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# Implementation of Six Sigma DMAIC Methodology for Eliminating Spot Crack Defects in Automotive Resistance Spot Welding Process

**Reza Febriyana[1*], Heru Darmawan[2], Rani Rahmadiyani[3]**
[1,2,3] *Universitas Pelita Bangsa, Bekasi Indonesia*

*Coresponding author-email: ** rezafebriyana265@gmail.com

**Abstract**

Automotive welding processes require high process stability because welding defects directly influence product reliability and manufacturing cost. This study investigates the reduction of spot crack defects in an automotive Rear Door welding process using the Six Sigma DMAIC (Define–Measure–Analyze–Improve–Control) methodology. A quantitative case study approach was applied by integrating defect analysis, process capability measurement, Pareto analysis, Fishbone analysis, and corrective action implementation. The initial assessment identified 20 spot crack defects from 2,400 production units, resulting in a DPMO value of 2,083.33 and a process capability level of 4.37 sigma. Root cause analysis revealed that the defects were mainly associated with insufficient operator knowledge, unstable welding gun positioning due to damaged gun shanks, limited inspection coverage, and the absence of welding position control. Improvement actions included operator retraining, equipment replacement, additional inspection points, and implementation of a welding gun guide fixture. After improvement implementation, monitoring of 2,380 production units showed zero spot crack defects, achieving a DPMO value of 0 and process capability above 6 sigmas. The findings demonstrate that a structured Six Sigma DMAIC approach combined with welding-specific process controls can effectively enhance automotive welding quality and support sustainable defect prevention.

***Keywords:*** Six Sigma, DMAIC, Automotive Welding, Resistance Spot Welding, Defect Reduction, Process Capability

## 1. Introduction

The manufacturing industry operates in an increasingly competitive environment where product quality has become a critical factor influencing organizational performance, operational efficiency, and customer satisfaction. The rapid development of industrial technology, driven by globalization and the adoption of advanced manufacturing systems, has intensified competition among manufacturers to produce high-quality products while maintaining cost efficiency. In Indonesia, the manufacturing sector represents one of the strategic industries prioritized under the Making Indonesia 4.0 initiative, which emphasizes technological innovation, productivity enhancement, and quality improvement to strengthen industrial competitiveness (Fonna, 2019). Therefore, manufacturing companies are required not only to achieve high production capacity but also to ensure that products consistently comply with established quality standards.

Quality control plays an essential role in maintaining production stability and preventing defects throughout manufacturing processes. Product quality is influenced not only by final product characteristics but also by the interaction between raw materials, production methods, equipment performance, and workforce competence. Consequently, quality control must be implemented systematically throughout the production cycle, starting from material preparation, process execution, and final product inspection to ensure conformity with predetermined specifications (Tripalupi et al., 2014). Effective quality control practices enable manufacturers to minimize waste, improve process efficiency, and reduce quality-related costs caused by defective products (Sihombing & Sumartini, 2017).

Despite continuous improvements in manufacturing quality systems, production defects remain a major challenge, particularly in welding processes where dimensional accuracy, joint strength, and process consistency directly influence product reliability. Welding defects may result in increased rework activities, additional inspection costs, production interruptions, and potential product failures. Therefore, manufacturing companies require systematic quality improvement methodologies that are capable of identifying defect sources, analyzing process variation, and implementing preventive corrective actions. Among various quality improvement approaches, Six Sigma has been recognized as an effective methodology because it emphasizes data-driven analysis, process variation reduction, and defect prevention (Khofifah, 2024).

In automotive manufacturing, welding processes represent critical production stages because welding quality directly affects the structural performance and reliability of vehicle components. One of the commonly applied welding technologies in automotive body manufacturing is resistance spot welding, which requires consistent control of welding parameters, equipment conditions, and operator performance. However, variations in welding position, electrode condition, and process execution may lead to defects such as spot cracks that reduce joint quality and increase production losses. At PT Manufaktur, the Rear Door welding line produces several product models, including CN810, CN330, and CN410. Production monitoring indicated that the CN810 model generated the highest number of defects, with 25 defective units, compared with 5 defects in the CN330 model and 3 defects in the CN410 model. Among these defects, spot crack was identified as the dominant quality issue because it affected welding integrity, increased rework activities, and contributed to additional production costs. These conditions indicate that existing quality control practices require further improvement to identify process variability and prevent recurring defects.

