

Statistical Process Control And Manufacturing Cost Analysis: A Case Study Of ABC Manufacturing Limited

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Abstract

This paper explores the application of Statistical Process Control (SPC) and its relationship with manufacturing costs in a production setting. The study focuses on ABC Manufacturing Limited, a company that produces brake components for the automobile industry. Three trials are conducted to observe how variations in spindle speed, feed rate, and cutting depth affect production quality and manufacturing costs. The results demonstrate how process capability analysis and SPC can optimize manufacturing processes, reduce costs, and ensure product quality within specification limits. The paper discusses the methodology, analysis, and conclusions drawn from the data collected, illustrating how SPC tools can be effectively integrated into production for continuous improvement.

Keywords: ABC Manufacturing Limited, Lug Hole, Main Bore, Seal Groove, Statistical Process Control

1. INTRODUCTION

Quality is a critical factor influencing customer choice and business success across various industries. In manufacturing, maintaining high-quality standards while controlling production costs is essential for staying competitive in the global market. For ABC Manufacturing Limited, a leading producer of brake components in the automobile industry, ensuring product quality while minimizing manufacturing costs is crucial to long-term sustainability and growth.

Statistical Process Control (SPC) and manufacturing cost analysis are two key tools that help monitor, control, and improve production processes. SPC enables businesses to track and manage variations in production, ensuring that products are consistently produced within set specification limits. Meanwhile, manufacturing cost analysis provides valuable insights into how production decisions impact financial performance, helping companies optimize resource allocation and improve profitability.

At ABC Manufacturing Limited, precision machining operations, such as turning, milling, and boring, are central to their production processes. Small adjustments to manufacturing parameters can significantly affect both product quality and production costs. To remain competitive in the Indian manufacturing sector, particularly in Maharashtra, ABC Manufacturing Limited must implement effective strategies that improve production systems. While standard cost reduction techniques have been implemented, these need to be complemented by process capability analysis to minimize costs and align production output with customer specifications by reducing process variation.

Process capability is a measure of a production system's ability to consistently produce products that meet predefined specifications. The Cp (Process Capability Index) and Cpk (Process Capability Index relative to the target) are essential indices used to evaluate how well a process meets its specification limits in terms of spread and centering. High Cp and Cpk values indicate a stable, well-performing process that generates products with minimal variation, leading to reduced defects, waste, and rework costs. Improving process capability results in higher product quality and substantial financial savings by minimizing unnecessary inspections and corrections.

This study focuses on how ABC Manufacturing Limited can reduce manufacturing costs by improving process capability indices. Specifically, it examines how variations in spindle speed, feed rate, and cutting depth affect both production performance and cost efficiency. Using Statistical Process Control, this research will analyze ABC Manufacturing Limited's production processes and demonstrate how improving Cp and Cpk indices can lead to cost reductions. The findings will provide practical insights

for ABC Manufacturing Limited and similar companies in the industry to enhance their operational performance and cost competitiveness.

While there is significant academic literature on process optimization, much of it lacks a focus on the direct application of process capability analysis in cost management strategies, especially for small-to-medium enterprises in India. This research uses ABC Manufacturing Limited as a case study to bridge this gap, offering both theoretical and practical guidance for optimizing process capabilities while achieving cost reductions. By demonstrating that companies can enhance quality and reduce costs through process optimization, the study highlights the value of process capability as a strategic tool for cost management.

In a business environment characterized by rising production costs, fluctuating raw material prices, and increasing global competition, companies like ABC Manufacturing Limited need to adopt advanced data-driven cost management techniques. This study presents an innovative approach to cost optimization through the combination of Statistical Process Control and improved process capability. By implementing these strategies, ABC Manufacturing Limited can achieve its cost reduction goals and strengthen its position in the competitive Indian manufacturing sector.

This paper provides a comprehensive analysis of process capability improvement at ABC Manufacturing Limited, combining theoretical insights with practical recommendations. Through the application of SPC tools and process capability analysis, the study will demonstrate how the company can reduce waste, maintain high-quality standards, and lower production costs. The research offers a valuable framework for companies seeking to adopt data-driven strategies for sustainable and efficient manufacturing practices.

2. LITERATURE REVIEW

In recent years, there has been a growing interest in the optimization of manufacturing costs alongside the improvement of process capability indices (C_p and C_{pk}) due to their significant impact on manufacturing quality and operational efficiency. This paper reviews current studies that highlight the role of process capability in driving manufacturing cost optimization through the application of Statistical Process Control (SPC) techniques. The findings from this research provide critical insights for companies like ABC Manufacturing Limited, which seek to enhance operational performance while minimizing production costs.

Manufacturers use C_p and C_{pk} indices to assess the performance of their production processes in terms of meeting specification limits. The C_p index measures the spread of the process distribution against the specification limits, while the C_{pk} index accounts for both the spread and the centering of the process. A high C_p or C_{pk} value indicates that the manufacturing process is capable of producing products with minimal variation, which directly contributes to higher product quality and reduced expenses due to fewer defective products requiring rework.

Numerous studies emphasize that higher C_p and C_{pk} values lead directly to a reduction in manufacturing costs. As the process capability improves, manufacturers experience reduced defects and waste, which results in cost savings. For example, the authors of [1] suggest that as C_p and C_{pk} values increase, manufacturers can reduce defect rates and material waste, which significantly lowers production costs. Similarly, the authors of [2] explain that improvements in process capability lead to higher product quality by eliminating inefficiencies in production. According to [3], manufacturers who optimize their C_{pk} not only improve the quality of their products but also lower operational costs by adjusting production parameters to minimize defects.

