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Application of Lean Principles to Reduce Waste in the Stamping Process of Automotive Parts

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Abstract

This study aims to improve the efficiency of the automotive parts manufacturing process, with a focus on the stamping operation. Lean Manufacturing principles, specifically ECRS (Eliminate, Combine, Rearrange, Simplify) and Kaizen, were applied to identify and reduce production waste, particularly defect-related waste. An analysis of the existing system revealed a high defect rate in the stamping process as the primary source of inefficiency. Lean-based improvements were implemented to address root causes and minimize non-value-added activities. As a result, the defect rate was reduced from 0.69% to 0.37%, representing an improvement of approximately 46%. A 2-proportion Z-test confirmed that the reduction in defects was statistically significant (p-value < 0.001). The findings demonstrate that integrating Lean tools with process-level improvements can effectively enhance process performance and production reliability. This study provides a practical case of Lean implementation with measurable quality improvement in automotive manufacturing.

Keywords
Lean Manufacturing, Waste Reduction, Process Improvement, Stamping Process

1. Introduction
The automotive parts manufacturing industry plays a significant role in driving Thailand's economic growth and industrial development. In the era of global competition, manufacturers are required to deliver products with high quality, lower production costs, and shorter lead times in order to maintain their competitive advantage. These requirements have encouraged many manufacturing organizations to improve their production systems and operational efficiency continuously.

In modern manufacturing environments, the Just-in-Time (JIT) production system has been widely adopted to ensure products are produced and delivered exactly when needed while minimizing inventory and production costs. This approach has been strongly influenced by the development of Lean Manufacturing and the Toyota Production System, which emphasize the elimination of waste and continuous improvement in production processes (Ohno, 1988; Womack, Jones, & Roos, 1990).

In automotive parts production, stamping is a fundamental process for forming metal sheets into structural components. The performance of this process depends heavily on machine precision, material properties, and process control conditions. However, due to the complexity of material deformation and thermal sensitivity in forming operations, stamping processes are highly susceptible to defects, including cracking, dimensional inaccuracies, and material failure. These defects can lead to significant process inefficiencies and quality losses.

Although Lean Manufacturing has been widely implemented to improve production performance, existing studies primarily focus on general waste reduction techniques and value stream optimization. Limited attention has been given to integrating Lean tools with process-specific engineering factors, such as thermal control and workpiece positioning, particularly in stamping operations. This gap highlights the need for a more context-specific approach that combines Lean principles with detailed process analysis to reduce defect-related waste effectively.

Therefore, this study aims to analyze waste in the automotive parts stamping process and to develop targeted improvement strategies by integrating Lean Manufacturing tools, specifically ECRS and Kaizen, with process condition optimization. The research is conducted as a real industrial case study, focusing on reducing cracking defects and improving process stability. The findings are expected to contribute to both theoretical understanding and practical implementation of Lean-based process improvement in automotive manufacturing.

1.1 Objectives

1. To identify and quantify defect-related waste and its root causes in the automotive parts stamping process.
2. To implement and evaluate Lean Manufacturing tools (ECRS and Kaizen) to reduce cracking defects and improve process performance.

2. Literature Review

Lean Manufacturing has been widely recognized as an effective approach for improving operational efficiency and eliminating waste in manufacturing systems. The concept originated from the Toyota Production System, which emphasizes continuous improvement, waste elimination, and efficient production flow (Ohno, 1988). Lean Manufacturing focuses on identifying and eliminating non-value-added activities in production processes to improve productivity, reduce operational costs, and enhance overall manufacturing performance (Womack & Jones, 2003).

Among various manufacturing operations in the automotive industry, the stamping process plays a critical role in shaping metal sheets into vehicle structural components. The effectiveness of this process heavily depends on material properties and process parameters. However, forming high-strength structural steel at room temperature often poses significant challenges, including severe springback, material cracking, and excessive tool wear (Pereira et al., 2024). These limitations can lead to a high rate of production defects and inefficiencies, making it difficult to maintain a smooth manufacturing flow and dimensional accuracy (Mori et al., 2017).

To address the formability limitations of structural steel, thermal assistance is often applied before stamping. The thermal properties of steel indicate that raising its temperature significantly alters its microstructure. When steel is heated to its critical temperature range, its ductility increases sharply while the required forming force decreases (Karbasian & Tekkaya, 2010). This thermal transformation allows complex structural parts to be stamped more effectively without material failure. However, maintaining the appropriate and consistent thermal conditions is essential, as any deviation can alter the mechanical properties and result in defective final products (Mori et al., 2017). Several researchers have reported that Lean tools and techniques can be effectively applied to improve manufacturing performance. Tools such as Value Stream Mapping, root cause analysis, and continuous improvement practices have been widely used to identify inefficiencies and eliminate waste in production systems (Liker, 2004). These approaches Help organizations enhance operational efficiency, reduce production waste, improve overall production performance, and drive sustainable growth.