Various quality management approaches have been developed to improve manufacturing performance, including Total Quality Management (TQM), Continuous Improvement (CI), Kaizen, Failure Mode and Effects Analysis (FMEA), Business Process Reengineering (BPR), Cost of Quality (COQ), and Voice of Customer (VOC). Although these approaches provide valuable contributions to organizational quality improvement, their implementation may require significant organizational commitment and does not always guarantee measurable process improvement. Previous studies have indicated that several TQM implementation programs fail to achieve their expected outcomes because organizations often focus more on quality principles and organizational culture rather than measurable process improvement activities (Fonna, 2019). Consequently, manufacturers increasingly adopt structured and data-driven methodologies that enable defect quantification, process capability evaluation, and evidence-based corrective actions.

Among various quality improvement methodologies, Six Sigma has become one of the most widely adopted approaches due to its ability to integrate statistical analysis with systematic problem-solving techniques. Six Sigma aims to achieve a process capability level equivalent to 3.4 defects per million opportunities (DPMO), allowing organizations to reduce variation, improve quality performance, minimize production costs, and increase customer satisfaction (Sirine & Kurniawati, 2017). Furthermore, Six Sigma has demonstrated effectiveness in identifying and eliminating process failures that negatively influence manufacturing performance (Nakhai & Neves, 2009). Previous studies have confirmed that the integration of Six Sigma with the DMAIC (Define, Measure, Analyze, Improve, Control) framework can significantly reduce defects, improve operational efficiency, and generate cost benefits through systematic improvement activities (Jirasukprasert et al., 2014). Similarly, Wulandari and Bernik (2018) reported that Six Sigma implementation can effectively identify dominant defect types and their root causes, providing a structured foundation for continuous improvement.

Although previous studies have demonstrated the effectiveness of Six Sigma DMAIC in various manufacturing sectors, its application for eliminating welding-specific defects remains insufficiently explored. Existing research has generally focused on general defect reduction or combined Six Sigma with other improvement approaches, while limited studies have investigated how DMAIC can be integrated with practical welding process controls to address spot crack defects. Therefore, this study aims to apply the Six Sigma DMAIC methodology to identify the root causes, evaluate process capability, and develop improvement strategies for reducing spot crack defects in the Rear Door welding process. This research contributes by demonstrating the application of DMAIC combined with

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welding-specific improvement actions, including operator competency enhancement, equipment condition improvement, inspection optimization, and welding position control, to improve manufacturing quality performance.

## 2. Literature Review

### 2. 1. Quality Control in Manufacturing

Quality has become a strategic factor that determines the competitiveness and sustainability of manufacturing companies. In an increasingly competitive industrial environment, manufacturers are expected to produce goods efficiently while consistently meeting customer expectations and established quality standards. Achieving these objectives not only improves organizational performance but also strengthens market competitiveness and ensures long-term business sustainability (Hariyanto et al., 2025). Consequently, companies are required to implement effective business strategies that emphasize operational excellence and continuous quality improvement (Fadhilah et al., 2023).

Quality refers to a product's ability to satisfy customer requirements through its functionality, reliability, durability, and conformity to specifications (Hikmah et al., 2024). To achieve these standards, organizations implement quality control, a systematic process that monitors production activities before, during, and after manufacturing to minimize process variation and prevent defects (Adji, 2022). Effective quality control enables management to identify quality deviations, evaluate production performance, and implement corrective actions to maintain product consistency (Suryatman et al., 2020). Its primary objective is to ensure that products comply with predetermined standards while minimizing production losses, inspection costs, and quality-related expenses (Nazia et al., 2023). Sustainable quality improvement also depends on process capability, compliance with product specifications, and systematic planning supported by continuous evaluation and corrective actions (Khamaludin et al., 2024; Putri, 2022).

### 2. 2. Six Sigma and the DMAIC Framework

Six Sigma is a data-driven quality improvement methodology that focuses on reducing process variation and eliminating defects through statistical analysis and structured problem solving. Unlike Total Quality Management (TQM), which primarily emphasizes organization-wide quality culture, Six Sigma is implemented through strategic improvement projects supported by measurable performance indicators and strong management commitment (Annas, 2025). The methodology aims to achieve a process capability equivalent to 3.4 Defects per Million Opportunities (DPMO), representing near-perfect production performance and high customer satisfaction (Gaspersz, 2007).

