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Jurnal Sistem dan Manajemen Industri

ISSN (Print) 2580-2887 ISSN (Online) 2580-2895

Reduced painting defects in the 4-wheeled vehicle industry on product type H-1 using the lean six sigma-DMAIC approach

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ARTICLE INFORMATION

Article history:

Received: October 3, 2023
Revised: November 27, 2023
Accepted: December 27, 2023

Keywords:

DMAIC
Four block diagram
Painting defect
Six sigma
Value stream mapping

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A B S T R A C T

The current era provides challenges for several automotive industries to be able to compete and maintain the quality of their products. For four-wheeled automotive companies, satisfying customers regarding the visual appearance of the vehicle body is very important. However, internally, automotive companies still found many defects or failures in painting, amounting to 32.6%. Apart from that, rework also results in additional costs that the company must incur during the painting process. This study aims to clarify types of painting defects, analyze root causes, provide solutions, improve process capabilities, and increase the sigma level in the painting process in the four-wheeled vehicle industry. This study uses the Lean Six Sigma method, which is integrated into the DMAIC approach and other improvement tools. As a result, this study clarifies four critical defects in the orange peel defects of the painting section, craters, melting, and blur. This study has resulted in several corrective action solutions, including tightening supervision of the performance of painting section operators so that they are consistent and committed to working according to the Standard Operational Procedure (SOP) or work instructions that have been created. A competency matrix is used to evaluate operator performance, which is reported to superiors and subordinates by the supervisory department. After carrying out corrective action, this study increased the process capability from 1.17 to 1.92. The higher the capability value, the higher the sigma level. This study also has increased the sigma level from 2.76 to 3.42, meaning an increase of 78%.

1. INTRODUCTION

In increasingly tight competition, companies are required not only to have high levels of productivity but also to provide products with good quality and competitive prices to consumers [1]. One method that can be used is to reduce production costs to a minimum by reducing defects to maintain the quality of the company's products [2].

One of the companies operating in the auto motive sector prioritizes product quality for each department [3]. Quality implementation is carried out from the Material Supply (MS) department to the Pre-Delivery Customer (PDC) department. At the end of each process, an inspection is always held, and a quality auditor is placed to control the quality of the product [4]. To maintain quality, this automotive company has a Housing Quality Standard (HQS) system version 2000, which contains standard specifications that have been determined from Korea, which are then compiled into a Standard Operating Procedure (SOP) [5].

The vehicles assembled come from components supplied from Korea in the form of CKD (Completely Knock Down). This type of four-wheeled vehicle, type H-1, is an MPV type car that is very suitable to be used as a family car because of its large size and spaciousness, so it can accommodate the family just for walking around or going on holiday somewhere. This type of H-1 four-wheeled vehicle has a newer design and carries contemporary technology, namely a head unit screen that looks floating [6]. Even though it looks big, this car still has a very good exterior design and is not inferior to the design of other MPV cars. By carrying the latest exterior design at this time, this car will be chosen as a family car, and the design presented will also attract other consumers' interest in owning this car [7]. There are several colors that customers can choose from, including artistic white, frosted mocha, metallic silver, and teamless black.

The main challenge that automotive companies often face regarding production quality is that there are still many defects in the production process for each department, especially in the Paint Shop Department (DPS) [8]. For this reason, automotive companies need to improve this situation by looking for the emergence of defects, reducing the variations that cause them, and increasing process capabilities [9].

The phenomenon that has occurred so far with the high percentage of H-1-type car products being reworked shows that the quality of services provided by automotive companies is still not good. Apart from that, rework also results in additional costs that the company must incur during the painting process [10]. Visually, perfect printing attracts customers during customer visits to four-wheeled vehicle displays. Internally, this is a challenge for how the automotive industry can increase productivity, especially in reducing the percentage of body painting defects [11].

Painting is important if carried out with the Standard Operational Procedure (SOP), standards for using paint mixtures, and methods of spraying paint materials onto four-wheeled vehicle bodies [12]. Several studies have examined product failures due to operators not working according to existing SOPs [13]. Some of these product failures immediately become waste, and some are reworked, meaning there are additional costs to improve the defect [14]. It is a motivation for researchers so that This study can hopefully reduce the percentage of defects so that rework on paintings does not occur and productivity can increase.

