

PROCESS CAPABILITY ANALYSIS OF WORK PROCEDURES TO REDUCE WASTE: A CASE STUDY OF AN AUTOMOTIVE PARTS MANUFACTURING PLANT

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Received: August 01, 2025; Revised: December 17, 2025; Accepted: February 02, 2026

Abstract

This study examines and enhances process capability for waste reduction in an automotive parts manufacturing plant. Problems and their root causes were identified and analyzed using a fishbone (cause-and-effect) diagram. Process capability analysis was then applied to assess the effectiveness of improvements to work procedures. The initial defect rate in May was 2.9%, consisting primarily of surface scratches, dents, discontinuous surfaces, and poor surface finishes. The primary causes were inappropriate insert selection and cutting direction, which led to inadequate tool strength and premature wear. Prior to the improvements, the process capability index (Ppk) was 0.67. Following implementation of the proposed improvements, a three-step modification process, which included altering the cutting tool path direction, adjusting the feed rate, and changing the cutting insert, was introduced. As a result, defect occurrences were eliminated, tool life was significantly extended, the process capability index increased to 1.39, and production costs were reduced by 5.10%.

Keywords: Defect; Process Capability Analysis; Production Cost; Work Procedures

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DOI: <https://doi.org/10.55766/sujst10959>

Suranaree J. Sci. Technol. 33(4):010437(1-9)

Introduction

The automotive industry is undergoing a significant transformation, shifting from vehicles powered by fossil fuels to those driven by electric propulsion systems (Electric Vehicles [EVs]). This transition has generated substantial impacts not only on the automotive industry but also on related sectors within the broader industrial ecosystem. (Monye *et al.*, 2023). One major consequence of this shift is the increasing complexity of automotive parts manufacturing. The use of lightweight yet strong materials, such as aluminum alloys, carbon fiber, and specialized alloys, combined with high-precision manufacturing technologies is essential to ensure that performance and safety standards are met. As a result, competition has intensified across both manufacturing and service sectors. To enhance competitiveness and establish product credibility, manufacturers must implement efficient production planning, ensure on-time delivery, and minimize overall production costs. (Kumar *et al.*, 2024). Production costs can be reduced by minimizing waste, which represents a form of non-value-added loss within the manufacturing process. Such waste directly contributes to unnecessary cost increases and overall productivity. Approaches aimed at improving productivity and reducing waste can be effectively implemented through the application of industrial engineering techniques. These techniques are employed with the objective of increasing output while minimizing waste throughout the production process. One such approach is the application of kaizen, which emphasizes the involvement of all employees in continuous improvement activities. In addition, the development of a preventive maintenance system is crucial for reducing both the frequency and duration of machine downtime, as well as minimizing product defects. Previous studies have shown that waste can be reduced by 1% through systematic improvement efforts. The application of the seven-quality control (7 QC) tools has been shown to significantly reduce the amount of waste generated in the production processes. For example, one study reported a 95% reduction in dent defects and an 81% decrease in cases where external diameters fell below specifications, resulting in cost savings of 7,919.76 THB (Ghelani, 2021). The integration of lean manufacturing systems with advanced technologies is a key factor in reducing waste, improving efficiency, and lowering production costs within manufacturing processes. This integration supports the maintenance of competitiveness as the industry undergoes rapid

