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Quality improvement of process on the Sealer Line: A Case Study of Six Sigma DMAIC in the Four-Wheel Automotive Industry

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ABSTRACT

The study applied the Six Sigma DMAIC method to reduce defects in the Sealer Line process in an automotive paint shop. This process has a is high defect rate, which is caused by four main factors, such as machine instability, misalignment between the nozzle and the body plate, improper material handling, and operator errors in carrying out work procedures. Improvement measures are focused on stabilizing the machine temperature within the range of 60°–80°C, precise nozzle alignment, standardization of material replacement procedures, and increasing operator competence through training. After the implementation of improvements, the defect rate was successfully reduced to 2.04% from 4.24%, in line with the project target under 3%, with the DPMO value decreasing from 3,851.01 to 1,862.37 and the sigma level increasing from 4.17 to 4.41. These results indicate that the application of the DMAIC method is efficacious in improving process stability, operational efficiency, and product quality, while strengthening the continuous quality control system in the automotive manufacturing process.

Keywords : Six Sigma, DMAIC, Sealer Line, Paint Shop, Quality Improvement.

INTRODUCTION

The four-wheeled automotive industry cannot be separated from modern life. The development of the times and the dynamics of the global economy have also caused significant changes in various sectors, especially in the four-wheeled automotive industry. This industry is one of the strategic manufacturing sectors that makes a significant contribution to the national economy, both through job creation, increased investment, and foreign exchange earnings from exports. In fact, in several periods, the growth of the four-wheeled automotive industry was able to exceed the rate of national economic growth in Indonesia [1]. Therefore, the four-wheeled automotive industry plays a significant role in the country's economic development. According to data from the Ministry of Industry, the automotive sector contributed approximately 1.49% to the national Gross Domestic Product (GDP) in 2023 and is included in the manufacturing industry group, which contributes significantly to GDP, contributing 18.25%. Furthermore, total investment in this sector reached approximately IDR 143 trillion, employing more than 1.5 million workers along the industrial supply chain. This fact demonstrates that the four-wheeled automotive industry is a strategic sector that is a major driver of national economic growth [2].

In line with that, automotive manufacturers are required and responsible for ensuring that consumers receive the best quality vehicles according to the value paid. Manufacturers must also maintain consistent quality standards by meeting the specified technical specifications through a controlled production process and an effective quality testing system [3]. One of the main foundations of reputation in the competition of four-wheeled automotive companies is product quality, performance reliability, process efficiency, quality costs, and the ability to deliver vehicles on time and according to the promised quantity, all of which require the implementation of comprehensive quality control [4]. Quality in the four-wheeled automotive industry is a dynamic condition reflected in products, workforce, processes, and activities that can meet or even exceed consumer expectations, along with changes in the environment and market needs[5].