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The implementation of Six Sigma commonly follows the Define–Measure–Analyze–Improve–Control (DMAIC) framework. During the Define phase, organizations identify customer requirements and establish Critical to Quality (CTQ) characteristics that serve as measurable quality standards. This phase is frequently supported by the Supplier–Input–Process–Output–Customer (SIPOC) model, which maps the overall production process and facilitates the identification of improvement opportunities (Irwanto et al., 2020; Sahelangi & Wulandari, 2023). The Measure phase evaluates process capability by calculating quality indicators such as DPMO, sigma level, and process stability using statistical quality control tools (Baldah, 2020). In the Analyze phase, Pareto and Fishbone diagrams are employed to identify dominant defects and determine their root causes (Baldah, 2020).

Based on the identified causes, the Improve phase develops corrective actions using structured planning techniques such as 5W+1H, enabling organizations to implement practical and measurable quality improvement initiatives (Adi, 2025; Sirine & Kurniawati, 2017). Finally, the Control phase ensures that implemented improvements are sustained through standardized operating procedures, continuous monitoring, and periodic evaluation to prevent recurring defects (Rifka, 2017; Wulandari & Bernik, 2018). Owing to its systematic and evidence-based approach, Six Sigma has become one of the most widely adopted methodologies for improving manufacturing quality and operational efficiency.

## 3. Research Method

This study employed a quantitative case study approach to investigate the effectiveness of the Six Sigma methodology in reducing spot crack defects in the Rear Door welding process at PT SGMW Motor Indonesia, Bekasi, Indonesia. The study was conducted between April and August 2025, covering preliminary observations, data collection, process improvement, and post-improvement evaluation. The research focused on identifying the root causes of welding defects, evaluating process capability, and proposing improvement strategies to enhance welding quality.

Primary data were obtained through direct observation of welding operations and semi-structured interviews involving production supervisors, welding operators, quality control personnel, and maintenance technicians. Observations focused on welding activities, equipment conditions, production parameters, material conditions, and the occurrence of spot crack defects. Secondary data included production records, defect reports, quality inspection documents, machine maintenance records, and standard operating procedures (SOPs). To improve data credibility, information collected from observations, interviews, and company documentation was cross-validated using technical triangulation.

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The research adopted the Six Sigma methodology because it provides a structured and data-driven framework for reducing process variation and improving product quality (Gaspersz, 2007). The analysis followed the DMAIC (Define–Measure–Analyze–Improve–Control) cycle, which has been widely recognized as an effective framework for continuous quality improvement (Annas, 2025). During the Define phase, the production process was mapped using the Supplier–Input–Process–Output–Customer (SIPOC) model to identify process boundaries and determine the Critical to Quality (CTQ) characteristics that directly influence welding quality (Irwanto et al., 2020; Sahelangi & Wulandari, 2023). In the Measure phase, production and defect data were collected to calculate Defects per Unit (DPU), Defects per Million Opportunities (DPMO), and the corresponding sigma level, providing an objective assessment of process capability (Gaspersz, 2007). The overall research procedure is illustrated in Figure 1, which summarizes the sequence of research activities from problem identification and literature review to the implementation of the DMAIC cycle and the formulation of conclusions.

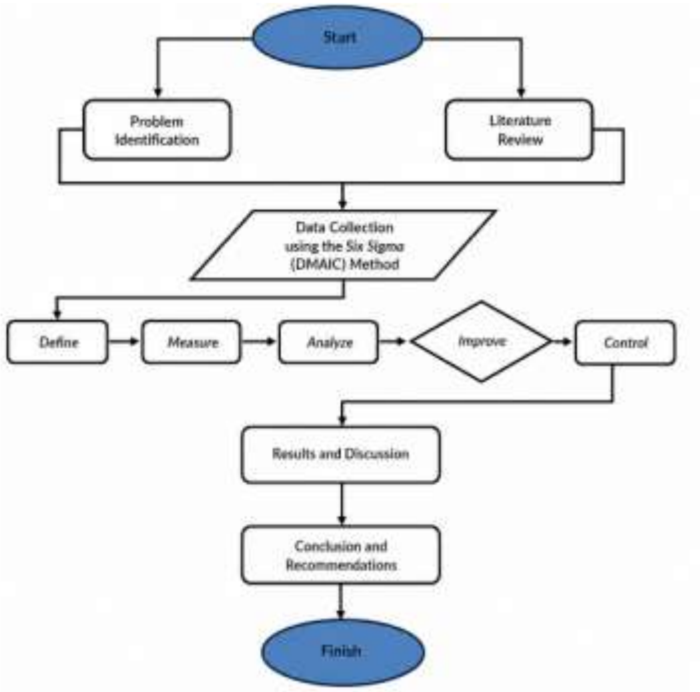


Figure 1. Research Framework

The Analyze phase employed Pareto and Fishbone (cause-and-effect) diagrams to determine the dominant defect category and identify its root causes according to the 5M+1E framework (Baldah, 2020). Based on the identified causes, the Improve phase developed corrective actions through brainstorming sessions and 5W+1H action planning to ensure that the proposed improvements were practical and measurable (Adi, 2025; Sirine & Kurniawati, 2017). Finally, the Control phase emphasized the implementation of standardized operating procedures (SOPs), continuous quality monitoring, and periodic process evaluation to sustain the improvements and prevent recurring defects (Wulandari & Bernik, 2018). The overall research framework is presented in Figure 1, while the analytical activities performed during each DMAIC stage are summarized in Table 1.