Despite widespread adoption of Lean Manufacturing across many industries, the effectiveness of Lean implementation often depends on the specific characteristics and contextual factors of the manufacturing process under study (Marodin & Saurin, 2013). Therefore, further research is required to analyze production waste in specific operational contexts and to develop appropriate improvement strategies for enhancing efficiency in automotive stamping processes.

3. Methods

The systematic approach of this research is illustrated in Figure 1. The methodology begins with a Current State Analysis to understand the existing stamping process and collect baseline data. Waste Identification follows this to determine the root causes of the defects. Subsequently, an ECRS and Kaizen Implementation phase is executed to reduce the cracking defects and improve the process. The outcomes are then assessed during the Result Evaluation phase. If the improvement target is not achieved, the process loops back to re-identify the waste and adjust the solutions. Once the target is successfully met, the new procedures are documented in the Standardization & Conclusion phase to sustain the improvements and prevent the recurrence of defects.

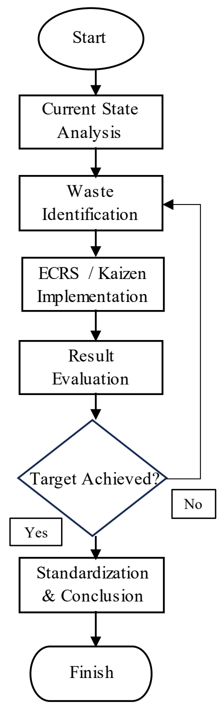

Figure 1. Research Methodology Flowchart

4. Data Collection

Data collection was conducted at the stamping department of the case study. The primary focus was on gathering baseline operational data before implementing Lean principles. Historical production data and defect records were collected over 4 months.

During the observation period, the production line manufactured a total of 646,069 parts. However, the quality inspection records revealed that 4,465 parts were identified as defective, resulting in a baseline defect rate of approximately 0.69%. An analysis of the rejected items showed that the critical quality issue was entirely due to "Cracking" defects that occurred during stamping. The summary of the production and defect data before the improvement is presented in Table 1.

Table 1. Production and defect data before improvement

Description	Month 1	Month 2	Month 3	Month 4	Total Quantity (Pieces)	Percentage (%)
Total Production Volume	211,050	204,960	163,069	66,990	646,069	100.00

Total Defective Parts (Cracking)	1,249	1,284	1,509	432	4,465	0.69
Good Parts	209,801	203,676	161,560	66,558	641,604	99.31

5. Results and Discussion

ECRS and Kaizen were systematically applied to analyze and reduce cracking defects in the stamping process. The effectiveness of the applied tools is evaluated by comparing baseline operational data with performance metrics obtained after the process improvements were implemented.

5.1 Numerical Results

Table 2 summarizes the production and defect data. The baseline defect rate was 0.69%. Following the implementation, the defect rate was successfully reduced to 0.37%. Overall, the application of ECRS and Kaizen techniques achieved a 46% relative reduction in cracking defects.

5.2 Graphical Results

Figure 2 presents the trend in the weekly defect rate before and after Kaizen implementation. Prior to improvement (Weeks 1–16), the process exhibited high variability, with defect rates ranging from 0.54% to 0.98%, indicating unstable process conditions and a lack of control.

Table 2. Production and defect data after improvement

Description	Month 5	Month 6	Total Quantity (Pieces)	Percentage (%)
Total Production Volume	273,820	171,690	445,510	100
Total Defective Parts (Cracking)	997	667	1,664	0.37
Good Parts	272,823	171,023	443,846	99.63