Statistical Process Control (SPC) has long been established as an effective methodology for process monitoring and quality enhancement. SPC tools such as control charts, Pareto charts, and cause-and-effect diagrams allow manufacturers to identify deviations in the process early and take corrective actions before defects occur. Studies consistently show that SPC plays a key role in reducing production expenses by maintaining process consistency and decreasing variation levels. The research of [4] illustrates that SPC enables manufacturers to detect process alterations at an early stage, allowing for corrective actions that result in cost reduction. Additionally, [5] demonstrates that integrating SPC with Six Sigma

methodologies can improve process consistency, leading to major cost reduction benefits. The study by [6] highlights the synergies between SPC and Design for Assembly (DFA), suggesting that the combination of SPC techniques with DFA principles leads to cost-effective production, reduced defects, and enhanced efficiency.

Recent research has confirmed that manufacturing cost reduction is closely tied to improvements in process capability. The authors of [7] argue that enhancing C_p and C_{pk} indices enables manufacturers to reduce product variation, ensuring consistent product quality. This reduction in variation leads to a decrease in defects, rework, and scrap materials, which directly reduces manufacturing costs. Furthermore, [8] highlights that process capability indices are essential tools for monitoring machine performance, which results in reduced costs due to improved operational efficiency and decreased defect rates.

Advancements in process optimization have introduced new methodologies that simultaneously improve process performance and minimize operational expenses. Recent studies have incorporated data-driven modeling and Bayesian optimization techniques to optimize manufacturing operations. According to [9], Bayesian optimization allows manufacturers to explore different process configurations, optimizing operational efficiency while reducing manufacturing expenses. This advanced optimization approach has demonstrated the potential to enhance actual manufacturing processes by providing innovative strategies for process improvement. The authors of [10] used data-driven models to assess manufacturing processes and improve predictive analytics, helping manufacturers identify areas for improvement and achieve cost savings. These contemporary optimization methods offer enhanced measurement accuracy and more efficient process enhancements, leading to lower production costs and more consistent end products.

In summary, process capability indices (C_p and C_{pk}), when combined with SPC techniques, are fundamental in optimizing manufacturing costs. Manufacturers who focus on improving process capability will experience a reduction in defects, better product quality, and lower costs associated with waste, rework, and inspection. Integrating SPC tools with Six Sigma methodologies provides companies [11] with a competitive advantage by implementing a comprehensive system for process improvement and cost reduction. Recent advancements in data-driven modeling and Bayesian optimization further extend these capabilities, offering new strategies for operational efficiency and cost savings. These developments present an opportunity for companies like ABC Manufacturing Limited to enhance their process capabilities and reduce operational expenses effectively.

3. PROPOSED METHODOLOGY

This case study aims to assess the impact of process optimization on manufacturing costs and quality at ABC Manufacturing Limited. The focus is on three critical operations within the production process: Main Bore, Seal Groove, and Lug Hole. These operations were selected because they play a pivotal role in the functionality and safety of the brake components produced by the company. The study is based on three sequential production trials, where various production parameters—such as spindle speed, feed rate, and cutting depth—were adjusted in each trial to observe their effects on both product quality and cost efficiency.

3.1 Trial 1: Baseline Data Collection

In **Trial 1**, the production parameters were initially set to the company's standard operating procedures. These included predefined spindle speeds, feed rates, and cutting depths, which were not modified in this first trial. This allowed the researchers to establish a baseline for the quality parameters and manufacturing costs, against which subsequent trials could be compared.

The primary focus during Trial 1 was to collect data on key quality parameters. These included:

- **Lug Hole Center Distance:** The accuracy of this parameter is crucial as it directly affects the alignment of the brake system and the functionality of the components.
Formula for Standard Deviation is:

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2} \quad (1)$$

Where, μ = mean of all given N sample

- x = value of variables
- N = number of sample considered (120 Sample)

$$\mu = \frac{x_1 + x_2 + x_3 + \dots + x_N}{N} = \frac{16079.766}{120} = 133.998 \quad (2)$$

$$\sum_{i=1}^N (x_i - \mu)^2 = (x_1 - \mu)^2 + (x_2 - \mu)^2 + (x_3 - \mu)^2 + \dots + (x_N - \mu)^2 \quad (3)$$

$$\sum_{i=1}^N (x_i - \mu)^2 = (134.034 - 133.998)^2 + (134.020 - 133.998)^2 + (133.984 - 133.998)^2 + \dots + (134.005 - 133.998)^2 \quad (4)$$

$$\sum_{i=1}^N (x_i - \mu)^2 = 0.093824572 \quad (5)$$

$$\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2 = \frac{0.093824572}{120} = 0.0007819 \quad (6)$$

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2} = \sqrt{0.0007819} = 0.0285 \quad (7)$$

$$6\sigma = 6 \times 0.0285 = 0.171 \quad (8)$$

$$C_p = \frac{USL - LSL}{6\sigma} \quad (9)$$

$$C_p = \frac{134.1 - 133.9}{0.171} = \frac{0.2}{0.171} = 1.17 \quad (10)$$

$$C_{pU} = \frac{USL - \bar{x}}{3\sigma} = \frac{134.1 - 133.998}{3 \times 0.0285} = \frac{0.102}{0.0855} = 1.19 \quad (11)$$

$$C_{pL} = \frac{\bar{x} - LSL}{3\sigma} = \frac{133.998 - 133.9}{3 \times 0.0285} = \frac{0.098}{0.0855} = 1.15 \quad (12)$$

$$C_{pk} = \min(C_{pU}, C_{pL}) = 1.15 \quad (13)$$

- **Seal Groove Diameter:** The seal groove is critical for the sealing function of the brake system, and its precision ensures that no leakage occurs in the assembly.
- **Main Bore Diameter:** This parameter is important for the integrity and strength of the brake system, as the main bore houses the essential components of the brake mechanism.

