customers. There is increasing pressure to stream a new ways of thinking as a source of competitive advantage and additional research in this area is necessary to subsidize the science and practice of implementation of Six Sigma in Indian SMEs. In the Table 2, most commonly used tools in all the DMAIC manufacturing case study are given below which can be used for effective Six Sigma implementations in manufacturing organisation .

| DMAIC Phase | Commonly Used Tools |
|---|---|
| Define | • Project Charter<br>• CTQ Tree<br>• SIPOC Diagram<br>• Process Map |
| Measure | • Pareto Chart<br>• Gauge R&R<br>• Normality Test<br>• Process Capability Analysis |
| Analyze | • Brain Storming<br>• Cause & Effect Diagram<br>• FMEA<br>• Pareto Analysis<br>• Why-Why Analysis |
| Improve | • Action Plan<br>• Advance Statistical Tools<br>• Design Of Experiments (DOE) |
| Control | • Control Plan<br>• Control Chart |

Table 2. Most Commonly used tools in DMAIC

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| No | Case Study Industry | Problem | Define | Measure | Analyse | Improve | Control | Sigma Level | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **Before** | **After** |
| 1 | Asbestos Roofing | Side Flat Rejection | Project Charter | Control Charts | FMEA | Anova Design Of Experiment | Control Charts | 4.91 | 5.02 |
| | | | SIPOC | | Action Plan | | Standard Operating Procedure(SOP) | | |
| | | | Pareto Chart | | Fish Bone Diagram | | | | |
| | | | Control Chart | | | | | | |
| 2 | Rubber Gloves Manufacturing Industry | Rubber Gloves Rejected By Customers Due Defective | Project Charter | Pareto Charts | Flow Chart | Design Of Experiments (DOE) | | 2.4 | 2.9 |
| | | | Voice Of Customer(VOC) | | Brainstorming Sessions | Two-Way Analysis Of Variance (ANOVA) | | | |
| | | | | | Cause-And-Effect Diagram | Boxplot | | | |
| 3 | Semiconductor Company | Low Level Performance Of Circuit In Electrical Test | Boxplot | Normality Test | Brainstorming Session | Boxplot | Test Of Equality Of Variances | 3.35 | 3.72 |
| | | | Critical To Quality (CTQ) | Gauge R&R | Pareto Chart | Test Of Equality Of Variances | | | |
| | | | Critical To Cost (CTC) | | Cause And Effect Matrix | | | | |
| | | | | | Hypotheses Test(ANOVA) | | | | |
| | | | | | Boxplot | | | | |
| | | | | | Residual Plots | | | | |
| 4 | Radial Forging Industry | To Optimize The Radial Forging Operation Variables | Project Charter | Gauge R&R | Design Of Experiments (DOE) | Response Surface Methodology (RSM) | Control Plan | - | - |
| | | | Critical To Quality (CTQ) Tree | Capability Analysis | | | Control Chart | | |
| | | | Process Map | | | | | | |
| 5 | Automotive Parts Production | Reduction Of Production Cost In The Deburring Process For Gravity Die-Castings | | Pareto Chart | FMEA | Gage R&R Analyses | Control Plan | - | - |
| | | | | Process Map | Normality Test | Process Capability | | | |
| | | | | | Analysis Of Variance | | | | |
| | | | | | Box Plot | | | | |
| | | | | | Correlation Analyses | | | | |
| | | | | | Multi-Vary Analysis | | | | |
| 6 | Manufacture Of Surface mounted Printed Circuit Boards (PCB) | Improvement Of The Sigma Level Of The PCB Screening Process. | Critical To Quality (CTQ) | Gauge R&R | Process Capability | Design Of Experiments (DOE) | Control Charts | 1.162 | 5.924 |
| | | | | Control Chart | | Capability Plot | Control Plan | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7 | Tractor Manufacturing Company | Relief Valve Assembly Failure In Field | Project Charter | Measurement System Analysis(MSA) | Cause & Effect Diagram | Process FMEA | Control Plan | 2.32 | 4.8 |
| | | | SIPOC | Capability Analysis | Pareto Analysis | Improvement Plan | Control Chart | | |
| | | | Critical To Quality (CTQ) Tree | Process Map | Hypothesis Testing | | | | |
| 8 | Hydraulic Jack Manufacturing Industry | To Reduce The Rejection Rate Of Pump Head Of Hydraulic Jack Set | Process Map | Gauge R&R | Capability Analysis | Design Of Experiments (DOE) | Control Chart | 2.21 | 5.64 |