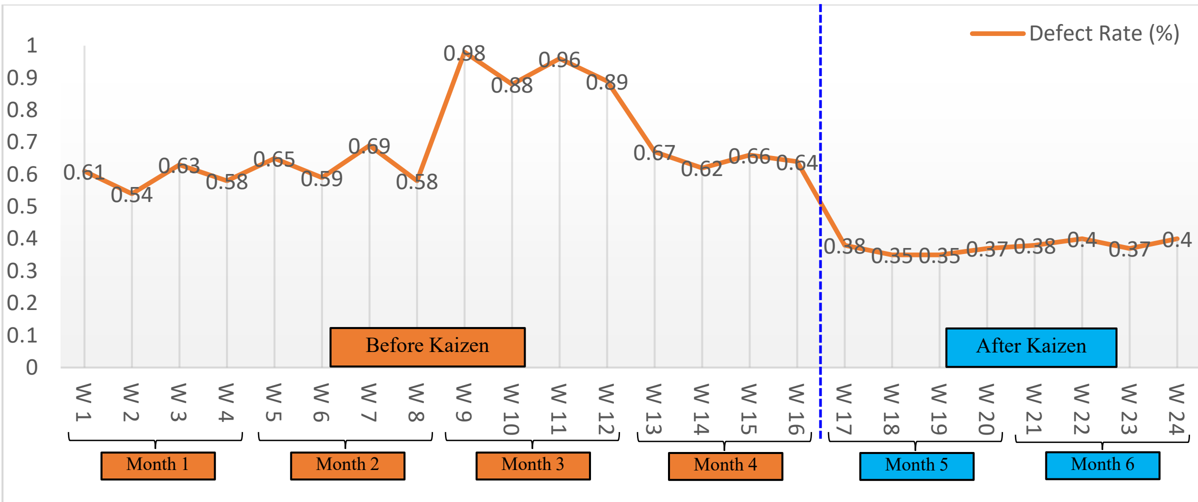

Figure 2. Weekly defect rate trend before and after Kaizen implementation.

Following the implementation of Lean-based improvements (Weeks 17–24), the defect rate significantly decreased and stabilized within a narrower band of 0.35% to 0.40%. This reduction reflects a substantial improvement in process capability and consistency. The observed trend clearly demonstrates the effectiveness of the implemented measures, particularly in controlling key process parameters such as heating conditions and workpiece positioning.

5.3 Proposed Improvements

Through experimental analysis of heating time and thermal characteristics, an optimal pre-heating cycle prior to the stamping process was established. A heating duration of 4.3 seconds successfully yielded a target temperature of 780–815°C, satisfying the optimal thermal conditions required for the subsequent forming of the workpiece.

5.3.1 Heating Time and Temperature Control

To resolve cracking defects caused by inconsistent heating of the 2-mm-thick SAE1050 steel parts (45x45 mm, extruded to an 8 mm height), the exact time required to reach the critical temperature was determined through an 8.0-second monitoring experiment. Applying the 'Simplify' principle of ECRS, a digital timer (Poka-Yoke) was subsequently installed to strictly control the heating cycle, as shown in Table 3.

Table 3. Time–Temperature Analysis of Steel Specimen

Time (Second)	Temperature (Celsius)	Status
1	186°C	Below Critical
2	372°C	
3	558°C	
4	744 - 850°C	Critical Range
5	930°C	Above Critical
6	1,116°C	
7	1,302°C	

Time (Second)	Temperature (Celsius)	Status
4.1	768°C	High resistance
4.2	784°C	Acceptable range
4.3	800°C	Target range
4.4	815°C	Acceptable range
4.5	829°C	Scaling risk
4.6	843°C	Overheated
4.7	856°C	Thinning risk

5.3.2 Heating Position Accuracy Improvement

While the experimental results provided the correct time and temperature settings, maintaining the exact alignment between the workpiece and the heating point was necessary. Consequently, a custom jig and fixture were fabricated to securely constrain the workpiece, standardize its position, and ensure identical heat exposure for every unit. Figures 3 and 4 illustrate the comparison of workpiece positioning before and after the Kaizen improvement enabled by the jig and fixture. The results clearly demonstrate that using the jig significantly reduces positional variation and improves process consistency.