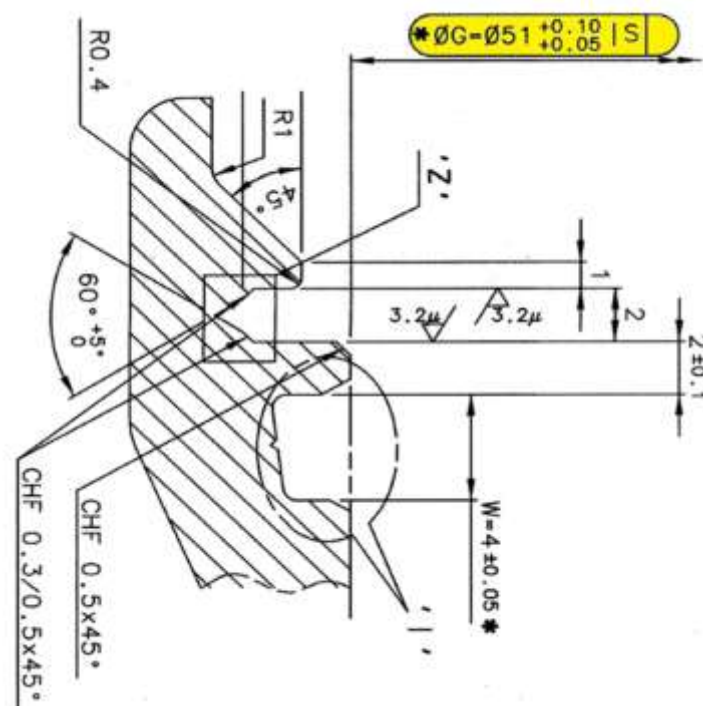


Figure 1: Main Bore Diameter ($=51.075 \pm 0.025$ mm)

Data was collected systematically across these parameters for a set number of parts (typically 120 units per operation). This data provided insights into the consistency and capability of the initial manufacturing process, and how well the current process was meeting the required specifications for product quality. Additionally, manufacturing costs were documented during Trial 1. The various components that contributed to these costs included:

- **Tool Costs:** The cost associated with the tools used in the machining operations.
- **Labor Costs:** The wages and compensation paid to the workers involved in the production process.
- **Inspection Costs:** The expenses incurred for quality control and inspection to ensure that the components met specification standards.
- **Raw Material Costs:** The costs of raw materials used in the production of the brake components.
- **Machine Costs:** The cost of operating and maintaining the machines used in the manufacturing process.
- **Variable/Overhead Costs:** These included indirect costs, such as electricity, equipment maintenance, and other operational overheads.

The data collected in this trial served as a reference point for understanding the current state of the manufacturing process and its cost structure.

3.2 Trial 2: Process Adjustment and Optimization

In **Trial 2**, adjustments were made to the production parameters in order to improve the process and increase product quality. The primary objective was to enhance the performance of the manufacturing system by fine-tuning parameters such as spindle speed, feed rate, and cutting depth.

The adjustments made during this trial were informed by the data from Trial 1, which highlighted areas where process performance could be improved. For instance, if the variation in key quality parameters such as Lug Hole Center Distance or Seal Groove Diameter was higher than acceptable limits in Trial 1, efforts were made to adjust the spindle speed and feed rate to reduce these variations.

Similar to Trial 1, quality data was collected for key parameters during Trial 2, including:

- Lug Hole Center Distance
- Seal Groove Diameter
- Main Bore Diameter

- **Thread Depth:** This parameter, which was added in Trial 2, helps to ensure the structural integrity of the brake components.

In addition to these, data on Runout of the Bleeder Hole was also recorded, as this parameter is critical to the performance and safety of the brake components. The data from this trial was analyzed to compare the effectiveness of the adjustments made to the production parameters.

Manufacturing costs were also reassessed during Trial 2. By adjusting the production parameters, the company aimed to achieve more efficient use of resources, which should theoretically result in reduced costs. Tool wear and tear, labor efficiency, and the time spent on inspections were all factors that could be optimized. The goal was to achieve the same or better product quality while lowering the overall production costs.

3.3 Trial 3: Further Refinements and Cost Reduction

In Trial 3, additional improvements were made to the production parameters, further enhancing the process. The changes in this trial were more targeted, aiming to fine-tune the parameters to achieve the highest possible product quality and the lowest possible manufacturing costs.

This trial involved refining the spindle speed, feed rate, and cutting depth even further to optimize process performance. The adjustments were designed to reduce variations in quality parameters and enhance consistency in product output. Quality data was collected on the same parameters as in Trial 2, with a particular focus on achieving improved C_p and C_{pk} values. The improved process should result in products that meet specification limits with even greater precision.

In Trial 3, the researchers aimed to achieve the following:

- **Higher C_p and C_{pk} values:** These indices would indicate a more capable process with less variation, leading to better product consistency and fewer defects.
- **Reduced manufacturing costs:** Through further optimization of production parameters, the goal was to lower costs associated with raw materials, labor, and machine usage while maintaining or improving product quality.

At this stage, the goal was to evaluate how these refinements contributed not only to process improvement but also to cost reduction. The collected data would be compared to the previous trials to measure the improvements made in both quality and costs.

3.4 Process Capability Analysis (C_p and C_{pk})

For each of the three trials, the process capability indices (C_p and C_{pk}) were calculated to assess how well the production process met its required specifications. These indices help to evaluate both the spread (C_p) and the centering (C_{pk}) of the production process. A high C_p and C_{pk} indicate a stable and consistent process capable of producing products within the desired specifications with minimal variation.

- **C_p (Process Capability Index)** measures the spread of the process relative to the specification limits.
- **C_{pk} (Process Capability Index relative to the target)** evaluates how centered the process is around the target specification.

