

Defect Reduction using Six Sigma Tools in Small Scale Mechanical Manufacturing Company: A Case Study

Sudhir B. Lambe¹, Girish R. Naik² and Poornima G. Naik³

¹P.G. Student, Department of Production Engineering, KIT's College of Engg, Kolhapur, India
Email: sudhir.lambe67@gmail.com

²Department of Mechanical Engg., KIT's College of Engg., Kolhapur, India
Email: girishnaik2025@gmail.com

³School of Computer Science and Applications, CSIBER, Kolhapur, India
Email: pgnaik@siberindia.edu.in

Abstract— Six Sigma is a structured methodology that helps organizations solve problems and achieve their goals by reducing defects and variation. This study applies the Six Sigma approach in a mechanical production engineering industry. Using the DMAIC cycle (Define, Measure, Analyze, Improve, and Control), the work systematically identifies the root causes of defects and develops reliable solutions to reduce or eliminate them. Moreover, the Multi-vari analysis and poka-yoke tools were used successfully in this study. Multi-vari analysis was used to find out effect of different process parameters on bore size variation and determine optimum parameters while poka-yoke tool was used to reduce tool resetting error in depth variation problem. After implementing the optimized process parameters, the defect of bore size variation was eliminated and after changing the process to machine both surfaces in one tool setting the depth variation problem vanished. Therefore, applying Six Sigma tools provides an effective approach to reducing defects, lowering costs, and enhancing customer satisfaction.

Index Terms— Six Sigma, Machining defect, Cause of defect, Process Improvement DMAIC.

I. INTRODUCTION

Over the years, Six Sigma [4] has been widely adopted by numerous companies, with many successful implementations documented in the literature. Notable examples include Motorola, General Electric, Honeywell, AlliedSignal, Raytheon, and Delphi Automotive. Originally developed at Motorola, Six Sigma is a statistically driven methodology designed to define, measure, analyze, improve, and control (DMAIC) [17] manufacturing processes, with the primary goal of reducing process variability. The current research presents a case study on the application of Six Sigma methodology to address machining rejections in a mechanical engineering component manufacturing company based in Kolhapur, Maharashtra. The study follows the DMAIC framework.

II. LITERATURE REVIEW

Mostly machining defects are concerned with process parameters, machine condition, measurement system quality etc. Hence one has to control the process parameters, maintain good machine condition and measurement system quality to achieve zero defect parts. To control process parameters effectively, it is important to understand how they affect machining quality and contribute to defects.

Many researchers have used the Six Sigma methodology to improve quality in this context. Research literature on research studies to overcome quality issues in manufacturing industries from 2011 to 2024 were studied. Method of different researchers to identify and define the problem, data collection, analysis of problem to find root cause, different tools used to eliminate cause of the problem from home appliance manufacturing company [4], automotive parts manufacturing company [5], rubber hose manufacturing company [7], screw manufacturing company [13] & bearing manufacturing company [16] were studied. Literature review shows six sigma methodology has been widely adopted by manufacturing companies to improve quality, reduce waste and enhance productivity. Six Sigma methodologies have proven highly effective in enhancing quality and productivity across diverse manufacturing sectors. Lean Six Sigma has improved machining processes by employing tools such as brainstorming, process mapping, and statistical analyses to reduce defects [1]. In small- and medium-scale industries, work study approaches and quality management systems have optimized production, reduced rework, and improved resource utilization [2], [12], [19], [22]. Lean management and total quality management principles have guided product quality improvement strategies, minimizing costs and defects [3], [11], [26]. The DMAIC cycle has been applied in automotive and home appliance manufacturing to address rejection issues, enhance process performance, and implement robust control measures [4], [6], [14], [20]. Implementation of quality tools, including seven quality tools and statistical process control, has successfully mitigated defects in shaft, gear, and screw production [5], [9], [15], [18], [21], [23], [24]. Case studies in Indian MSME firms demonstrate the applicability of Six Sigma for improving productivity and achieving customer satisfaction [7], [10].