PT XYZ, a large and well-known company, is an automotive company engaged in the four-wheeled sector. The four-wheeled automotive industry includes an assembly process that combines thousands of different components into a final product in the form of a car with specific quality standards [6]. One of the many processes that is gone through is the painting process to provide corrosion protection as well as aesthetic value to the vehicle through the application of a paint layer with a particular technique [7]. High-quality painting results determine the attractiveness of the product and customer satisfaction [8] However, the defect rate in the Paint Shop Department is relatively high, especially in the Sealer Line area. Failure of the sealer coating process often causes surface defects, such as Sealer Line, which impacts the final quality of the painting results[9]. The defect rate in Sealer Line is 4.8% where the types of defects found in Sealer Line include: Sealer Hole, Sealer contamination (SCT), Sealer wrinkle, Sealer misplacement, and Sealer bad appearance (SBA). The most significant defect contributions are Sealer Line and SCT sealer, with a total of defects 3,050, making it the most significant problem in the painting production line due to the higher proportion compared to the company's tolerance standards, and causing an increase in rework costs and impacting the decrease in production line efficiency[10]. This condition is a serious concern because the quality of the sealer plays a crucial role in ensuring the vehicle's resistance to corrosion and maintaining the final appearance of the product. The sealing part is needed to protect the vehicle body joints from potential water and dust leaks before proceeding to the final painting process [11]. Therefore, stricter process control at the sealing stage must be carried out to minimize Sealer Line defects and improve the quality of the painting results. This effort is significant so that the resulting product can compete in the domestic and global markets, while strengthening the company's image in the four-wheeled automotive industry. Because visual appearance is a crucial aspect that determines the aesthetic value of a vehicle, where the quality of the paintwork and the smoothness of the car body surface are the main factors that influence consumer perception of the beauty and quality of the product as a whole [12]. Due to the ever-increasing need for quality improvement in the manufacturing industry, one method that can be implemented easily and effectively is Six Sigma with the DMAIC approach [13], [14]. Six Sigma is a quality control methodology that uses statistical techniques to identify and eliminate product defects and reduce variation in the production process, thereby significantly improving quality. Implementing Six Sigma DMAIC can also lower operational costs by reducing waste and production errors, as well as creating a work environment more conducive to continuous improvement [15]. This method is very popular and trusted in various manufacturing sectors as a strategic tool to achieve world-class quality standards with a systematic and measurable approach, thus helping manufacturing companies meet customer expectations while reducing production costs through structured continuous improvement [16].

The application of Six Sigma DMAIC has been successfully applied in various manufacturing industries, such as the textile industry, carding [17], and winding [18], and the healthcare sector. [19], transportation and logistics industry, especially in the railway sector, [20], and the financial industry [21]. In the context of the automotive industry, the Six Sigma DMAIC method is also widely applied at various stages of the production process to improve quality and efficiency on the assembly line, used to reduce the level of defects and waste that occur during the vehicle assembly process, thus having a direct impact on improving the quality of the final product and the operational efficiency of the factory [22]. Furthermore, in the production process and repair of the body and interior of the vehicle, the application of DMAIC focuses on controlling the quality of components such as seats and other interior parts to minimize defective products and reduce the need for rework [23]. Not only that, this method is also applied at the welding and component joining stages, where DMAIC plays an important role in ensuring that each connection and weld meets strict quality standards, thereby increasing the strength, safety, and reliability of the vehicles produced [24].

This research is a case study that aims to propose a step-by-step procedure using DMAIC stages to reduce the defect rate on the Sealer Line in the Paint Shop Department. In the analysis and improvement stage, several tools in lean manufacturing are used, such as the Pareto diagram and the Ishikawa diagram (fishbone), to identify the leading causes of defects. The main objective of this research is to reduce the chance of Sealer Line defects that have an impact on the quality of the painting results and the achievement of production targets, so that the product rejection rate can be reduced. The uniqueness of this research lies in the application of the Six Sigma DMAIC approach combined with lean manufacturing tools to improve quality and reduce the defect rate in the painting process in the four-wheeled automotive industry.

METHODS

This case study applies the Six Sigma DMAIC methodology as a systematic framework to identify problem statements and collect relevant data through field observations, discussions with the quality control team, and literature reviews. The focus of the research is directed at efforts to reduce the level of defects that occur in the Sealer Line in the Paint Shop Department, which is proven to be a major contributor to overall production defects. The DMAIC stages are used to analyze the root cause, formulate improvement strategies, and implement sustainable control measures to reduce the frequency of defects. The research flow design presented in Figure 1 comprehensively illustrates the methodological approach applied in this study