transformation. Furthermore, quality control techniques have also been employed to enhance productivity and reduce waste (Salim, 2024; Pacana & Czerwińska, 2023). Process Capability Analysis (PCA) has been widely applied across industries to evaluate the capability of production processes meet specified requirements following improvement efforts. This analysis is conducted using the process capability index (Cpk) and the process performance index (Ppk). It is an index used to measure the true capability of a production process. To ensure the accuracy and precision of the process capability analysis, the suitability for the analysis has been defined in two distinct cases. First, process capability analysis, using the Cpk value, is appropriate for analyzing samples collected over a short period or when the sample size is limited. Second, process capability analysis, using the Ppk value, is suitable for analyzing samples over an extended period or when a large number of samples are available. Generally, Cpk and Ppk values equal to or greater than 1.33 indicate that a process operates within a good-to-excellent capability range (Ploypanichcharoen, 2004; Senvar & Tozan, 2010; Haktanır & Kahraman, 2021; Kwilinski & Kardas, 2023). Ensuring accurate and reliable production processes contributes to more effective quality control systems (Odeyinka & Popoola, 2021; Altuntas & Atalan, 2024; Benkova *et al.*, 2024). Integrating process capability analysis with machine learning (ML) techniques has been shown to enhance real-time process monitoring and predictive analysis, by enabling trend forecasting and simulation of possible scenarios. This integration allows for more efficient maintenance management (Qader *et al.*, 2025). In addition, methods for enhancing the definition of boundaries in process capability measurement are proposed using the new hybrid capability wavelet approach (NHCWA). It was found that the process capability index (Cpk) increased by 30% compared to traditional methods. Overall, the assessment of process capability provides valuable insights for ensuring product quality and the overall performance of the manufacturing processes (Mahapatra *et al.*, 2020; Benkova *et al.*, 2024).

This research focuses on analyzing process capability in automotive parts manufacturing to reduce waste by utilizing the seven-quality control (7 QC) tools, Failure modes and effects analysis (FMEA), Process Capability Analysis, and Production Cost Analysis.

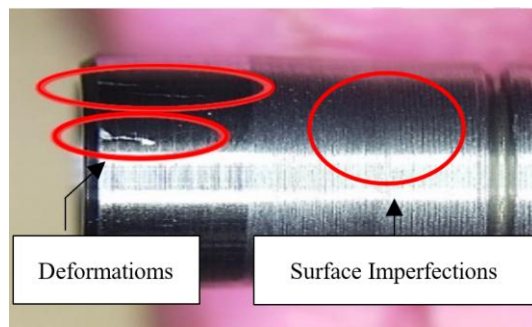


Figure 1. Defect characteristics

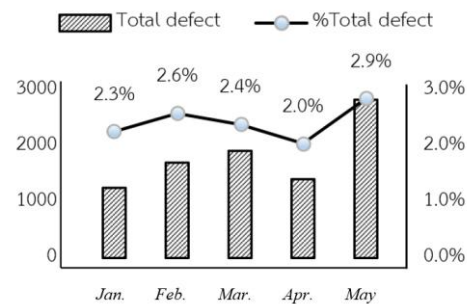


Figure 2. Defect rate from January to May: Process capability analysis

Materials and Methods

This study analyzes process capability to improve operational methods for waste reduction through a case study of an automotive parts manufacturing plant. The analysis utilizes production materials, equipment, and the research methodology described below.

Automotive parts manufacturing process of the case study company. A case study of an automotive parts manufacturing company revealed that the company produces high-precision metal components using twelve six-axis CNC lathe machines. These machines are equipped with primary and secondary workpiece fixtures that allow for dual-sided turning without the need to reposition the workpiece. The cutting inserts used in the turning process are made of tungsten carbide. The workforce consists of five personnel, divided into two roles. Technicians are responsible for inspecting and repairing machinery when malfunctions or damages occur, as well as replacing cutting tools once they reach the end of their service life. Machine operators are responsible for inspecting finished workpieces and placing them into packaging trays for transfer to the subsequent process step, which involves cleaning off oil residue from the components. The workpieces have a standard diameter of $6.255 \pm 0.01\text{mm}$, with an average production rate of 8,077 pieces per day. A problem was identified with the cutting tool used to machine the external diameter, in which cutting occurred along the z- to z+ axis. During this operation, the debris from the workpieces were unable to flow out from the front of the cutting tool, resulting in heat accumulation at the tip of the tool. This condition caused the workpiece material to fuse with the cutting tool, causing tool wear and eventual tool breakage. Consequently, the external diameter of the workpieces failed to meet the specified dimensional standard. Between January and May 2024, defects such as scratches, dents,

discontinuous workpiece surfaces, and incomplete finishes were observed, with a maximum defect rate of 2.9%, as shown in Figures 1 and 2.