III. PROBLEM DOMAIN

The problem domain of the research is quality improvement and defect reduction in small-scale mechanical component manufacturing, focusing on machining defects in a brake box component. It deals with bore size and depth variation problems and addresses them using Six Sigma DMAIC, Multi-Vari analysis, Poka-Yoke, and process capability analysis to reduce rejections and improve process performance.

IV. METHODOLOGY

In this case study, the Six Sigma and DMAIC [4][17] methodologies were applied to identify existing problems, determine their root causes, and implement appropriate solutions to reduce or eliminate them. Following the DMAIC approach, the problem was first clearly defined. Data were then collected to measure process performance and identify the Critical to Quality (CTQ) [25] requirements. The potential causes were examined to identify the most likely root issues using tools like cause-and-effect diagrams and Pareto charts. Various improvement solutions were then assessed with Multi-Vari analysis and Poka-Yoke techniques, and the most effective solution was implemented. Finally, to ensure sustained results, appropriate control procedures were implemented for maintaining the improvements and preventing a decline in process performance.

V. PROBLEM STATEMENT AND PROPOSED SOLUTION

Renuka industries was having quality problem for product Brake box and offered it for quality improvement. The project is focusing on Brake box, Part No. 0.008.5162.0/80/0 manufacturing for Same Duetz-FAHR India Ltd. Company. The demand for this is 1500 pieces per month. Current output is average 1250 pieces per month. The current sigma level of the company is 3.5 with about 26400 defective parts per million opportunities. The current cost of poor quality is 3.9 lakh/annum. Thus, there is need to improve quality of brake box by applying six sigma tools.

A. Define Phase

Renuka Industries was facing a rise in defective products, increasing customer complaints and higher costs due to rework and scrap material. These issues significantly negatively impacted production processes by lengthening the production cycle. This resulted in hindering the company's ability to meet delivery commitments. To address these challenges, the company adopted the Six Sigma methodology with the goals of improving customer satisfaction, reducing costs and enhancing the sigma levels of its production processes.

Among the various products manufactured, the Brake Box was identified as the main contributor to losses due to non-conformance with specifications. Consequently, the company focused its defect reduction efforts on this product. The initial phase involved clearly defining the problem and identifying the factors which contributed most significantly to it. Project selection was then carried out using Pareto analysis for prioritizing the areas with

the highest impact. Table I presents the defect-wise rejection data for the last six months, showing that out of a total of 197 rejected parts, the highest rejections are due to bore size 100H7 and depth 14.5 mm variations. Rejection Analysis of Last Six Months : Total Production Quantity : 7450 Nos

TABLE I. REJECTION ANALYSIS FOR THE LAST SIX MONTHS

Sr. No.	Defect	Rejection Quantity
1	Bore size 100H7	86
2	Depth 14.5	71
3	OD size 242f7	08
4	Surface finish Ra 3.2	07
5	Surface Ra 6.3	04
6	Depth 12.5	06
7	Depth 113.5	06
8	tool mark	04
9	CR	05
	Total	197

Figure 1 shows defect-wise pareto chart.

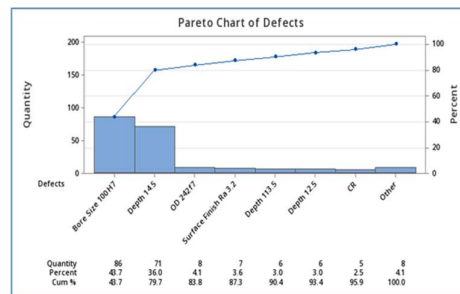


Figure 1. Pareto Chart Showing Defects by Type

Project Selection

The pareto diagram shows that bore size $\varnothing 100 +0.035$ variation and depth 14.5 ± 0.1 variation are vital few causes as they contribute more to the rejection loss. So these two defects are selected for defect reduction using six sigma tools. In house rejection as well as customer complaints are highlighting the seriousness of the problem. These critical to quality elements address the voice of the customers. Tools like pareto analysis, cause effect analysis, multi- vary analysis, poka-yoke are used in this study.

B. Measure Phase

Inspection of machined products was done and data collected. The data for bore size variation and depth variation problems is tabulated below. Table II shows 30 bore size measurements for $\varnothing 100 +0.035$ mm taken before improvement, providing baseline data on dimensional variation in the machining process.