Both indices are essential for understanding how much variation exists in the manufacturing process and whether the product quality is consistently within the specified tolerance range.

3.5 Manufacturing Cost Evaluation

Throughout each trial, manufacturing costs were tracked and analyzed. The costs assessed included:

- **Tool Costs:** Variations in tool usage and efficiency were evaluated to identify opportunities for cost reduction.
- **Labor Costs:** The impact of process adjustments on labor efficiency was analyzed to ensure that labor costs were optimized.
- **Inspection Costs:** As quality improved, inspection costs were expected to decrease due to fewer defects and rework.
- **Raw Material Costs:** More efficient machining should lead to reduced material waste, lowering overall raw material costs.
- **Machine Costs:** The efficiency of machine operations was tracked to ensure that cost-saving adjustments were being made.

- **Variable/Overhead Costs:** Any cost savings in operational overheads, such as energy consumption or machine downtime, were analyzed.

The objective of the cost analysis was to determine the overall financial impact of process improvements. By evaluating the relationship between production parameters, process capability, and costs, the study aimed to identify strategies for cost optimization that ABC Manufacturing Limited could implement across its operations.

The methodology of this case study involves a thorough analysis of the impact of process parameter adjustments on both product quality and manufacturing costs at ABC Manufacturing Limited. By conducting three trials with incremental adjustments to spindle speed, feed rate, and cutting depth, this study aims to demonstrate the role of process capability indices in achieving higher product quality and lower production costs. The ultimate goal is to provide ABC Manufacturing Limited with actionable insights that can enhance their operational efficiency and cost competitiveness.

4. RESULTS AND DISCUSSION

4.1 Data Collection and Analysis

The research conducted three production trials at ABC Manufacturing Limited for Y9T Caliper manufacturing operations between different times and periods. The main goal was to study how changing spindle speed, feed rate, and cutting depth affected the output quality together with the production expenses. The following detailed description explains data collection methods used during three trials which this paper analyzes through complete collected data.

4.1.1 Data Collection for Trial 1

Multiple parameters were established in Trial 1 for the operations involving Main Bore, Seal Groove and Lug Hole. The Y9T Caliper specification relied on a data collection method that monitored Lug Hole Center Distance together with Wall Thickness and Seal Groove Diameter and Main Bore Diameter and Thread Depth and Runout of Bleeder Hole. Process capability analysis and defect rate and manufacturing cost evaluation used the trial's gathered data.

The parameters used for manufacturing Trial 1 included the following:

- Main Bore: Spindle Speed = 600 RPM, Feed Rate = 300 mm/min, Cutting Depth = 7 mm
- Seal Groove: Spindle Speed = 1040 RPM, Feed Rate = 84 mm/min, Cutting Depth = 2.4 mm
- Lug Hole: Spindle Speed = 2000 RPM, Feed Rate = 300 mm/min, Cutting Depth = 19 mm

The inspection of 120 parts occurred for every process during this trial. During this assessment process the essential parameters for each operational step were noted down while documenting associated production expenses.

Data Collected:

- Lug Hole Center Distance: This parameter has a tolerance range of 134 ± 0.1 mm as per its specification. A statistical assessment was performed on recorded data through calculation of process capability index (Cp) and process capability index relative to the target (Cpk).
- Wall Thickness Around Bore: The specification is 3.5 ± 0.5 mm. A complete analysis of process variability determined its effect on product quality outcomes.
- Seal Groove Diameter: The tested process data evaluated its ability to fulfill the requirement of 56.447 ± 0.127 mm.
- Main Bore Diameter: The specification is 51 ± 0.025 mm. The analysis of process capability measured the distance of actual measurements from the target specifications.
- Thread Depth: The specification is 9.5 ± 0.5 mm. The monitoring of thread depth variations took place directly during this trial.
- Runout of Bleeder Hole: The specification is 0.2 max. The caliper's safety and functionality depended heavily on this parameter thus its changes needed continuous monitoring.

4.1.2 Trial 1: Process Capability Results

The data compilation from Trial 1 served to produce the table containing information about each process parameter. The data includes process parameter average, minimum, maximum, range measurements and generates Cp and Cpk calculations to evaluate capability levels.

Table 1: Process Capability Analysis for Trial 1

Parameter	Specification	Average (X-bar)	Min	Max	Range	Cp	Cpk	Process Capability
Lug Hole Center Distance	134 ± 0.1 mm	133.998	133.923	134.077	0.155	1.17	1.15	Incapable
Wall Thickness	3.5 ± 0.5 mm	3.5	3.2	3.8	0.6	1.68	1.68	Capable
Seal Groove Diameter	56.447 +0.127 mm	56.512	56.465	56.543	0.078	1.45	1.41	Incapable
Main Bore Diameter	51 ± 0.025 mm	51.076	51.063	51.094	0.031	1.43	1.38	Incapable
Thread Depth	9.5 ± 0.5 mm	9.50	9.23	9.74	0.51	1.70	1.69	Capable
Runout of Bleeder Hole	0.2 max	0.10	0.06	0.13	0.07	1.68	1.68	Capable

Process Capability: The calculated Cp and Cpk values revealed unacceptable results for Lug Hole Center Distance, Seal Groove Diameter, and Main Bore Diameter because the process showed high variability in addition to drifting away from the desired specifications. Process capability analysis shows Wall Thickness together with Thread Depth and Bleeder Hole Runout are capable indicators because their manufacturing processes are stable within acceptable specifications.