Process capability analysis is a statistical method used to assess the ability of a manufacturing process to meet specified requirements and is commonly classified into short-term and long-term analyses. In short term analysis, the Cpk index is used, for example, to evaluate the performance of machinery after installation. Conversely, long term analysis employs the Ppk index to study the impact of variations introduced by repetitive processes that influence the overall process capability. Improvement efforts are typically directed toward processes with Cpk or Ppk values below the accepted standard (Avramova *et al.*, 2024). The collected data shows that the process capability of the automotive parts production process prior to improvements is illustrated in Figure 3.

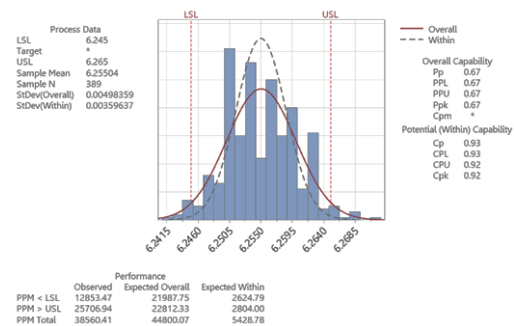


Figure 3. Process capability before improvements

As shown in Figure 3, the process capability prior to improvement indicates that a Ppk value of 0.67, which is below the standard threshold. This corresponds to approximately 38,560.41 parts per million (ppm), or 3.8 % of total production, resulting in defective components. These results indicate that the production process capability is inadequate and is influenced by both predictable and unpredictable sources of variation. Predictable

variations, although unavoidable, can be controlled within acceptable limits, whereas unpredictable variations, which are difficult to forecast, can be mitigated or eliminated through targeted improvement efforts. Therefore, it is essential to improve the process by targeting a Ppk value greater than or equal to 1.33. This improvement should begin with an analysis of the root causes contributing to defects in the production process.

The problem analysis using a fishbone diagram or a cause-and-effect diagram (Sakdiyah *et al.*, 2022)

To identify the root causes of defects in the production process and other issues requiring resolution, a fishbone diagram (cause-and-effect diagram) was used as the primary analytical tool. This analysis was conducted through structured brainstorming sessions involving key stakeholders in the production process. The investigation aimed to uncover the true causes of the issue by applying the 4m principle, which includes man (Employees), machine (Equipment), material (Raw materials), and method (Operating procedures). The analysis is illustrated in Figure 4.

The problem analysis derived from the cause-and-effect diagram before the improvement can be summarized as follows:

1. Operator-related issues: Differences in work methods were observed among the operators, particularly due to the presence of new employees. This led to inconsistencies in the standardization of work procedures.

2. Machine-related issues: The machines lacked regular maintenance, resulting in wear and

tear from continuous use over extended periods of time which led to degradation in performance.

3. Material-related issues: The cutting inserts were found to be unsuitable due to an insufficient nose radius (0.1 mm), which negatively affected tool strength and caused premature wear or cracking before the expected tool life was reached.

4. Method-related issues: The direction of movement along the tool axis was inappropriate, preventing effective chip evacuation from the front of the cutting tool. This caused heat accumulation at the cutting edge, resulting in premature cutting tool wear before the end of its expected service life.

Based on the analysis of these causes, the key areas for improvement were identified as follows: 1) Method-related issues: The direction of movement of the cutting tool was found to be inappropriate, leading to premature wear before the tool's expected service life. 2) Material-related issues: The cutting inserts were deemed unsuitable due to the insufficient insert angle, which resulted in reduced strength and contributed to premature wear of the tools.

Failure mode and effect analysis (FMEA) is a tool used to analyze production process in order to identify potential failure modes, associated risks, and their underlying causes. This method also involves assessing the expected damage and finding ways to prevent it before it occurs (Li & Zhu, 2025). In this study, the impact of each failure mode was assessed and prioritized using the risk priority number (RPN), which follows the pareto principle (80:20), as illustrated in Figure 5.