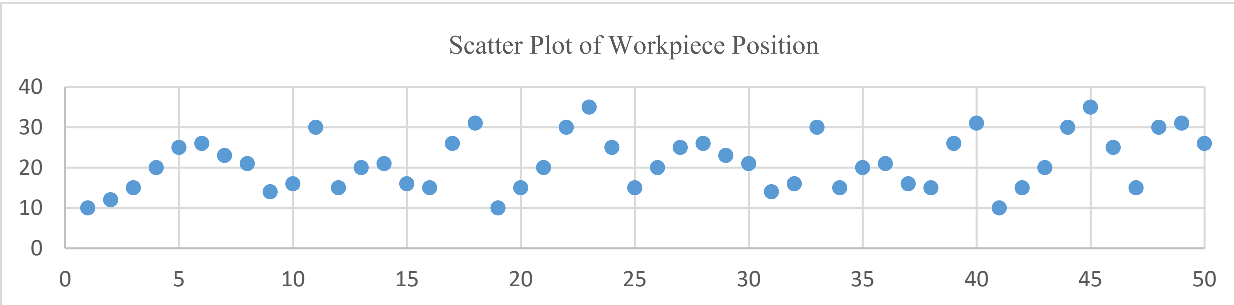

Figure 3. Scatter Plot of Workpiece Position Before Jig Fixture Implementation

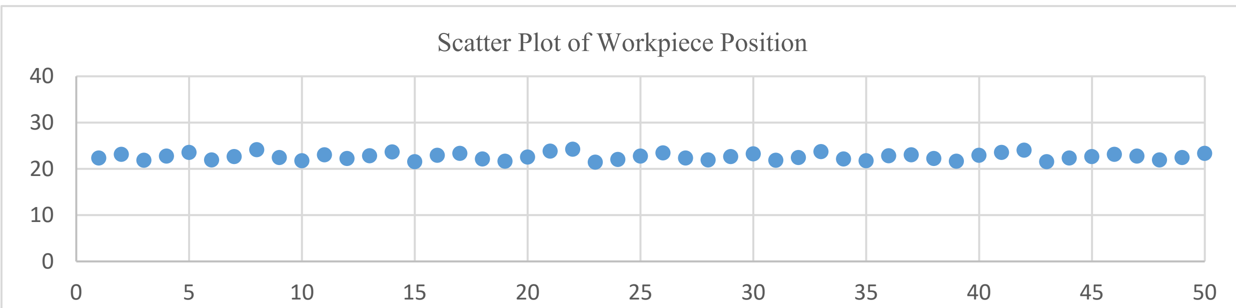

Figure 4. Scatter Plot of Workpiece Position After Jig Fixture Implementation

Experimental results indicate that the integration of the designed fixtures substantially minimized the deviation in workpiece placement. This improvement is clearly reflected in the resulting data plots, which exhibit a marked reduction in variance and a transition toward a more stabilized trend. The narrowed control limits signify enhanced process stability and a significant reduction in the Standard Deviation (σ) compared to the baseline manual process.

5.4 Validation

Prior to conducting the hypothesis test, the assumptions for a 2-proportion Z-test were verified. The samples collected before and after the improvement were strictly independent. The analysis was set at a 95% confidence level ($\alpha = 0.05$). Furthermore, the large sample size condition was perfectly met, as both $n\hat{p}$ and $n(1 - \hat{p})$ for both groups significantly exceeded the minimum threshold of 5, thereby validating the use of the normal approximation. Let p_1 and p_2 represent the true defect proportions before and after the improvement, respectively. The statistical hypotheses are defined as follows

$$H_0 : p_1 = p_2$$

$$H_1 : p_1 > p_2$$

Decision: As illustrated in Figure 5, the calculated Z-value (21.8) exceeds the critical value (1.645) at $\alpha = 0.05$, with a p-value < 0.001. Therefore, the null hypothesis (H_0) is rejected. This result indicates that the defect rate before improvement is significantly higher than after, confirming the effectiveness of the implemented Lean improvements.

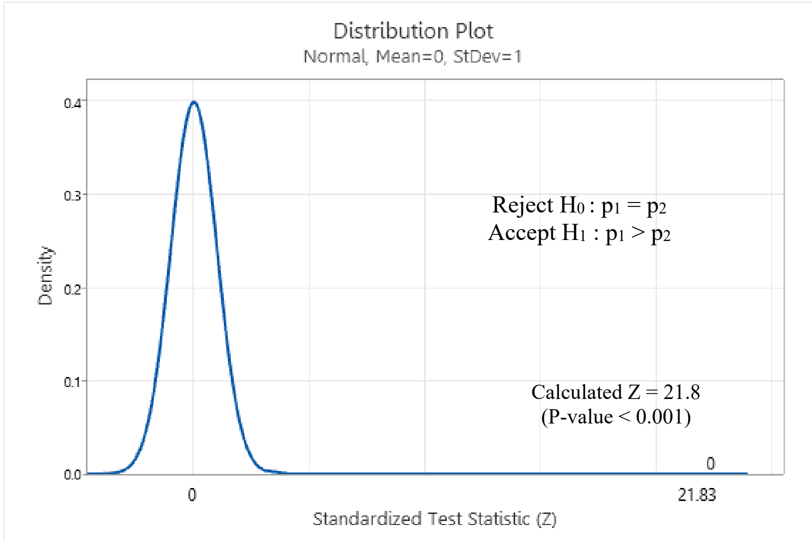

Figure 5. Statistically Significant Reduction in Defects ($\alpha = 0.05$)

As shown in Figure 6, the defect rates before and after the implementation of Lean Manufacturing improvements are compared. Prior to the improvement, the defect rate was 0.69%. After implementing Lean techniques, including ECRS and Kaizen, the defect rate decreased to 0.37%, representing a reduction of approximately 46.3%.