**Tabel 1.** Research Activities Based on the DMAIC Framework

| DMAIC Stage | Objective | Analysis Tools | Expected Output |
|---|---|---|---|
| Define | Identify quality problems and determine Critical to Quality (CTQ) characteristics | SIPOC, CTQ | Identification of dominant spot crack defects |
| Measure | Evaluate process capability and defect level | Check sheet, DPU, DPMO, Sigma calculation | Process capability and sigma level |
| Analyze | Identify the root causes of defects | Pareto diagram, Fishbone diagram (5M+1E) | Root causes of spot crack defects |
| Improve | Develop corrective actions | Brainstorming, 5W+1H Action Plan | Improvement recommendations |
| Control | Sustain process improvements | SOP implementation, quality monitoring | Stable process with reduced defects |

## 4. Result

### 4.1. Define Phase

The Define phase aimed to identify the dominant quality problem occurring in the Rear Door welding process and determine the scope of improvement. Production records showed that several product models, namely CN810, CN330, and CN410, experienced

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welding-related defects during the observation period. Among these models, CN810 contributed the highest number of defects, recording 25 defective units, compared with 5 defects for CN330 and 3 defects for CN410. Therefore, the CN810 model was selected as the focus of the Six Sigma improvement project because it represented the largest contribution to overall production defects.

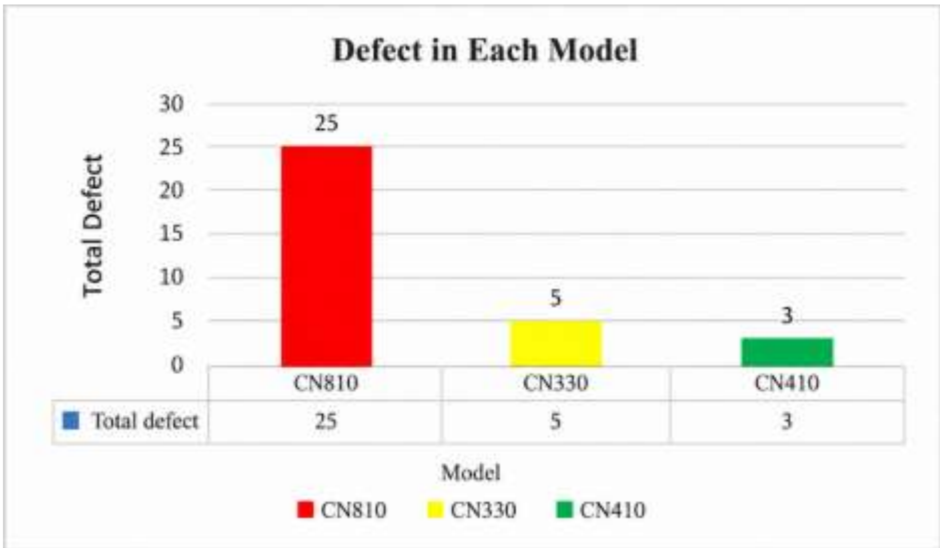

Figure 2. Defect Distribution by Product Model

To determine the priority defect, defect records from the CN810 model were further analyzed. Five defect categories were identified during the observation period: spot crack, spatter, missing, pin hole, and cold weld. Among these categories, spot crack was identified as the dominant defect, accounting for 20 occurrences (80%) of the total 25 defects, while the remaining defect types contributed only a small proportion of total quality issues. These findings indicate that improvement efforts should primarily focus on reducing spot crack defects because they represent the most significant source of process failure in the Rear Door welding line.