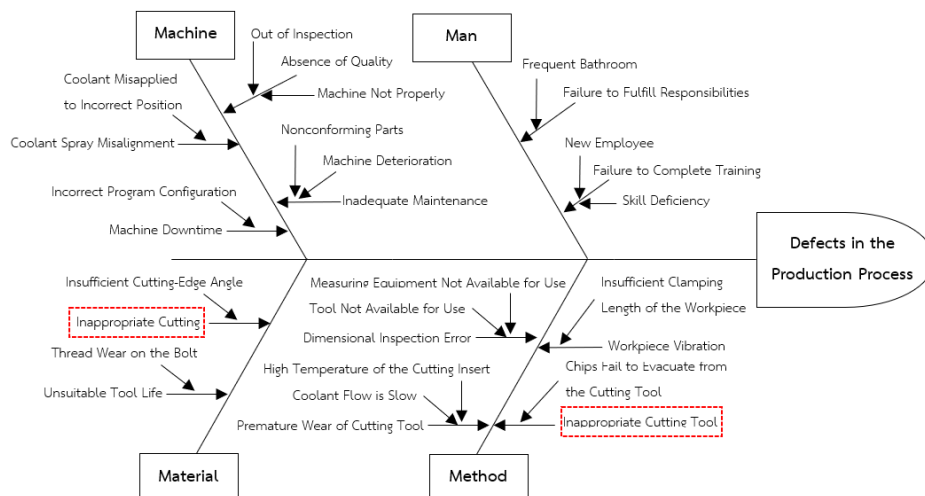


Figure 4. Problem analysis

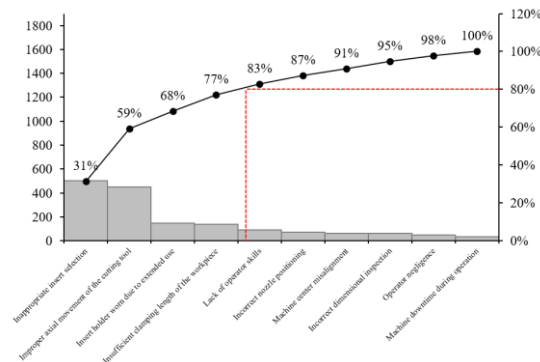


Figure 5. Prioritization of Causes

As shown in Figure 5, the prioritization of causes contributing to the most significant waste in the production process indicates that the most critical issue was the inappropriate cutting tool insert, with an RPN value of 504. The second most critical issue was the improper movement direction of the cutting tool, with an RPN value of 448. Both factors represent the highest priority issues. Therefore, to address waste in the production process, the production process was improved by changing the direction of the cutting tool movement and replacing the cutting inserts with higher strength alternatives.

Results and Discussion

Results

Through brainstorming sessions with stakeholders, root causes of the issue were analyzed using the fishbone diagram (cause and effect diagram), and improvement priorities were established. Based on this, three primary conclusions were drawn for addressing the problem: 1) changing the direction of the cutting tool movement, 2) adjusting the feed rate, and 3) replacing the cutting inserts. The experimental results are presented below.

Results of changing the direction of the cutting tool movement and its impact on workpiece surface quality: a comparison of cutting tool movement directions. An analysis of the cutting tool movement direction revealed that changing the movement direction affects both the geometric dimensions and the surface finish quality of the workpiece (Alyehya, 2024). In this study, the cutting direction was changed from z^+ to z^- , which resulted in an increase in scrap rate to 3.59%. The modification did not effectively reduce waste in the production process, as it failed to adequately expel debris from the cutting area. This led to material build-up at the cutting tool tip, leading to heat buildup. As a result,

the cutting tool experienced accelerated wear and fractured before reaching its expected service life.

Results of changing cutting tool movement direction and feed rate factors affecting workpiece quality in turning operations. In turning operations, several key factors influence workpiece quality, including spindle speed, depth of cut, cutting angle, and notably, the cutting tool movement direction and feed rate (Nita *et al.*, 2022). This study examined the combined effect of altering the cutting tool's movement direction from z^+ to z^- and adjusting the feed rate. The results showed that 16 defective pieces were produced out of a total of 1,462 workpieces, equating to a 1.09% scrap rate. Although the scrap rate in the production process decreased, the cutting tool lifespan remained below standard due to the accumulation of debris and clogging at the tool tip (Rodjananugoon *et al.*, 2021). The findings suggest that selecting an appropriate cutting tool radius plays a significant role in surface quality, as increasing the tool radius directly enhances the tool's strength and its longevity. To date, limited research has addressed the issue of scrap reduction and workpiece quality improvement through the combined alteration of cutting tool movement direction, feed rate, and cutting tool inserts.