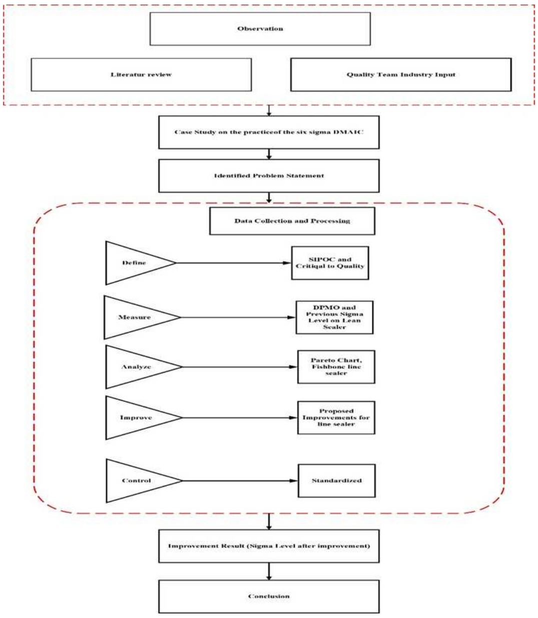

Figure 1. Research Methodology

The Six Sigma-DMAIC method is applied as a systematic approach to reduce defects in the production process, particularly on the Sealer Line in the Paint Shop Department. This approach consists of five main stages.

- First, the Define stage focuses on determining the problem and research objectives, as well as process mapping using the SIPOC (Supplier-Input-Process-Output-Customer) diagram to identify critical factors that influence quality [25].
- Second, the Measure stage aims to assess the actual condition of the process through data collection and calculation of defect levels using Defect Per Million Opportunities (DPMO) and Sigma Quality Level (SQL) to describe the current process performance [26].
- Third, the Analyze stage is carried out by evaluating the dominant causes of Sealer Line defects using Pareto analysis and cause-and-effect diagrams (fishbone diagrams) to identify the root causes that most contribute to the high defect rate [27]. The Pareto Principle, also known as the 80/20 rule, is a concept that states that approximately 80% of results come from 20% of causes. This means that a small portion of input factors or efforts cause most of the output or consequences [18]. The function of the Fishbone Diagram (or Ishikawa Diagram) is to help identify, organize, and analyze the root causes of a problem systematically and visually. This diagram illustrates cause-and-effect relationships by grouping various causal factors into main categories such as people, methods, machines, materials, environment, and measurements. With this function, the Fishbone Diagram makes it easier for teams or organizations to find the root cause comprehensively and formulate targeted solutions, thereby effectively improving the quality of processes or services [28].
- Next, the Improve stage focuses on developing and implementing appropriate solutions to address the root causes of defects, including process improvement efforts and implementing error prevention measures. Finally, the Control stage emphasizes the preparation of Standard Operating Procedures (SOPs) to ensure the sustainability of improvement results and long-term stability of process performance. This comprehensive DMAIC approach is expected to reduce the percentage of Sealer Line defects by 4.24% and increase product quality consistency and customer satisfaction [29].

RESULTS AND DISCUSSIONS

The defect rate in the painting process in the Paint Shop Department is high, at 4.24%, causing financial losses for the company and impacting customer satisfaction. The application of the Six Sigma-DMAIC method is used as an approach to reduce the defect rate in the Sealer Line. The DMAIC methodology used in this study consists of five main stages that are interconnected.

Define Phase

The project charter document is a crucial initial step in the Define phase of the DMAIC methodology because it determines the direction and success of the quality improvement project. This document serves to identify customer requirements that form the basis for determining Critical to Quality (CTQ), namely, the main quality metrics that must be met to achieve customer satisfaction. In this case, the project focused on the Sealer Line process in the Paint Shop Department, where the high Sealer Line defect rate caused a significant increase in [30] rework activity and production costs.