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**Table 2.** Distribution of Welding Defects in the CN810 Model

| Defect Type | Frequency | Percentage (%) |
|---|---|---|
| Spot crack | 20 | 80 |
| Spatter | 2 | 8 |
| Missing | 1 | 4 |
| Pin hole | 1 | 4 |
| Cold weld | 1 | 4 |
| Total | 25 | 100 |

The physical characteristics of the dominant defect were also examined. A conforming spot weld exhibited a weld diameter of 5–7 mm, measured using a Go/No-Go gauge, with a smooth surface free from visible cracks. In contrast, defective spot welds showed weld diameters outside the acceptable range and exhibited irregular surfaces accompanied by visible cracking, indicating inadequate welding quality.

Figure 3. Visual Comparison of Spot Weld Conditions

## 4.2. Measure Phase

Following the identification of the dominant defect, process performance was evaluated using production and defect data collected during July 2025. The Rear Door production line manufactured 2,400 units, of which 25 units were classified as defective. Among these defects, 20 cases were identified as spot crack defects and were selected as the Critical to Quality (CTQ) characteristic for subsequent Six Sigma analysis. Weekly production data indicated that the highest defect occurrence was observed during the

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third week, when 16 defects were recorded, corresponding to approximately 2% of weekly production.

**Table 3.** Production and Defect Data Before Improvement

| Week | Production (Units) | Defects | Defect Rate (%) |
|---|---|---|---|
| Week 1 | 600 | 2 | 0.33 |
| Week 2 | 550 | 1 | 0.18 |
| Week 3 | 650 | 16 | 2.46 |
| Week 4 | 600 | 6 | 1.00 |
| Total | 2,400 | 25 | — |

Process capability was subsequently evaluated using the Six Sigma metrics. Considering 20 spot crack defects, 2,400 production units, and four Critical to Quality (CTQ) opportunities per unit, the total number of opportunities was 9,600. The calculated Defects per Million Opportunities (DPMO) was 2,083.33, corresponding to a Yield of 99.79% and an estimated sigma level of 4.37. These results indicate that although the welding process demonstrated relatively high capability, considerable opportunities for quality improvement remained because spot crack defects continued to occur during production.

**Table 4.** Process Capability Before Improvement

| Indicator | Value |
|---|---|
| Production units | 2,400 |
| Spot crack defects | 20 |
| CTQ opportunities | 4 |
| Total opportunities | 9,600 |
| DPMO | 2,083.33 |
| Yield | 99.79% |
| Sigma level | 4.37 |

### 4.3. Analyze Phase

The Analyze phase was conducted to identify the root causes of the dominant spot crack defects identified during the Measure phase. Based on the Pareto analysis, spot crack defects accounted for 80% of all defects in the CN810 model, indicating that quality improvement efforts should focus primarily on this defect category. To systematically investigate the causes, a Fishbone (cause-and-effect) diagram was developed by classifying potential causes into four major factors: Man, Machine, Method, and Inspection Method.

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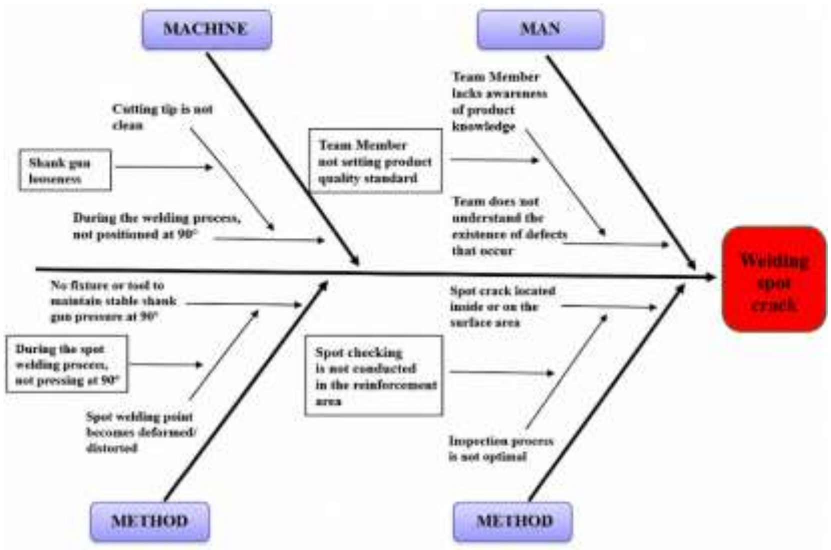


Figure 4. Fishbone Diagram of Spot Crack Defects

The analysis revealed that the occurrence of spot crack defects was influenced by several interconnected factors. The human factor was associated with insufficient operator awareness regarding product quality standards and inadequate knowledge of defect-prone welding locations. Consequently, operators were unable to recognize abnormal welding conditions during production.