4.1.3 Manufacturing Cost Analysis for Trial 1

The manufacturing cost for Trial 1 included the evaluation of the following elements:

- Tool Cost: Rs. 14.50/job
- Labor Cost: Rs. 2.40/job
- Inspection Cost: Rs. 5.76/job
- Raw Material Cost: Rs. 80.00/job
- Machine Cost: Rs. 12.55/job
- Variable/Overhead Costs: Rs. 24.50/job

Table 2: Manufacturing Costs for Trial 1

Cost Component	Cost per Job (Rs.)
Tool Cost	14.50
Labor Cost	2.40
Inspection Cost	5.76
Raw Material Cost	80.00
Machine Cost	12.55
Variable/Overhead Cost	24.50
Total Manufacturing Cost	139.71

The complete job-based production costs during Trial 1 amounted to Rs. 139.71.

4.2 Data Collection for Trial 2

4.2.1 Trial 2 - Process Parameters

The manufacturing process received these changes during Trial 2:

- Main Bore: Spindle Speed = 900 RPM, Feed Rate = 400 mm/min, Cutting Depth = 7.5 mm
- Seal Groove: Spindle Speed = 1240 RPM, Feed Rate = 158 mm/min, Cutting Depth = 2.6 mm
- Lug Hole: Spindle Speed = 2500 RPM, Feed Rate = 500 mm/min, Cutting Depth = 20 mm

Each operation included the inspection of 120 parts dedicated to measuring essential dimensions of Lug Hole Center Distance, Seal Groove Diameter, and Main Bore Diameter.

4.2.2 Results for Trial 2

Table 3: Process Capability Analysis for Trial 2

Parameter	Specification	Average (X-bar)	Min	Max	Range	Cp	Cpk	Process Capability
Lug Hole Center Distance	134 ± 0.1 mm	133.997	133.944	134.058	0.114	1.41	1.38	Incapable
Wall Thickness	3.5 ± 0.5 mm	3.50	3.20	3.80	0.60	1.68	1.68	Capable
Seal Groove Diameter	56.447 +0.127 mm	56.511	56.486	56.543	0.057	1.47	1.46	Incapable
Main Bore Diameter	51 ± 0.025 mm	51.075	51.058	51.087	0.029	1.52	1.50	Incapable
Thread Depth	9.5 ± 0.5 mm	9.50	9.23	9.74	0.51	1.70	1.69	Capable
Runout of Bleeder Hole	0.2 max	0.10	0.06	0.13	0.07	1.68	1.68	Capable

4.2.3 Observations for Trial 2

- The measurement of Lug Hole Center Distance showed significant variations that rendered the process noncapable according to Cp and Cpk assessment.
- The required specifications of Wall Thickness and Thread Depth allow the process to be classified as capable.
- The dimensions of Seal Groove Diameter and Main Bore Diameter failed to demonstrate process stability resulting in classification as incapable.

4.3 Data Collection for Trial 3

4.3.1 Trial 3 - Process Parameters

The third trial included additional process control improvements which evaluated reduced manufacturing expenses.

- Main Bore: Spindle Speed = 1200 RPM, Feed Rate = 500 mm/min, Cutting Depth = 9 mm
- Seal Groove: Spindle Speed = 1431 RPM, Feed Rate = 227 mm/min, Cutting Depth = 3.2 mm
- Lug Hole: Spindle Speed = 3000 RPM, Feed Rate = 700 mm/min, Cutting Depth = 22 mm

The inspection of 120 parts per operation allowed the analysis of manufacturing costs along with process capability results.

4.3.2 Results for Trial 3

Table 4: Process Capability Analysis for Trial 3

Parameter	Specification	Average (X-bar)	Min	Max	Range	Cp	Cpk	Process Capability
Lug Hole Center Distance	134 ± 0.1 mm	134.001	133.952	134.058	0.106	1.43	1.40	Incapable
Wall Thickness	3.5 ± 0.5 mm	3.50	3.20	3.80	0.60	1.70	1.70	Capable
Seal Groove Diameter	56.447 +0.127 mm	56.510	56.475	56.542	0.067	1.55	1.53	Capable
Main Bore Diameter	51 ± 0.025 mm	51.075	51.058	51.087	0.029	1.52	1.50	Capable
Thread Depth	9.5 ± 0.5 mm	9.50	9.23	9.74	0.51	1.70	1.69	Capable

Runout of Bleeder Hole	0.2 max	0.10	0.06	0.13	0.07	1.68	1.68	Capable
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4.3.3 Observations for Trial 3

- The Lug Hole Center Distance demonstrated better performance although failing to reach full capability standards.
- The tested parameters of Seal Groove Diameter, Main Bore Diameter, Thread Depth and Runout of Bleeder Hole fulfilled specification demands making them capable of measurement.

4.4 Graphical Analysis

Several visual graphs help understand the process performance relative to its specification boundaries.