- Problem Statement: The Sealer Line defect rate reached 4.24% of the total defects in the Paint Shop Department.
- Project Objective: To reduce the defect rate of the Sealer Line to below 3%, thus achieving Good Manufacturing Practice (GMP) (long-term) 97% Good product [31]
- CTQ (Critical to Quality): Eliminate the Sealer Line in the sealer coating process so that the painting results are free from defects and meet quality standards [32].
- Financial Benefits: Reduces rework costs and production material waste.
- Benefits for Customers: Improve the quality of vehicle painting results, customer satisfaction, and company image in the global automotive market.

floor areas), installing plugs and anti-pads, coating Sealer 2 (on the door hemming, engine room, and rear panel areas), coating Under Body Sealer (UBS) using a robot, oven and cooling processes, and ending with the inspection stage to ensure the coating results meet standards. These stages produce several main outputs, namely the vehicle body with a perfectly closed sealer layer, defect-free painting results, especially from the Sealer Hole, as well as quality inspection data that is the basis for process evaluation. Furthermore, the production results are forwarded to the Customer, namely the Top Coat Department for the advanced painting process, the Final Inspection Department for the final inspection, and finally to the end consumer through the finished vehicle product. Through this SIPOC mapping, it can be understood that the critical point that is the scope of the research lies in the Sealer 1 and Sealer 2 coating stages, because it is in this process that Sealer Line defects most often appear. Thus, the results of the SIPOC analysis become an important reference in formulating more targeted and effective quality improvement steps in the Paint Shop Department.

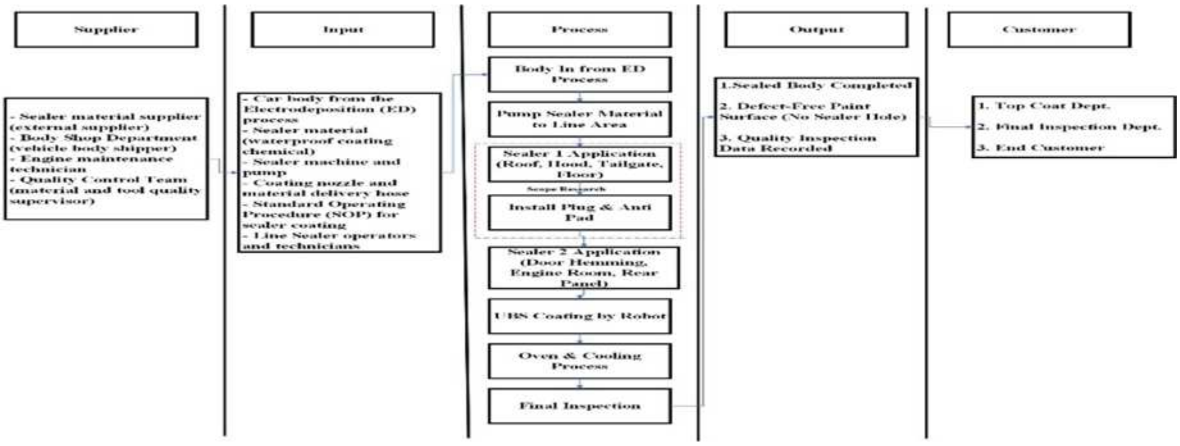

Figure 2. SIPOC Diagram

Figure 2 explains that at the Supplier stage, the primary source of the process comes from the sealer material supplier, the Body Shop Department that sends the vehicle body, as well as technical support from the maintenance and quality control departments. Furthermore, in the Input section, important components used include the vehicle body resulting from the ED process, sealer material, sealer pump machine, coating nozzle, coating SOP, and operator labor who carry out the process. The core process consists of eight stages, namely receiving the vehicle body from the ED process, pumping the sealer material to the production area, coating Sealer 1 (on the roof, hood, tailgate, and

Table 1. **Sealer Line Defect Data (March-May)**

Month	Units check	Total Defect	defect percentage per month
March	24,000	1355	1.88%
April	24,000	964	1.34%
May	24,000	731	1.02%
Total Per Month	72,000	3,050	4.24%

Table 1 displays defect data on the Sealer Line over three months, during the three-month observation period, the total units inspected reached 72,000 units with a cumulative number of defects of 3,050 units. This indicates that the total defect rate in the Sealer Line process is 4.24%.