The machine factor was primarily related to a damaged gun shank, which prevented the welding gun from maintaining a stable perpendicular position during operation. As a result, the welding electrode was not properly centered, increasing the likelihood of spot crack formation.

Two major issues were identified under the method factor. First, inspection activities were performed mainly in the reinforcement area, making several spot crack locations difficult to detect during routine quality inspection. Second, operators manually maintained the welding gun angle without any supporting fixture, resulting in inconsistent positioning and reducing welding stability throughout the production process.

The identified root causes were subsequently validated using the Why-Why Analysis, enabling each problem to be traced to its underlying source. The findings confirmed that the spot crack defect originated not from a single cause but from the interaction between operator competency, equipment condition, and process execution. A summary of the validated root causes is presented in Table 5.

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**Table 5.** Root Cause Analysis of Spot Crack Defects

| Factor | Root Cause | Identified Problem |
|---|---|---|
| Man | Limited product knowledge | Operators were unfamiliar with quality standards and defect-prone locations. |
| Machine | Damaged gun shank | The welding gun could not maintain a stable 90° position. |
| Method | Inadequate inspection point | Spot crack defects inside the reinforcement area were difficult to detect. |
| Method | No welding guide | Operators relied on manual positioning, causing inconsistent welding angles. |

### 4.4. Improve Phase

Based on the validated root causes, improvement initiatives were formulated to eliminate the dominant sources of spot crack defects. Each corrective action was designed to directly address the corresponding factor identified during the Analyze phase and to improve process consistency without disrupting production activities.

For the human factor, refresher training was conducted to strengthen operators' understanding of product quality standards. The training program included product knowledge sessions, one-point lessons, and the use of boundary samples to improve operators' ability to distinguish conforming and non-conforming welds.

To address the machine factor, damaged gun shanks were replaced to restore proper electrode alignment and ensure stable welding performance. This corrective action reduced equipment-related variability that could lead to unstable weld formation.

For the method factor, two process improvements were introduced. First, an additional inspection point was established after the hemming process, allowing quality inspectors to detect spot crack defects that were previously hidden within the reinforcement area. Second, a welding gun guide was designed and installed on the datum locator to maintain a constant 90° welding angle, thereby improving welding consistency and reducing operator-dependent variation during spot welding operations.

The proposed improvement actions and their implementation are summarized in Table 6.

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**Table 6.** Improvement Actions Implemented

| Factor | Root Cause | Improvement Action |
|---|---|---|
| Man | Limited product knowledge | Conduct refresher training, one-point lessons, and provide boundary samples. |
| Machine | Damaged gun shank | Replace the damaged gun shank. |
| Method | Hidden inspection area | Add an inspection point after the hemming process. |
| Method | No welding guide | Install a welding gun guide to maintain a constant 90° welding position. |

The implementation of these corrective actions is illustrated in Figure 5, which presents examples of operator retraining, gun shank replacement, the additional inspection point, and the installed welding gun guide.

(a) Operator Training (b) Gun Shank Replacement (c) Additional Inspection Point (d) Welding Gun Guide Installation

Figure 5. Implementation of Improvement Actions

## 4.5. Control Phase

The Control phase was conducted to evaluate the effectiveness of the implemented improvement actions and ensure that the enhanced welding process could be maintained consistently. Following the implementation of operator retraining, gun shank replacement, additional inspection points, and the welding gun guide, production performance was monitored throughout August 2025. The objective of this phase was to verify whether the corrective actions successfully eliminated spot crack defects and improved overall process capability.

Production monitoring indicated that the Rear Door welding line manufactured 2,380 units during the observation period. Unlike the previous month, no spot crack defects were recorded throughout all four production weeks. Weekly monitoring consistently showed a 0% defect rate, indicating that the implemented corrective actions effectively prevented the recurrence of the dominant welding defect. The production results after process improvement are summarized in Table 7.

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**Table 7.** Production Performance After Improvement

| Week | Production (Units) | Spot Crack Defects | Defect Rate (%) |
|---|---|---|---|
| Week 1 | 600 | 0 | 0.00 |
| Week 2 | 650 | 0 | 0.00 |
| Week 3 | 550 | 0 | 0.00 |
| Week 4 | 580 | 0 | 0.00 |
| Total | 2,380 | 0 | 0.00 |

Based on the post-improvement production data, process capability was recalculated using the Six Sigma performance indicators. With 2,380 production units, four Critical to Quality (CTQ) opportunities per unit, and zero recorded defects, the total number of defect opportunities was 9,520. Consequently, the calculated Defects per Opportunity (DPO) and Defects per Million Opportunities (DPMO) were both 0, while the process achieved a Yield of 100%. These results indicate that every product manufactured during the monitoring period satisfied the specified quality requirements without any occurrence of spot crack defects.