Results of the analysis on the capability of changing the cutting tool movement direction and feed rate.

The process capability analysis revealed that the Ppk value was 0.84, corresponding to approximately 12,311.9 PPM, or 1.2% of the total production. This result indicates that process capability remained below the acceptable standard threshold. The automotive parts manufacturer in the case study set a target scrap rate of no more than 1.0% in the production process. The results of the cutting tool movement direction and feed rate analysis are presented in Figure 6. Therefore, it is necessary to replace the cutting inserts (Darji & Patel, 2024).

Results of the cutting tool insert change prior to the process improvement; the cutting tool insert with a radius of 0.1 mm was used. Following the implementation of process improvements, the insert radius was changed to 0.2 mm, and the direction of the tool movement was altered from z^+ to z^- , along with changes to the feed rate. The experimental results of the experimental adjustments indicated that no defects were observed in the production process across a total of 4,050 parts. These operational improvements eliminated defects in the production process and increased the tool life by 30%. The improvement in tool performance was attributed to more effective evacuation of chips,

which allowed for more effective heat dissipation and prevented the formation of built-up edges on the cutting tool during the initial turning phase. No chip buildup was observed at the cutting tool edge, and only minimal tool wear was observed. These findings demonstrate that process improvements, such as adjusting the tool insert radius, modifying tool movement direction, and optimizing feed rates, can substantially reduce defects in the production process while extending tool life. Effective management of chip removal and heat dissipation was identified as key factors, contributing to a more stable and efficient machining operation.

Results of process capability analysis for changing tool insert, tool movement direction, and feed rate.

After modifying the cutting tool insert, tool movement direction, and feed rate, the process

capability index, Ppk, was found to be 1.39, exceeding the established standard. Generally, a Ppk value of 1.33 or greater is considered indicative of good process capability, corresponding to approximately 0.00 PPM, or 0.0 % of the total production. In contrast, the actual waste generated during the production process was 0.1 percent, indicating that the manufacturing process had achieved a stable operating condition. These findings are consistent with the findings of Senvar and Tozan (2010), who stated that a Ppk greater than 1.33 reflect high-capacity processes capable of consistently producing parts within specifications while extending tool life. The results of the process capability analysis are shown in Figure 7.

After the implementation of improvements, including the use of cutting tool inserts with a larger

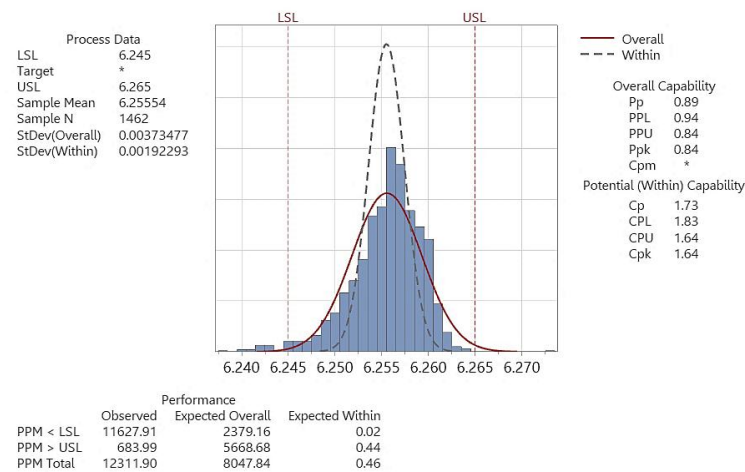


Figure 6. Results of the analysis on the capability of changing the cutting tool movement direction and feed rate