Measure Phase

Data collection in the Measure phase is conducted to assess the level of process performance under actual conditions. Therefore, measuring the number of defects and efforts to reduce them are crucial steps in improving process quality. The Defects Per Million Opportunities (DPMO) value is then calculated using the following formula as the basis for evaluating quality performance [18]:

$$\text{Defect per unit (DPU)} = \frac{\text{Number of Defets}}{\text{Total number of units}} \quad (1)$$

$$\text{Defect per opportunity (DPO)} = \frac{\text{DPU}}{\text{Number of defects opportunities per unit}} \quad (2)$$

$$\text{DPMO} = 1.000.000x\frac{\text{Total defect samples}}{\text{defects opportunities samples}} \quad (3)$$

$$\text{Yield} = 1 - \text{DPO} \quad (4)$$

$$\text{Sigma level} = \text{Normsinv}\frac{\text{Total defect samples}}{\text{defects opportunities samples}} \quad (5)$$

Table 2 shows that the average DPMO value in the Sealer Line production process is 3,851.01, which means there are approximately 3,851 defect opportunities in every one million production opportunities. Meanwhile, the average Sigma level of 4.17 indicates that the process is in the sound quality category [33]. However, further improvements to the Sigma level are still needed to minimize defect variations, improve process stability, and encourage more optimal productivity for the company.

Analyze Phase

In the Analyze stage, the collected data is analyzed using a Pareto diagram as shown in Figure 3. This analysis is used to identify the type of defect with the highest cumulative percentage that has the most influence on the total product defects. Next, to trace the leading cause of the dominant defect, a cause-and-effect diagram (Fishbone Diagram) is used, as shown in Figure 4, to find the root cause of the problem that becomes the focus of process improvement.

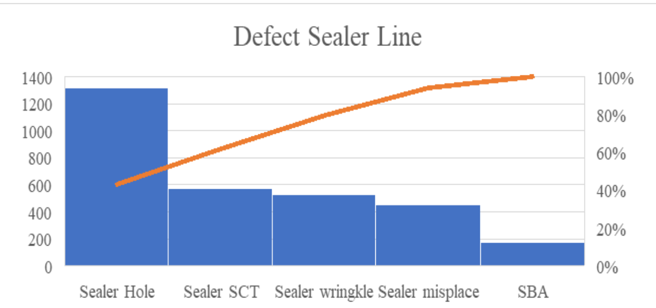

Figure 3. Pareto diagram

Figure 3 shows five types of defects identified as the leading causes of the increasing level of non-conformity in the process. Based on the results of the Pareto diagram analysis, it is known that the first two types of defects, namely Sealer Hole and Sealer Contamination (SCT), have a significant contribution, namely around 62.89% of the total defects. Therefore, the focus of the analysis is directed at these two types of defects to find the root cause. Next, the leading causes of these two dominant defects are analyzed using a fishbone diagram, which serves to identify potential factors causing the problem so that appropriate and systematic corrective actions can be formulated.

Figure 3 above explains the five types of defects most frequently found in the coating process in the Sealer Line Department of the Paint Shop, namely:

1. Sealer Hole: A defect in the form of a hole or area not entirely covered by sealer at a vehicle body joint. This type of defect has the highest percentage compared to others, potentially causing leaks and reducing the quality of the paint job.
2. Sealer Contamination (SCT): occurs when the sealer material mixes with dirt, dust, or foreign particles that stick to the body surface, thus disrupting the final appearance of the paint.
3. Sealer Wrinkle: a defect in the form of a wrinkled or uneven sealer surface due to air pressure or mismatched material viscosity.
4. Sealer Misplace: occurs when the sealer application position does not match the specified path or area, causing certain areas not to be correctly sealed.
5. Sealer Bad Appearance (SBA): refers to the sealer coating results that appear non-uniform, both in terms of thickness and smoothness, thus reducing the aesthetic quality of the vehicle's surface.

Sealer hole is the defect with the highest frequency and makes the most significant contribution to the total defects that occur in Sealer Line.