| | | | SIPOC | | Cause And Effect Diagram | Main Effect Plot | | | |
| | | | | | Two Sample T-Test | Interaction Plot | | | |
| 9 | Small Engine Manufacturing | Engine Step Bore Depth Variation | | Measurement System Analysis(MSA) | Fault Tree Analysis(FTA) | Action Plan | Control Plan | - | - |
| | | | | Gauge R&R | Multi-Vari Regression Analysis. | Box Plot Comparison | Training | | |
| | | | | | Analysis Of Variance | | Control Charts | | |
| 10 | Electronics Industry | Improvement Of First Time Pass Of Assembled Pcbs | Pareto Analysis | Gauge R&R | Cause And Effect Diagram | Main Effect Diagram | | 3.87 | 5.14 |
| | | | | Process Map | Hypothesis Test | Interaction Diagrams | | | |
| | | | | | Design Of Experiments | | | | |
| 11 | Welding Electrode Manufacturing Industry | Non Conformance Of Welding Electrodes Diameter | Identifying Key Quality Characteristics(QCH) | Probability Plot | Pareto Chart Analysis | Brainstorming Session | Process Control Charts | 3.41 | 4.43 |
| | | | SIPOC | Process Capability | Fishbone (Ishikawa) Diagram Analysis | Dot Plot | Pareto Charts | | |
| | | | Process Mapping | | Regression Analysis | Pareto Chart | | | |
| 12 | Casting Foundry Industry | Minimize Process Defect Of Flywheel Casting | Project Charter | SIPOC | Cause And Effect Matrix | Response Surface Methodology (RSM) | Statistical Process Control | - | - |
| | | | Process Map | Critical To Quality (CTQ) Tree | Pareto Chart | ANOVA | PDCA Cycles | | |
| | | | SIPOC | Voice Of Customer (VOC) | Process FMEA | | | | |
| 13 | Automotive Ancillary Units | Trimming Down Defects Level Of Product Assembly | Critical To Quality (CTQ) Tree | Pareto Chart | Cause And Effect Matrix | Design Of Experiments (DOE) | Control Plan | - | - |
| | | | Process Map | Process FMEA | Box Plot | Pareto Chart | Control Chart | | |
| | | | SIPOC | | Validation Of Root Causes | | | | |
| | | | Critical To Quality (CTQ) Tree | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 14 | Manufacturing Enterprise | Identifies The Root Causes Of Failure For A Welding Process | Critical To Quality (CTQ) Tree | Process Map | Cause And Effect Diagram | Advance Statistical Tools | Control Plan | - | - |
| | | | Voice Of Customer (VOC) | | Pareto Analysis | Design Of Experiments (DOE) | Periodic Review | | |
| | | | Quality Function Deployment | | Why-Why Analysis | | | | |
| | | | Critical To Quality (CTQ) Tree | | Design Of Experiments (DOE) | | | | |
| | | | SIPOC | | Brain Storming | | | | |
| | | | Pareto Chart | | FMEA | | | | |
| | | | | | | | | | |
| 15 | Belt Manufacturing Industry | Minimizing Fabric Rework | Project Charter | Normality Test | Cause And Effect Diagram | Capability Analysis | Periodic Review | 2.7 | 3.2 |
| | | | Critical To Quality (CTQ) Tree | Capability Analysis | Pareto Analysis | Action Plan | | | |
| | | | SIPOC | Cost Of Poor Quality(COPQ) | FMEA | | | | |
| | | | Process Map | | | | | | |
| | | | | | | | | | |
| 16 | Bicycle Chain Manufacturing Unit | Reduce The Bush Rejection Rate | Process Map | Gauge R&R | Process Capability Analysis | Main Effect Plot | | 1.4 | 5.46 |
| | | | High-Level Process Map | | Fishbone Diagram | | Control Chart | | |
| | | | SIPOC | | Two-Sample T-Test | | | | |
| | | | | | | | | | |
| 17 | Garment Industry | High Rate Of Rejections | Project Charter | Capability Analysis | Pareto Analysis | Action Plan | Control Plan | 3.2 | 3.56 |
| | | | Critical To Quality (CTQ) Tree | | Cause And Effect Diagram | Capability Analysis | | | |
| | | | SIPOC | | | | | | |

In the above table all 17 case studies of Six Sigma implementation in manufacturing SMEs research papers is summarised based on tools used in each phase of DMAIC and sigma level improvement in particular industry. From the above table one can easily select the tools for each stage of DMAIC and implement Six Sigma methodology for continuous quality and operation improvement in any manufacturing SMEs.