Bore size variation problem - Bore Size Data Before Improvement

Insert : TNMG 160408

Cutting Speed : 260 m/min Depth of Cut : 0.35 mm Feed : 0.25 mm/rev

TABLE II. DATA COLLECTION FOR BORE SIZE $\varnothing 100 +0.035$ VARIATION (BEFORE IMPROVEMENT)

Reading No.	Size	Reading No.	Size $\varnothing 100 +0.035$	Reading No.	Size
1	100.011	11	100.010	21	100.010
2	100.022	12	100.020	22	100.020
3	100.030	13	100.031	23	100.003
4	100.032	14	100.030	24	100.034
5	100.045	15	100.048	25	100.046
6	100.025	16	100.024	26	100.025
7	100.032	17	100.031	27	100.029
8	100.030	18	100.032	28	100.032
9	100.039	19	100.040	29	100.038
10	100.018	20	100.020	30	100.018

Figure 2 illustrates the process capability analysis for bore size variation, showing how the measured values compare with the specified tolerance limits before improvement.

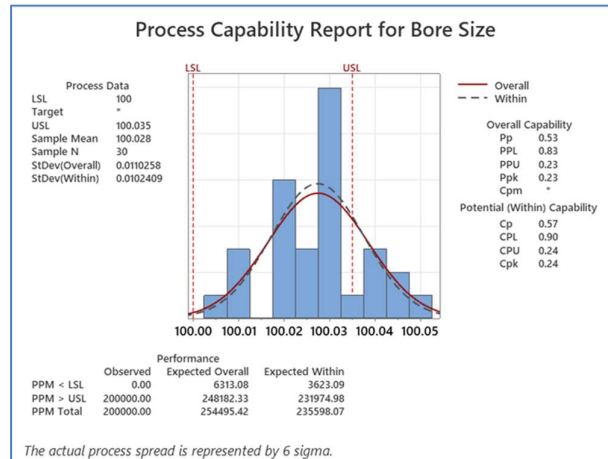


Figure 2. Process Capability Study for Bore Size Variation

Depth size variation problem

Table III presents 30 measurements of depth 14.5 mm ± 0.1 mm taken before improvement, providing baseline data on depth size variation in the machining process.

TABLE III. DATA COLLECTION FOR DEPTH 14.5 MM ± 0.1 MM VARIATION (BEFORE IMPROVEMENT)

Reading No.	Size Variation	Reading No.	Size Variation 14.5 ± 0.1	Reading No.	Size Variation 14.5 ± 0.1
1	14.499	11	14.599	21	14.595
2	14.579	12	14.593	22	14.594
3	14.596	13	14.599	23	14.596
4	14.597	14	14.584	24	14.596
5	14.592	15	14.585	25	14.594
6	14.62	16	14.579	26	14.551
7	14.592	17	14.588	27	14.589
8	14.583	18	14.591	28	14.590
9	14.566	19	14.590	29	14.592
10	14.597	20	14.446	30	14.592

Figure 3 shows the process capability analysis for depth 14.5 mm ± 0.1 mm, indicating how the observed depth measurements compare with the specified tolerance limits before improvement.