Based on the background of the problem that has been described, the formulation of the problem in this study is to look for the dominant factors causing defects in type H-1 car products and take action to improve product quality in type H-1 car products. Meanwhile, the limitations of this study problem lie in the research carried out in the Paint Shop Department (DPS) area of a four-wheeled automotive company.

Research on applying the Lean Six Sigma (LSS)-DMAIC approach in various industries has proven a reduction in product defects and increased productivity. Reducing ceiling interference product defects from fans with Six Sigma-DMAIC can increase the sigma score in a better direction [15]. Reducing the dominant defects in the automotive battery production process using the Kaizen approach through 8 PDCA cycles has reduced the percentage of defects from 2.47% to 1.52% [8].

The new approach of this study is the application of the LSS-DMAIC approach combined with other Kaizen methods in terms of actions to improve painting quality in the four-wheeled vehicle industry. This study focuses on LSS and also discusses mapping the stages of the painting process to reduce wastage of process time using the Value Stream Mapping (VSM) method combined with the Kaizen method implementation in a DMAIC approach. This study aims to clarify types of painting defects, analyze root causes, provide solutions, improve process capabilities, and increase the sigma level in the painting process in the four-wheeled vehicle industry.

2. RESEARCH METHODS

Data was collected using historical data, directly observing the body painting work process, and conducting interviews with operators and section heads [16]. There are two ways of collecting data, namely secondary and special. Secondary data such as company history, employment, and organizational structure are

http://dx.doi.org/10.30656/jsmi.v7i2.7512

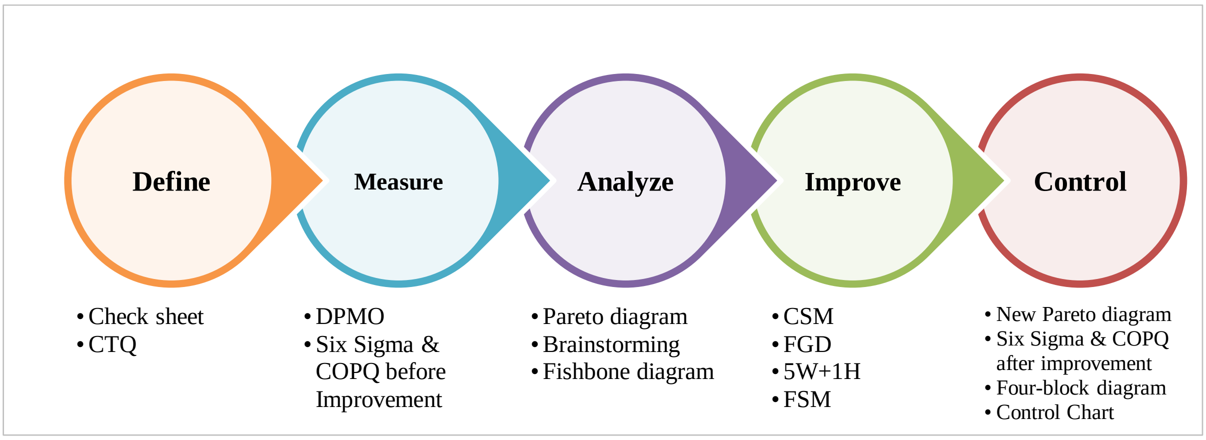

Fig. 1. Research framework

collected. Meanwhile, the special data collected is observation data on the number of production defects, where the data obtained is attribute data, The data is also collected on types of defects, factors causing defects, production processes, and types of machinery [17]. The definition stage is the definition of problems that greatly influence product quality. This Stage contains the definition of the number and types of defects [18].

The study steps used in This study are the LSS method with the Define Measure Analyze Improve Control (DMAIC) stages (Fig. 1). This study is based on the DMAIC approach, where each Stage of the process uses several methods that can solve problems [19].