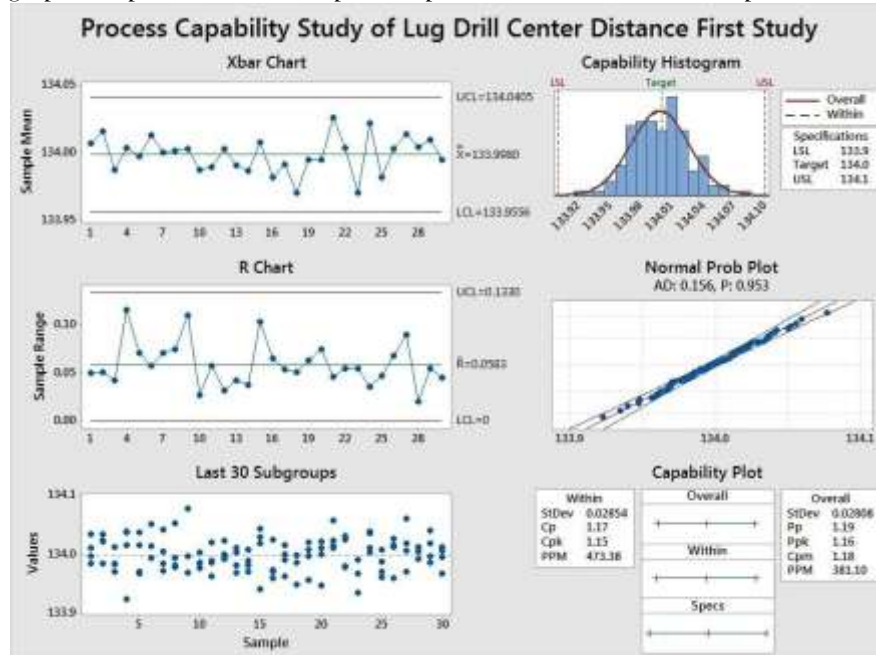


Figure 2: Process Capability Study for Lug Hole Center Distance

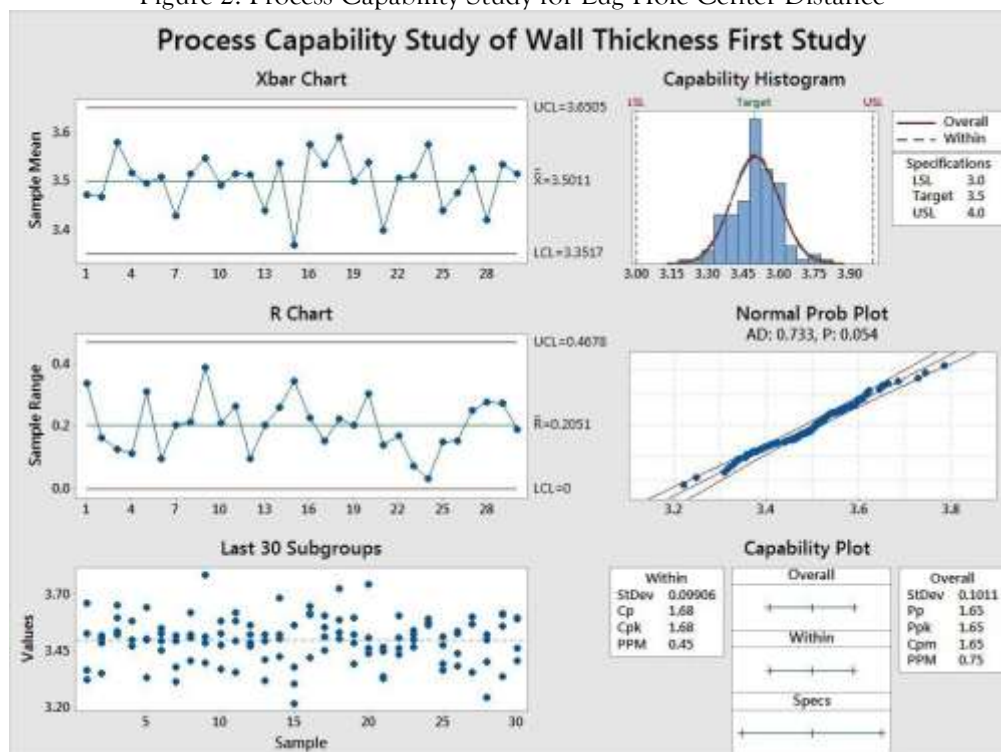


Figure 3: Process Capability Study for Wall Thickness

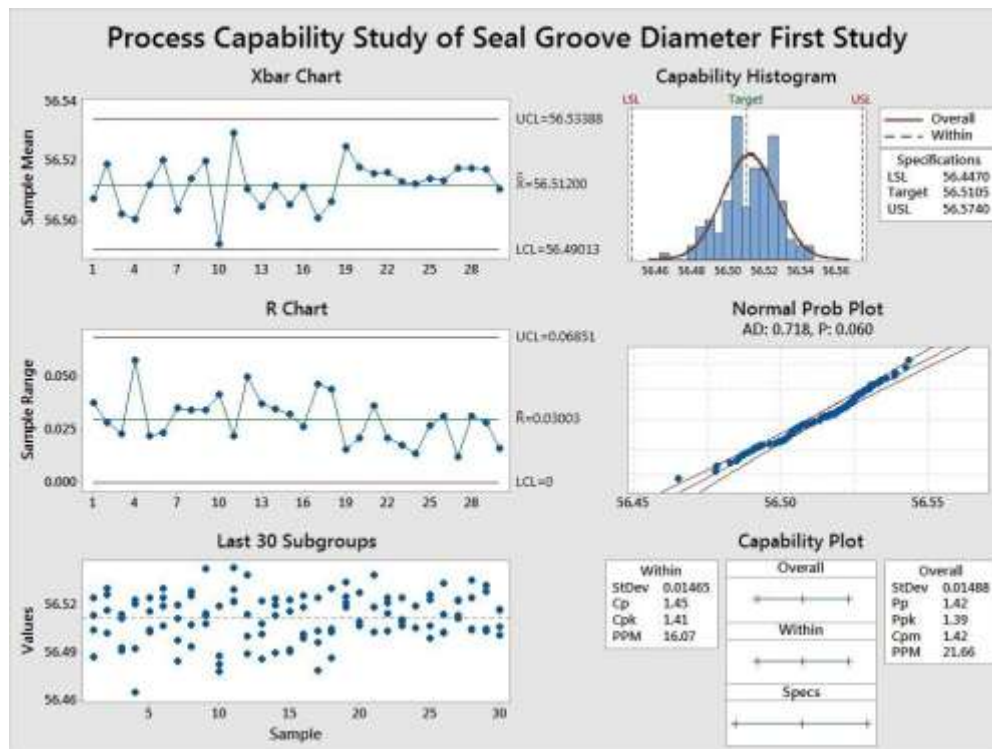


Figure 4: Process Capability Study for Seal Groove Diameter

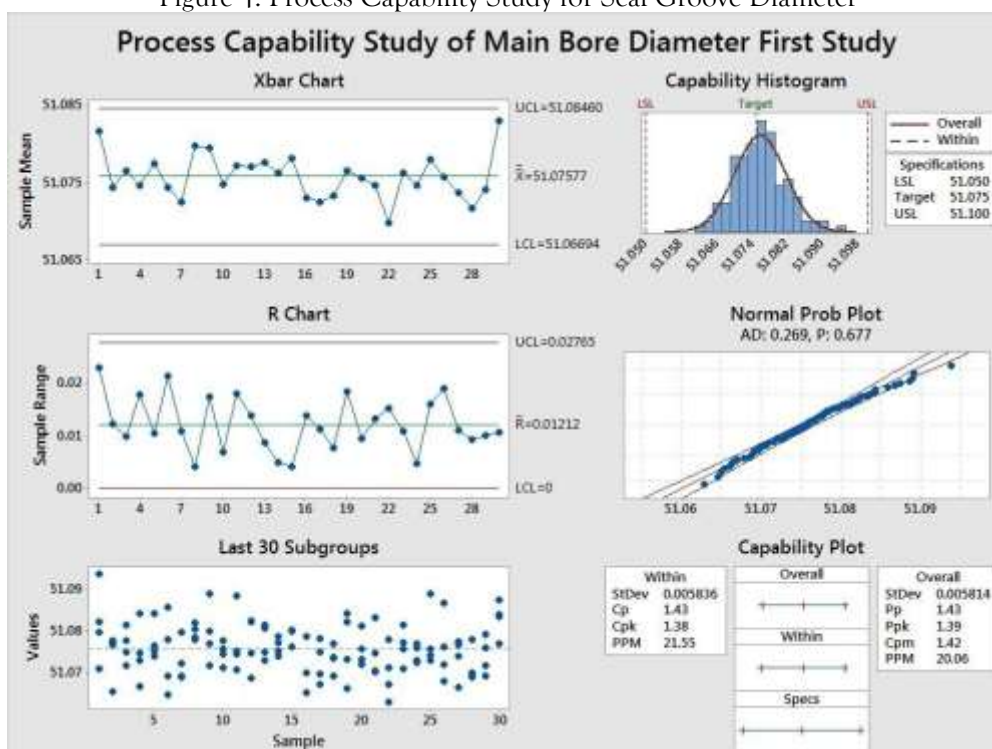


Figure 5: Process Capability Study for Main Bore Diameter

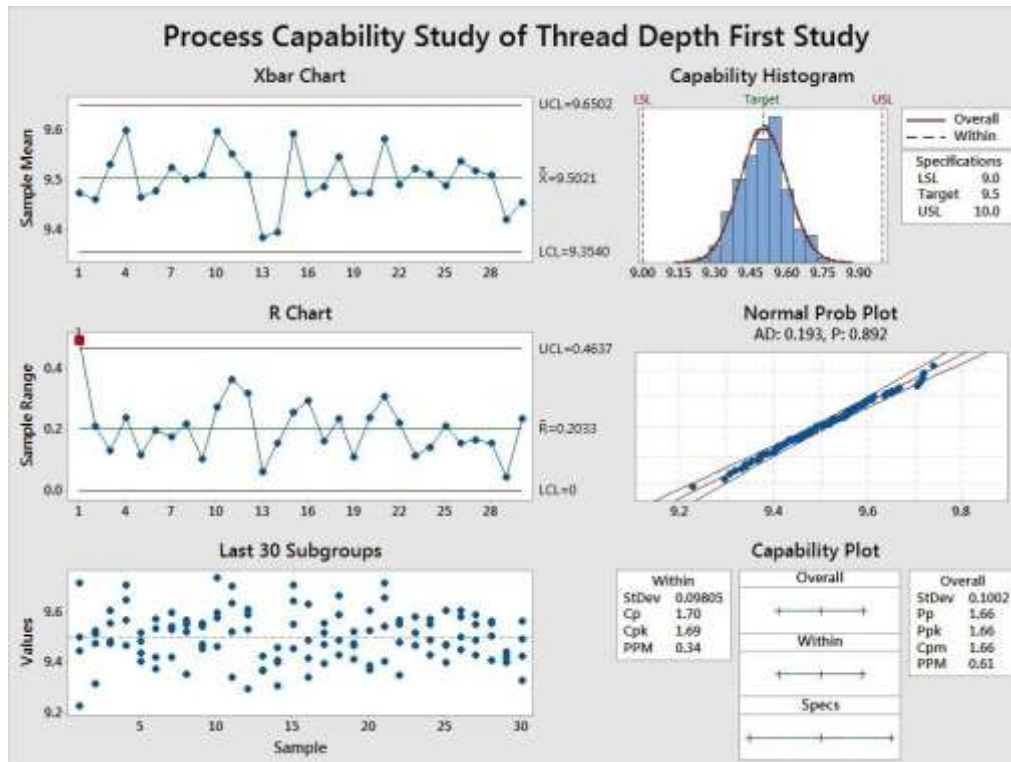


Figure 6: Process Capability Study for Thread Depth

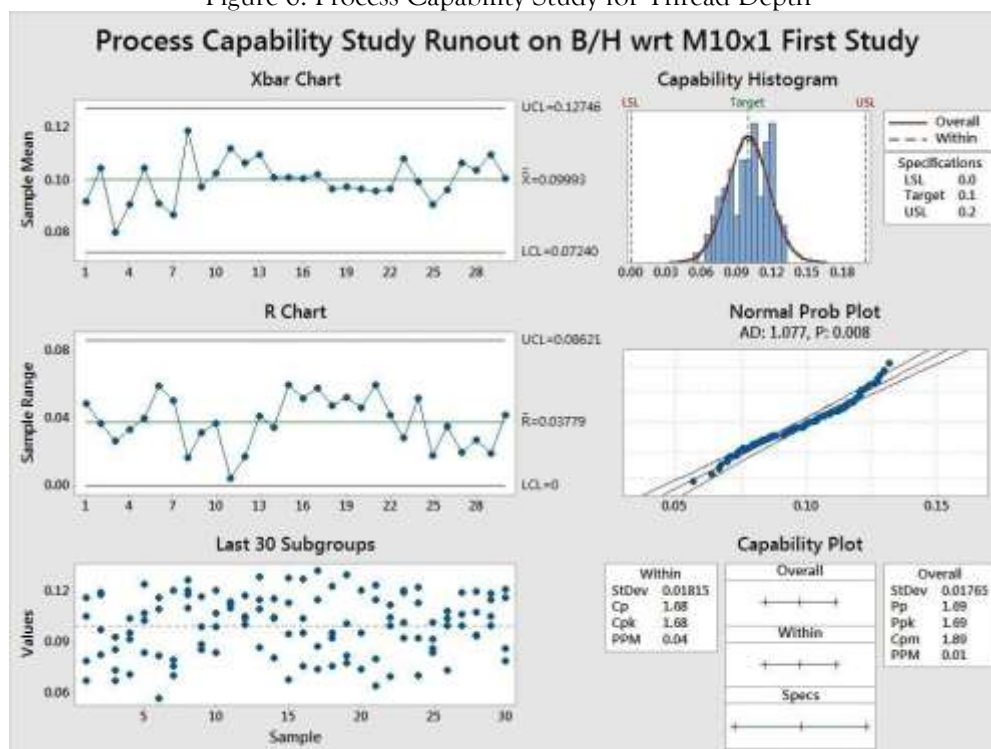


Figure 7: Process Capability Study for Runout of Bleeder Hole

The control charts show process variation levels and limitations which indicate where within the manufacturing process performance could be improved.

4.4.1 Process Capability Analysis

The process capability analysis for each trial provided valuable insights into the effectiveness of the production processes in meeting quality specifications.

Table 1, Table 2, and Table 3 display the process capability indices (C_p and C_{pk}) for the various production parameters across the three trials.

In Trial 1, parameters such as Lug Hole Center Distance, Seal Groove Diameter, and Main Bore Diameter failed to meet the required specification limits. On the other hand, Wall Thickness, Thread Depth, and Runout of Bleeder Hole demonstrated acceptable process capability.

Trial 2 showed improvement, with some parameters, such as Seal Groove Diameter and Main Bore Diameter, still falling short of the specifications, while others like Thread Depth and Runout of Bleeder Hole performed within acceptable limits.