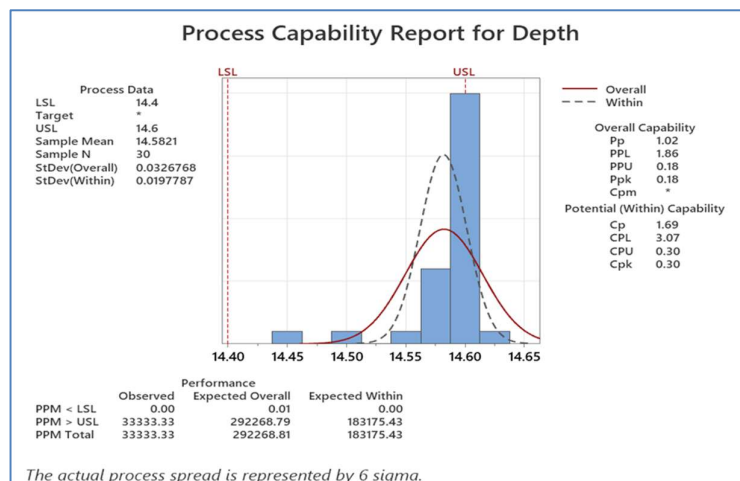


Figure 3 Process Capability Study for Depth Variation

C. Analysis Phase

The Analyze phase of the DMAIC methodology focuses on examining the manufacturing processes—in this case, the brake box machining operations. The primary goal of this phase is to pinpoint the root causes of the problem using analytical tools like cause-and-effect diagrams, brainstorming, process mapping, Multi-Vari analysis, and Poka-Yoke. In this study, the researchers specifically used Multi-Vari analysis, brainstorming, cause-and-effect diagrams, and Pareto charts, as outlined in the following steps:

Step 1: A cause-and-effect diagram was created for identification of the possible causes of machining rejections. The key parameters considered included the man, material, machines, methods, measurement system and working environment.

Step 2: Once all potential causes of machining rejection were identified, the rejected parts were thoroughly examined to gain a deeper understanding of the defects.

Step 3: The historical data collected over six months on rejected parts was thoroughly analyzed. This data included information on production volumes, defective parts, and various types of defects such as bore size variation, depth variation, OD size variation, surface finish issues, casting defects, and tool marks. A Pareto diagram was created to identify and prioritize the most significant causes of rejection, revealing that the main issues were bearing bore size variation and face-to-face depth variation as depicted in Figure 4.

Bore size variation problem

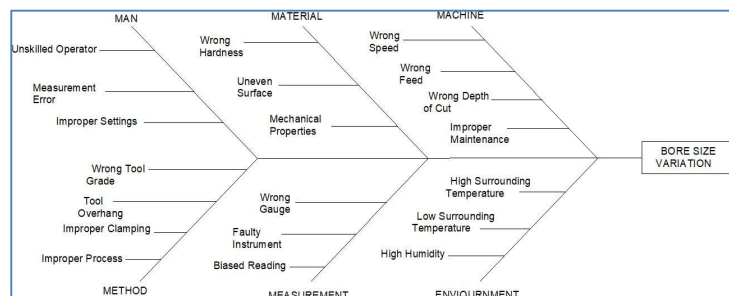


Figure 4 Cause-and-Effect Diagram for Bore Size Variation

Multi-variate analysis to study the effect of machines, and operators (shifts) is performed. As one machine is used machine to machine variation is not applicable and shift to shift variation is not significant. Part to part variation is significant so tests for finding out effect of process parameters and optimum process parameters will be conducted by varying process parameters viz. cutting speed, feed and depth of cut.

Experiment 1: Cutting Speed Variation

By keeping feed, depth of cut constant and changing cutting speed size variation has been checked.

Experiment 2: Feed Variation

By keeping cutting speed, depth of cut constant and changing feed size variation has been checked.

Experiment 3: Depth of Cut Variation

By keeping cutting speed, feed constant and changing depth of cut size variation has been checked.

Depth Size Variation Problem

Figure 5 presents a cause-and-effect (Ishikawa) diagram for depth variation, identifying potential root causes related to man, machine, method, material, measurement, and environment.

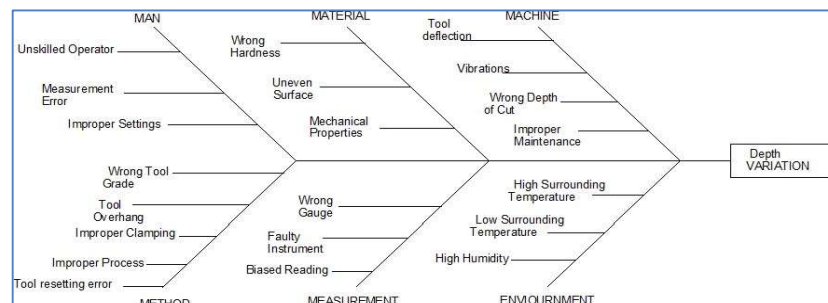


Figure 5 Cause-and-Effect Diagram for Depth Variation

D. Improve Phase

The Improve phase focuses on developing, testing, and implementing solutions to tackle the identified root causes, using data to assess how effective these solutions and their implementation are. The key outputs of this phase include:

- Actions are carefully planned and tested to eliminate or minimize the effects of the identified root causes.
- “Before” and “after” data analysis demonstrating the improvement achieved compared to the initial performance gap.
- A comparison is made between what was planned and what was actually implemented..