2.1. Define stage

This Stage uses the improvement tool in the form of a production check sheet on the painting of four-wheeled vehicles and defects for 6 months from July 22 to December 22, to determine the percentage of defects using the formula (1) [2].

$$\%\ Defects = \frac{Defect}{(Defect+Production)}\ x\ 100\% \quad (1)$$

After the percentage of defects is known, the next step is to analyze the types of defects that often appear every month or are called Critical to Quality (CTQ) in the painting section. CTQ is obtained from the types of defects each month, which are added so that the total number of defects for 6 months will be known later.

2.2. Measure stage

This stage uses data processing to calculate the sigma level for 6 months of data before improvement. The sigma level can be known in advance by calculating Defects per Unit (DPU), Total Opportunities (TOP), Defects per Opportunities (DPO), and Defects Per Million Opportunities (DPMO), and the Sigma Level can be known using the formula (2), (3), (4), (5), and (6) [20].

$$DPU = \frac{Defect}{Unit} \quad (2)$$

$$TOP = Production\ x\ CTQ \quad (3)$$

$$DPO = \frac{Defect}{TOP} \quad (4)$$

$$DPMO = DPO\ x\ 1{,}000{,}000 \quad (5)$$

$$Sigma = NORM.S.INV\left(\frac{1{,}000{,}000-DPMO}{1{,}000{,}000}\right) + 1.5 \quad (6)$$

Cost of Poor Quality (COPQ) is a useless activity that can happen again to work to improve it, causing harm to the company [21]. Once the total defects are known, the next step is to calculate the COPQ before improvement using the formula (7), (8) and (9).

$$Scrap\ Cost = Total\ Defect\ x\ \frac{Wasted\ paint}{pcs}\ x\ Paint\ price \quad (7)$$

$$Repair\ Cost = Total\ Defect\ x\ \frac{Repair\ paint}{pcs}\ x\ Paint\ prices + Purchase\ sandpaper \quad (8)$$

$$COPQ = Scrap\ cost + Repair\ cost \quad (9)$$

2.3. Analysis stage

This stage provides research steps in analyzing the most dominant sources of problems using the Pareto diagram. The diagram comes from data processing before improvements from Jul-22 to Dec-22, collected in the previous section as defect analysis results from the types of defects in the painting section. Then the data is entered into Minitab software, especially for processing Pareto diagram data. After knowing the dominant type of defect, the next step is to identify the problem using a cause-and-effect diagram.

Cause and effect diagrams are also often called Fishbone diagrams, which search for the root of the problem by analyzing several factors that will significantly influence the characteristics of improving the quality of defects in the painting part. To determine the fishbone diagram in this study, seven employees who were experienced and had skills above the average were brainstormed, consisting of two operators (working for more than 7 years), two technicians (working for more than 10 years), two leaders (working for more than 7 years). mixing and painting leader has worked for more than 10 years) Moreover, one supervisor has worked for more than 15 years. Fishbone diagrams can be created using Visio software, especially for processing cause and effect diagram data [22], [23].

2.4. Improve stage

In this section, we discuss mapping process stages that could potentially waste processing time, called VSM. Process mapping for each Stage can be created using the Microsoft Visio software application [24]. The initial stage of mapping current conditions is called Current State Mapping (CSM).

After identifying the source and root cause of quality problems, the next step is to plan and take corrective action. These plans and corrective actions increased the sigma level so that the quality of the painting results could be improved. The method used in this study is the 5W+1H method. This method can be created by holding a Focus Group Discussion (FGD) meeting conducted by an odd number of stakeholders to implement a 5W+1H plan to determine future corrective actions [25]. There were five FGD members in this study consisting of one supervisor (who worked more than 15 years), one production manager (who worked more than 10 years), one process engineering manager (who worked more than 12 years), one project manager (worked more than 9 years old) and one warehouse manager (has worked for more than 10 years). The final step in this section is value stream mapping, called VSM for the future state (FSM) after improvements, to map waste on the four-wheeled vehicle painting line. The Microsoft Visio application software can assist in creating process flow maps.