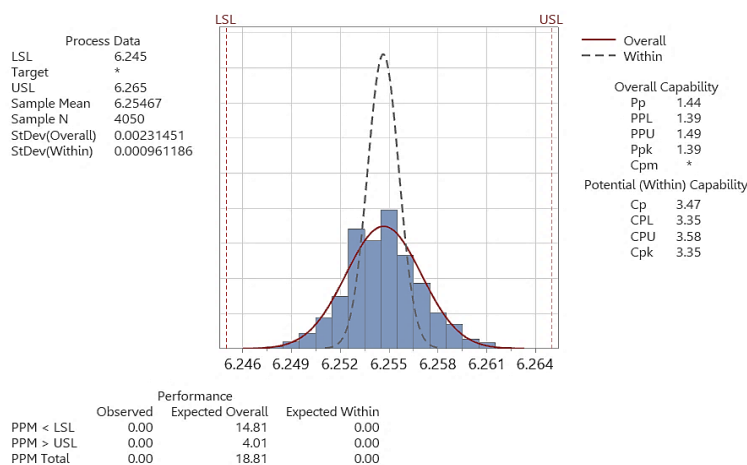


Figure 7. Process capability: tool insert change, tool movement direction change, and feed rate adjustment

radius, changing the tool movement direction from z^+ to z^- , and adjusting the feed rate, the amount of waste generated during the adjustment phase began to decrease. Following the implementation of these changes, the waste in the production process was found to be 0.9%, 0.2%, 0.0%, and 0.1% in sequence, as shown in Figure 8.

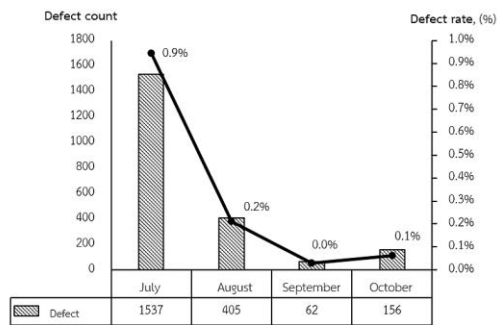


Figure 8. The amount of waste after the improvements

The comparison of costs before and after improvements.

Process improvement in automotive component manufacturing process aimed at reducing waste was achieved through the application of engineering techniques combined with statistical process capability analysis. The process improvement in the automotive component manufacturing aimed at reducing waste involved the application of engineering techniques in conjunction with statistical methods for process capability analysis. The improvements resulted in an additional unit cost of 290 THB for the cutting tool. However, the findings of this study indicate that these process improvements led to a significant reduction in waste and contributed to lowering overall production costs, reflecting increased process efficiency after the improvements. The cost comparison can be calculated using Equation (1), with the results presented in Figure 9.

$$\text{Production cost} = \frac{\text{Total cost}}{\text{production output}} \times 100 \quad (1)$$

A comparison of production process costs before and after the improvements revealed the following trends. Prior to the improvements, from April to June, the unit production cost was 10.07%, 9.98%, and 11.14%, respectively. After the improvements, from July to September, the unit production cost was 14.80%, 6.06%, and 5.10%, respectively. These results show that the modifications made to the production process, such as replacing the cutting tool and altering the movement direction of the cutting tool, and with adjusting the feed rate, had a positive impact on

process efficiency. The reduction in waste directly contributed to lowering the overall production cost. A comparison of the cutting tool cost per production unit is shown in Figure 9.