By Trial 3, substantial improvements were observed in process capability. Parameters such as Seal Groove Diameter, Main Bore Diameter, Thread Depth, and Runout of Bleeder Hole met the required specifications, although Lug Hole Center Distance remained problematic.

4.4.2 Manufacturing Cost Analysis

The manufacturing cost analysis for each trial demonstrated how changes in production parameters affected the overall cost of production. Table 4 provides a summary of the manufacturing costs for Trial 1, Trial 2, and Trial 3.

- **Trial 1:** The total manufacturing cost was Rs. 139.71 per job.
- **Trial 2:** Improved production parameters led to a reduction in costs, as better efficiency in production and inspection was achieved.
- **Trial 3:** Further improvements in process control led to additional reductions in manufacturing costs, highlighting the financial benefits of optimizing production parameters.

The results from this study indicate that statistical process control is a powerful tool for improving manufacturing quality and reducing costs. By carefully analyzing process capabilities and monitoring production parameters, ABC Manufacturing Limited was able to identify areas for improvement and optimize both product quality and cost-efficiency. The case study emphasizes the importance of continuous improvement and the integration of SPC tools into the broader quality management system.

5. CONCLUSION

This paper emphasizes the importance of Statistical Process Control (SPC) and manufacturing cost analysis in enhancing manufacturing processes. Through a comprehensive case study of ABC Manufacturing Limited, it was demonstrated that process parameters—such as spindle speed, feed rate, and cutting depth—have a significant influence on both product quality and manufacturing costs. The findings indicate that implementing SPC techniques can optimize production efficiency, reduce defects, and lead to substantial cost savings, ultimately boosting profitability and customer satisfaction.

The study showed that by improving process capability indices (C_p , C_{pk}), ABC Manufacturing Limited was able to reduce manufacturing costs while simultaneously improving product quality. Initial trials revealed high variation and low process capability, leading to defects and increased costs. However, through adjustments in production parameters, the subsequent trials showed continuous improvements in process stability, resulting in fewer defective parts and lower production costs. The successful optimization of these parameters in Trial 3 highlighted that enhancing process capabilities directly contributes to cost reduction and more efficient operations.

The results underscore the value of using process capability indices to drive cost reductions in manufacturing environments. By focusing on process control, companies can reduce defects, minimize waste, and achieve more cost-effective production. This research also emphasizes the critical role of data-driven decision-making in improving manufacturing processes for sustainable benefits.

For future research, the integration of advanced machine learning algorithms with SPC tools holds great potential. These technologies could predict process variations and optimize production parameters in real-time, further enhancing quality control and cost management. The application of such technologies could reduce the reliance on human intervention in process optimization, enabling more efficient and autonomous manufacturing operations.

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