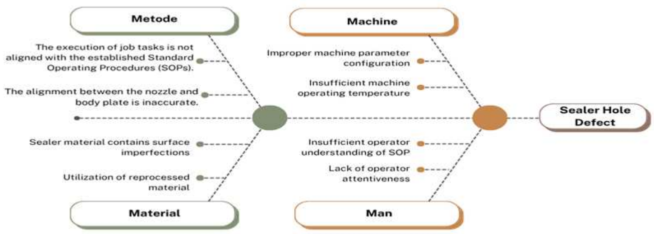

Figure 4. Fishbone Diagram

Table 2. DPMO Calculation and Sigma Level

Month	Number of Units	Number of Defects	DPU	DPO	Yield	DPMO	Sigma Level
March	24,000	1355	0.056	0.0051	0.995	5,132.58	4.06677
April	24,000	964	0.040	0.0037	0.996	3,651.52	4.18270
May	24,000	731	0.030	0.0028	0.997	2,768.94	4.27396
		Average DPMO and Sigma Level				3,851.01	4.17448

Figure 4 displays a fishbone diagram used to identify the various leading causes of defects in the Hole Sealer. Based on the analysis results, eight leading causes were identified and grouped into three main factors, namely machines, humans, materials, and methods. Each factor was further analyzed by compiling a problem cause table to determine the root cause that most influences the occurrence of defects, so that appropriate corrective actions can be formulated to improve process quality in the Sealer Line.

Table 3. Causes of Sealer Line Problems

No	Factor	Problem	Causes
1	Machine	The sealer pump machine is experiencing deflation (does not work)	The air temperature in the Sealer Pump machine is too low, so the air is unstable.
2	Method	It often happens that the sealer is misplaced on the body plate.	The nozzle and body plate are not centered when applying the sealer material to the car body.
3	Material	The sealer material exhibits surface roughness defects.	Sealer material replacement is often not in accordance with SOP, and uses the material cycle
4	Man	Insufficient operator understanding of SOP.	Operators are not careful in carrying out their respective job descriptions

Table 3 show that four main factors contribute to the occurrence of Sealer Line defects in the Sealer Line process. Machine factors are related to the condition of the sealer pump, which is not functioning optimally due to low air temperatures, which cause instability in air pressure. From a methodological aspect, defects occur due to inaccurate positioning (misplacement) between the nozzle and the body plate during the coating process. Material factors indicate that the quality of the sealer decreases due to the use of substitute materials that do not comply with standard operating procedures (SOP). Meanwhile, from the human factor, it was found that the operator's lack of understanding and accuracy regarding the work SOP also contributed to the occurrence of defects. Thus, improvements need to be focused on increasing machine stability, compliance with standard procedures, and operator training to minimize the potential for Sealer Holes.

Improve Phase

The improve phase is the fourth stage in the DMAIC methodology, which focuses on implementing corrective actions to minimize product defect rates based on factors occurring in the field. In this phase, an in-depth analysis of process functions and actual data is conducted to identify potential causes of failure. Based on the results of this analysis, various effective solutions have been developed to address the root causes. The proposed corrective action plan is presented in Table 4.

Table 4. Proposed Improvements

No	Factor	Problems	Proposed Improvements
1	Machine	The sealer pump machine experienced a malfunction (flat).	Establish Standard Operating Procedures (SOP) regarding air temperature settings in the sealer pump machine between 60 °C and 80°C to maintain stable air pressure and prevent malfunctions.
2	Method	Misplacement of the sealer coating on the body plate often occurs.	Ensure the nozzle and body plate are aligned (centered) and follow the SOP in the sealer coating process so that the coating results are even and precise.
3	Material	The sealer material shows defects in the form of an uneven surface (bumps).	Establish procedures for inspection and replacement of sealer material through a drain process three times according to SOP to maintain material homogeneity.
4	Man	Operators do not fully understand work SOPs.	Provide regular training and education to all operators in the Sealer Line regarding work procedures and their respective responsibilities to improve compliance with operational standards.