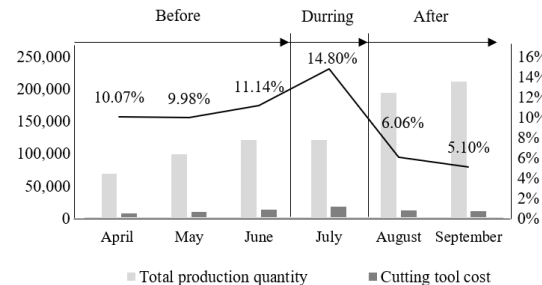


Figure 9. Comparison of Cutting Tool Cost per Production Unit

Discussion

The presence of waste in a production process represents a form of inefficiency that leads to unnecessary increases in production costs and reduced yield. Reducing waste not only lowers operational costs but also benefits the environment by minimizing industrial waste and the energy used in recycling processes (Siddique, 2020). Waste reduction can be achieved through various approaches, including the design of work holding fixtures, the use of LEAN techniques, ECRS, PDCA, fishbone diagrams, poka-yoke, and process capability analysis techniques (Setiawan *et al.*, 2021). In the case study company, the quality of the produced parts was found initially to be substandard, with issues such as dents, uneven surfaces, and discontinuities. Prior to the improvement phase, between January and May, the waste rate reached a peak of 2.9%. Upon analyzing the process capability, a Ppk value of 0.67 was found, which was below the required standard. This necessitated a detailed investigation into the root causes of waste in the production process. A cause-and-effect diagram (fishbone diagram) was used to identify the key contributing factors (Setiawan & Hernadewita, 2022). Through brainstorming sessions with relevant stakeholders, it was determined that the primary cause of waste was related to the raw materials (cutting inserts) and the methodology employed. Subsequently, failure mode and effect analysis (FMEA) was conducted, to prioritize these causes using the risk priority number (RPN) (Sahu & Arora, 2022). The most significant contributor to waste was the use of inappropriate cutting inserts, followed by improper tool movement along the machine's axis. To address these issues, the production process was improved by changing the direction of the tool movement and upgrading the cutting inserts to a stronger model.

The results of the tool movement direction change experiment showed a waste rate of 3.59% (14 defective parts out of 398). When both the tool movement direction and feed rate were modified, the waste rate dropped to 1.09% (16 defective parts out of 1,462) (Siahsarani *et al.*, 2025). When the cutting insert, tool movement direction, and feed rate were improved simultaneously, no defects were observed in a total production of 4,050 parts. Subsequent process capability analysis demonstrated that the post-improvement process achieved a Ppk value of 1.39, exceeding the required standard and indicating a stable production process capable of consistently producing parts within specification (Kwilinski & Kardas, 2023). In addition, production costs were reduced from 11.14% to 5.10%. These research findings suggest that an effective approach to reducing waste and production costs should begin with improvements in operational techniques, as such measures are relatively low-cost and straightforward to implement. In particular, changes in the direction of tool movement and feed rate should be prioritized. However, operational adjustments alone may not be sufficient to achieve the optimal reduction in waste. Therefore, the adoption of modern technologies represents a suitable long-term solution. In this study, upgrading to stronger and more durable cutting inserts proved beneficial, although it did come with an increase in material costs (Abolghasem & Mancilla-Cubides, 2021).

Summary

The primary objective of the process capability analysis in production improvement is to reduce waste. Prior to the implementation of improvements, the waste rate was 2.9%. Accordingly, a root cause analysis was conducted using a fishbone (cause-and-effect diagram) diagram, followed by a failure mode and effect analysis (FMEA) to identify and prioritize corrective actions. After the improvements were implemented, no waste was observed in the production process. The improved production system achieved a process capability, Ppk, value of 1.39, and the production cost was reduced to 5.10%. This study has certain limitations, as it was conducted within a single factory setting; therefore, the findings may not be directly applicable to all manufacturing environments. For future development, further research should explore the use of alternative cutting tool materials, such as carbide or ceramic, as well as implementing artificial intelligence (AI) technologies for predicting tool wear.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Author Contributions

Conceptualization: Phongsak Runkratok; Methodology: Panuput Satu Wong, Supattra Muparang; Investigation: Phongsak Runkratok; Formal Analysis: Panuput Satu Wong, Supattra Muparang; Validation: Jittiwat Nithikarnjanatharn, Panuput Satu Wong; Resources: Nattawut Somnuek; Data Curation: Phongsak Runkratok, Nattawut Somnuek; Visualization: Wannisa Nutkhum; Writing – Original Draft: Phongsak Runkratok; Writing – Review & Editing: Jittiwat Nithikarnjanatharn, Wannisa Nutkhum; Supervision: Jittiwat Nithikarnjanatharn, Wannisa Nutkhum; Project Administration: Jittiwat Nithikarnjanatharn. All authors have read and agreed to the published version of the manuscript.

Ethics Approval and Consent to Participate

Ethical approval was not required for this study because it involved the analysis and improvement of manufacturing processes in an industrial setting. The research did not involve human participants, animals, biological samples, or the collection of identifiable personal data.

Declaration of Generative AI

Generative AI tools were used solely for language editing and grammar improvement during the preparation of this manuscript. The authors carefully reviewed and revised all AI-assisted content and take full responsibility for the accuracy, integrity, and originality of the final manuscript.

Acknowledgements

The authors would like to express their sincere gratitude to Global-Thai Son Precision Industry Co., Ltd. for providing the data, technical support, and facilities necessary to conduct this study.

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