**Table 8.** Process Capability After Improvement

| Indicator | Value |
|---|---|
| Production units | 2,380 |
| Spot crack defects | 0 |
| CTQ opportunities | 4 |
| Total opportunities | 9,520 |
| DPO | 0 |
| DPMO | 0 |
| Yield | 100% |
| Sigma level | ≥ 6 |

A comparison of process performance before and after the implementation of improvement actions demonstrates a substantial enhancement in welding quality. Prior to improvement, the production process recorded 20 spot crack defects, corresponding to a DPMO of 2,083.33 and a sigma level of 4.37. After implementing the proposed corrective actions, no spot crack defects were observed, resulting in a DPMO of 0, a Yield of 100%, and an improvement of the process capability to at least Six Sigma. This comparison is illustrated in Figure 6.

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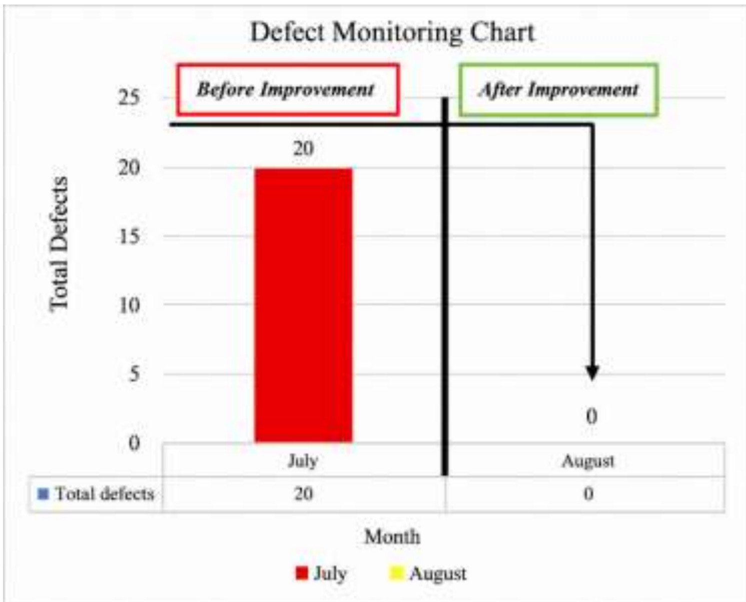

Figure 6. Comparison of Spot Crack Defects Before and After Improvement

**Table 9.** Comparison of Process Performance Before and After Improvement

| Performance Indicator | Before Improvement | After Improvement |
|---|---|---|
| Production units | 2,400 | 2,380 |
| Spot crack defects | 20 | 0 |
| DPMO | 2,083.33 | 0 |
| Yield (%) | 99.79 | 100.00 |
| Sigma level | 4.37 | ≥ 6 |

The results demonstrate a marked improvement in process capability following the implementation of the Six Sigma DMAIC methodology. The complete elimination of spot crack defects and the increase in sigma level indicate that the corrective actions effectively enhanced process stability and product quality during the observation period.

## 5. Discussion

The findings demonstrate that spot crack was the most critical quality issue in the Rear Door welding process, accounting for 80% of all identified defects. This result indicates that process variation was concentrated in a single defect category rather than being evenly distributed across multiple defect types. Consequently, prioritizing spot crack defects through the Six Sigma DMAIC methodology enabled the company to allocate improvement efforts more effectively and achieve substantial quality improvements. The Pareto analysis confirmed that eliminating the dominant defect would significantly

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reduce the overall defect rate, supporting the principle that a small number of causes are often responsible for the majority of quality problems. This finding highlights the importance of prioritization in manufacturing quality management rather than attempting to address all defects simultaneously.

The calculated DPMO of 2,083.33 and sigma level of 4.37 indicate that the welding process had already achieved a relatively high level of process capability before improvement. Nevertheless, the occurrence of 20 spot crack defects demonstrates that process variation remained sufficiently large to affect product quality and production efficiency. Although a sigma level above four generally reflects satisfactory manufacturing performance, further improvement is necessary for industries such as automotive manufacturing, where product reliability and safety requirements demand extremely low defect rates. Therefore, reducing process variation rather than merely increasing production output becomes an essential strategy for maintaining product quality and operational competitiveness.