The implementation of the proposed corrective actions in the Sealer Line process is expected to increase the sigma level value, which acts as a key indicator of quality in the manufacturing process.

After the implementation of the improvements, the Sealer Line defect percentage, DPMO value, and sigma level can be measured again to assess the effectiveness of the quality improvements that have been made.

Table 5. Sealer Line after Improvement

Month	Units check	Total Defect	Defect percentage per month
June	24,000	590	0.82%
July	24,000	468	0.65%
August	24,000	410	0.57%
Total Per Month	72,000	1,468	2.04%

Table 5 shows that the defect rate in the Sealer Line after the repairs was carried out successfully decreased significantly to below the 3% threshold, namely 2.04%. This result demonstrates the effectiveness of the implemented improvement steps, while also confirming that the project implementation has been carried out in accordance with the objectives stated in the project document. This achievement also reflects the improvement in quality control and efficiency of the production process in the Sealer Line area, thus having a positive impact on the stability of overall product quality.

Table 6 shows that after improvements were made to the Sealer Line process, the DPMO value decreased significantly from 3,851.01 to 1,862.37. In addition, the Sigma level increased from 4.17 to 4.41, indicating an improvement in process quality and production stability. This decrease in the number of defects proves the effectiveness of the application of the Six Sigma DMAIC method, primarily through improvements made to four main factors, namely machines, methods, materials, and humans, which directly contribute to defect control in the Sealer Line process.

Control Phase

This phase includes the implementation of a control plan to monitor the performance of the Sealer Line process and ensure corrective actions are taken if there are deviations from the established standards. The Control phase is the fifth and final stage in the DMAIC methodology, which aims to maintain the sustainability of improvement results and ensure consistent process quality. Control is carried out through direct supervision by the Quality Assurance (QA) department and routine coordination between the Production and Quality Control (QC) teams. Several control steps implemented include: (1) conducting routine maintenance and maintaining the cleanliness of the Sealer Line area ; (2) checking machine settings before the coating process begins; (3) ensuring that cleaning of tools and work areas is carried out according to schedule; (4) increasing operator understanding of sealer coating standards to prevent Sealer Line defects; (5) conducting periodic checks by supervisors, shift managers, and related teams throughout the process; and (6) providing routine training regarding the implementation of SOPs to all workers, especially for new operators in the Sealer Line area.

CONCLUSIONS

The implementation of the Six Sigma DMAIC method in the Sealer Line process has succeeded in significantly reducing the Sealer Line defect rate. After the implementation of improvements, the DPMO value decreased from 3,851.01 to 1,862.37, and the sigma level increased from 4.17 to 4.41. These results indicate an increase in the stability and quality of the production process in the Paint Shop Department. Four main factors causing defects were identified, namely machines, methods, materials, and humans. Dominant problems include unstable machine air pressure, inaccurate nozzle position, use of materials not according to SOP, and lack of operator understanding and accuracy. Corrective actions through engine temperature regulation (60°–80°C), standardization of procedures, and operator training have proven effective in reducing defects below the 3% target. Overall, the application of DMAIC not only improves the quality of sealer coating results but also reduces rework costs, increases efficiency, and strengthens continuous quality control in the four-wheeled automotive manufacturing process. In addition, the results of this study can also be a reference for further research in the four-wheeled automotive industry, especially in efforts to control the quality of the production process to minimize defect rates and increase manufacturing efficiency.

Table 6. DPMO Value and Sigma Level after Improvement

Month	Number of Units	Number of Defects	DPU	DPO	Yield	DPMO	Sigma Level
June	24,000	590	0.025	0.0022	0.998	2,234.85	4.34296
July	24,000	468	0.020	0.0018	0.998	1,772.73	4.41600
August	24,000	410	0.017	0.0016	0.998	1,553.03	4.45704
Average DPMO and Sigma Level						1,853.54	4.40533

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