In this study, during the Improve phase, new process parameters were implemented to address bore size variation. After the changes, the bore size was checked and found to be within specifications. Additionally, the tool life was measured and determined to be sufficient for 120 jobs.

In improve phase for depth size variation new process with top facing and inside facing done by single tool in single setting was implemented after tool holder modification. The size variation was checked and found within specification.

E. Control Phase

The Control phase aims to sustain the improvements achieved by standardizing work methods and processes, anticipating opportunities for further enhancements, and ensuring that the improved processes remain stable and in control. New cutting parameters for bore size machining and modified process with new tool holder for depth variation were set. Inspection at regular frequency and the variable control charts, run chart etc. [8] are used to monitor the performance of the process.

VI. RESULTS AND ANALYSIS

As part to part variation in bearing bore size was highest the process parameters viz. cutting speed, feed and depth of cut were studied. Multi-vari method of analysis was used. Process capability study for bore size variation and analysis by Minitab after implementation is depicted in Figure 6.

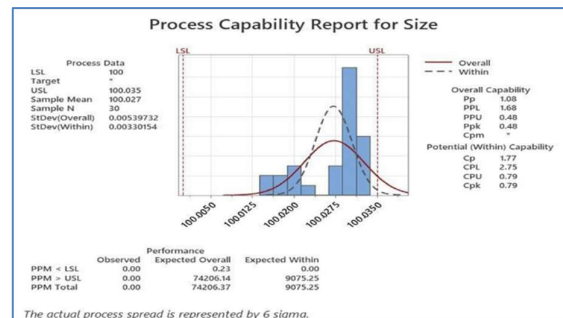


Figure 6. Process Capability Analysis Using Minitab Software

Process capability study for depth size variation and analysis by Minitab software after improvement is depicted in Figure 7.

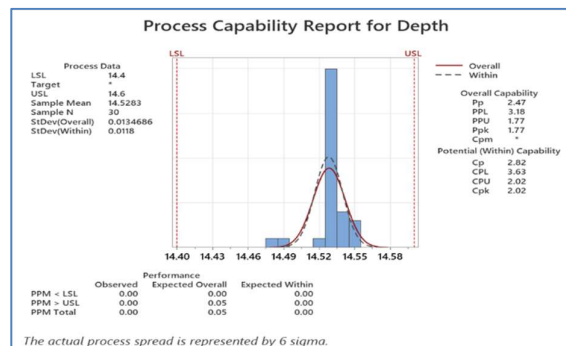


Figure 7. Process Capability Analysis Using Minitab Software (After Improvement)

VII. CONCLUSION

The implementation of six sigma methodologies in the small scale industry under study has demonstrated substantial improvements in process efficiency and product quality. Through the application of tools such as multi-vary analysis for optimizing process parameters and the integration of poka-yoke technics for mistake proofing, the organization achieved a significant reduction in defect rates. These enhancement not only improved operational reliability but also led to a notable decrease in cost associated with scrap and rework. The findings conform that even within small scale industries structured quality improvement methodology like six sigma can deliver measurable and sustainable benefits. This case reinforces the potential of data driven problem solving approaches in driving continuous improvement across small scale manufacturing set up.

SCOPE FOR FUTURE WORK

Future work can extend this study by applying the Six Sigma approach to other components and processes within the company and similar small-scale industries. Further research may also focus on combining Six Sigma with advanced data analytics or Industry 4.0 tools (such as sensors and real-time monitoring) to predict defects and optimize parameters proactively. Comparative studies across different MSMEs further can help in validation of the method and assist in developing practical guidelines. Finally, exploration of structured training for employees can provide support for long-term sustainability of Six Sigma practices.

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