The root cause analysis showed that spot crack defects were not generated by a single factor but rather resulted from the interaction of human, machine, and method-related factors. Operators lacked sufficient awareness of quality standards and defect-prone locations, damaged gun shanks reduced welding stability, and the absence of standardized inspection points and welding guides introduced inconsistencies during production. These findings emphasize that welding quality depends on the integration of human competence, equipment condition, and standardized production procedures. Consequently, corrective actions addressing only one factor would likely provide limited improvement because the defect originated from multiple interconnected causes.

The improvement initiatives implemented during this study successfully eliminated all observed spot crack defects, resulting in zero defects, 100% yield, and a process capability exceeding the Six Sigma benchmark during the monitoring period. These outcomes indicate that combining operator retraining, equipment replacement, additional inspection points, and welding gun guides effectively stabilized the welding process and minimized process variation. Unlike corrective actions that focus solely on equipment maintenance, the integrated improvement strategy simultaneously addressed technical and human-related sources of variation, thereby producing more sustainable process improvements.

The present findings are consistent with previous studies reporting the effectiveness of Six Sigma in manufacturing quality improvement. Kurnia et al. (2022) demonstrated that integrating the DMAIC framework with Failure Mode and Effects Analysis (FMEA) significantly reduced product defects in the elastic tape industry. Similarly, Mittal et al. (2023) reported improvements in rubber manufacturing quality through systematic defect analysis and corrective actions based on Six Sigma principles. Comparable improvements were also reported by Supriyati & Hasbullah (2020) in automotive painting processes and by Nirfison & Soesilo (2022) in household appliance

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manufacturing, where Six Sigma contributed to substantial reductions in process variation and defect occurrence. These similarities confirm that the DMAIC framework provides an effective and adaptable approach for improving manufacturing quality across different industrial sectors.

Despite these similarities, the present study offers several distinctive contributions. Previous studies generally combined Six Sigma with complementary approaches such as Lean Manufacturing, Failure Mode and Effects Analysis (FMEA), Value Stream Mapping (VSM), or 5S to improve overall manufacturing performance. In contrast, this study demonstrates that the DMAIC framework alone can effectively eliminate spot crack defects in an automotive Rear Door welding process when supported by systematic root cause analysis and practical corrective actions. Furthermore, this study provides quantitative evidence of improvement through direct comparison of DPMO, yield, and sigma level before and after implementation, offering a clearer evaluation of process capability improvement than many previous studies.

From a managerial perspective, these findings suggest that manufacturers should prioritize systematic root cause analysis before implementing corrective actions. Investments in operator competency, preventive equipment maintenance, standardized inspection procedures, and simple process-supporting devices such as welding gun guides can substantially improve process stability while reducing quality-related costs. Consequently, the Six Sigma DMAIC methodology represents not only a statistical quality improvement tool but also a practical management framework for achieving sustainable manufacturing excellence in automotive welding operations.

## 6. Conclusion

This study investigated the application of the Six Sigma DMAIC methodology to reduce spot crack defects in the Rear Door welding process at PT SGMW Motor Indonesia. The Define phase identified the CN810 model as the main contributor to welding defects, with spot crack defects representing 80% of the total defects recorded. The Measure phase showed that 20 spot crack defects occurred from 2,400 production units, resulting in a DPMO value of 2,083.33 and a process capability level of 4.37 sigma. These findings indicate that although the welding process demonstrated a relatively good capability level, further improvement was required to minimize process variation and prevent defect recurrence.

The Analyze phase revealed that spot crack defects were generated by the interaction of human, machine, and method-related factors. The main contributing factors included limited operator understanding of defect characteristics, unstable welding conditions caused by damaged gun shanks, insufficient inspection coverage, and inconsistent welding gun positioning. Based on these findings, improvement actions were implemented through operator refresher training, replacement of damaged gun shanks, additional inspection points after the hemming process, and installation of a welding gun guide to maintain a consistent 90° welding position.

After the implementation of the improvement actions, no spot crack defects were observed during the monitored production period of 2,380 units, resulting in a DPMO value of 0 and a yield of 100%. The observed process performance corresponded to a theoretical sigma level above Six Sigma during the evaluation period. These results indicate that the combination of DMAIC-based analysis and welding-specific process improvements can effectively reduce spot crack defects and enhance process stability in automotive welding operations.

This study provides practical insights for manufacturing organizations by demonstrating that defect reduction requires not only statistical analysis but also the integration of technical improvements, equipment control, inspection optimization, and operator capability development. However, the evaluation period was limited to the observed production period; therefore, further monitoring over a longer production cycle is recommended to verify the long-term sustainability of the implemented improvements.

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