This significant reduction indicates that the applied Lean improvements were effective in minimizing defect occurrence and enhancing process performance. The results demonstrate a clear improvement in production quality and reflect the successful elimination of key sources of waste in the stamping process.

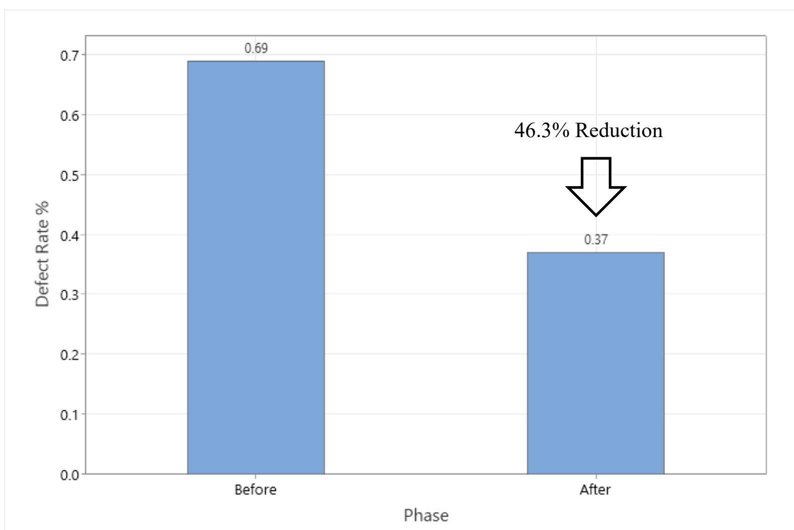

Figure 6. Comparison of defect rates before and after Lean implementation.

Furthermore, the practical and economic impacts of this defect reduction were evaluated through a Cost of Poor Quality (COPQ) analysis. Based on an average monthly production volume of 300,000 units, the 0.32% reduction in the defect rate successfully prevents 960 defective parts from being produced each month. To precisely calculate the financial impact, the net loss per defective part was determined. The estimated production cost is 12.00 THB per unit, while the scrap recovery value is 0.14 THB per unit (based on a part weight of 0.02 kg and a scrap rate of 7.00 THB/kg). Therefore, the actual net loss for each defect is 11.86 THB. By preventing 960 defects monthly, the facility achieves a direct net financial savings of 11,385.60 THB per month, resulting in an annualized cost savings of 136,627.20 THB. This economic validation strongly complements the statistical significance, fully justifying the practical feasibility and business value of the implemented Lean methodologies (Figure 7).

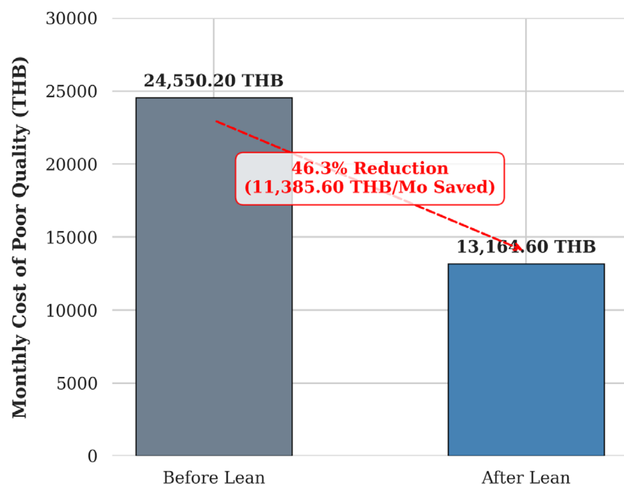

Figure 7. Comparison of the monthly Cost of Poor Quality (COPQ) before and after Lean implementation.

6. Conclusion

This study investigated the application of Lean Manufacturing principles to reduce waste and improve product quality in the automotive parts stamping process. By implementing targeted Lean tools, including ECRS and Kaizen, the study addressed key sources of inefficiencies and defect-related waste in the production system.

The results indicate a reduction in the defect rate from 0.69% to 0.37%, corresponding to an improvement of approximately 46%. A 2-proportion Z-test confirmed that this reduction is statistically significant (p-value < 0.001), indicating a meaningful improvement in process performance after the implementation of Lean interventions.

This study provides a practical and statistically validated case of Lean implementation in a real industrial context. The findings highlight the importance of integrating Lean methodologies with process-level improvements to reduce defects and enhance production stability in stamping operations effectively. Future research may extend this approach to other production lines and investigate the long-term sustainability of Lean-based improvements under varying operational conditions.

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Biographies

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