2.5. Control stage

This control stage is carried out after all plans and corrective actions have been carried out. Data processing was taken 6 months from Jan-23 to Jun-23 to make the Pareto diagram after improvement using Minitab software. This control step takes the form of calculating the sigma level after improvement using formulas (2), (3), (4), (5), and (6), and then measuring COPQ after improvement using formula (7), (8), and (9). The next step is to create four-block diagram processes using Visio software. The data displayed in the Visio software regarding the four-block diagram process are the results of the Sigma and DPMO levels (before and after improvements). The difference between the two data will be visible in the four-block diagram [20]. The formula used to control process capability results can use the formula (10), and (11).

$$Zst = Zbench.lt + 1.5 \quad (10)$$

$$Zshif = Zbench.st - Zbench.lt \quad (11)$$

Finally, the control stage makes a control chart for 6 months from Jan-23 to Jun-23 (data after correction). Enter the data processing results into the Minitab software, especially in the P-Chart attribute section. Then, the control chart data will appear graphically in quantities adjusted to the data input [26]. As for calculating the average defect value ($\bar{p}$) or Control Limits (CL), n is the amount of production per month, the Upper Control Limit (UCL), and the Low Control Limit (LCL) can be used by the formula (12), (13), and (14).

$$\bar{p} = \frac{\sum n\bar{p}}{\sum n} \quad (12)$$

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (13)$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad (14)$$

3. RESULTS AND DISCUSSION

3.1. Define stage

This defined Stage is often called the initial Stage, where problems are identified by collecting data or reports [27]. The results of this Stage are production and defect data for Jul-22 to Dec-22 to obtain the percentage of defects. The evidence of production and defect reports is outlined in a check sheet (Table 1). Based on Table 1, to get the defect percentage, they can use formula (1) as in the simulation example for July-22:

$$\%\,Defects = \frac{192}{(192 + 378)}\,x\,100\% = 33.7\%$$

After calculating the 6 months, the average

http://dx.doi.org/10.30656/jsmi.v7i2.7512

defect percentage was 32.6%, meaning that the number of painting defects in automotive companies was still high and did not follow the defect target of 10%. After obtaining the average percentage of defects for 6 months, we can analyze the presence of critical types of defects that always appear every month. Based on Table 2, from the 6 months of data that has been collected regarding production defect data, 4 types of defects have been produced, which are critical defects or called CTQ.

Table 1. Production and defect results before improvement

Month	Production amount	Defect amount	% defect
Jul-22	378	192	33.7%
Aug-22	362	174	32.5%
Sep-22	394	192	32.8%
Oct-22	394	194	33.0%
Nov-22	378	180	32.3%
Dec-22	362	165	31.3%
Amount	2,268	1,097	32.6%

Table 2. CTQ in the painting section

No	Defect name	Amount
1	Orange Peel	432
2	Molting	227
3	Cratering	259
4	Blur	179
Total		1,097

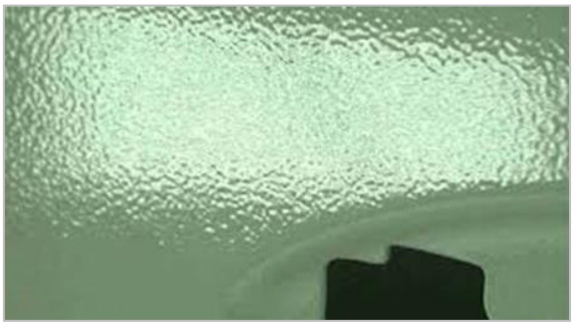

Fig. 2. Orange peel defect

The illustration of the dominant defect above, namely the orange peel defect, can be seen in Fig. 2. The orange peel defect is that the surface of the paint layer is uneven and wavy, like orange peel. Cratering defects are a type of painting damage characterized by small craters on the surface of the paint layer, which spread evenly over the affected area. A mottling defect is that on the surface of the paint layer, there are no uniform spots (for metallic paint) or darker and irregular in color (for colored paint). Meanwhile, the blur's defect is that the paint layer's surface is less shiny and does not reflect light.

3.2. Measure stage

The measurement stages have resulted in several data calculations from data processing [20]. The calculation results in the form of DPU, TOP, DPO, and DPMO can be seen in Table 3. The sigma level result was 2.67, meaning there were still 120,922 defects per one million opportunities.

Table 3. Six sigma measurement results before improvement

Parameters	Unit	Results
Total Productions	pcs	2,268
Total Defects	pcs	1,097
CTQ	defects	4
DPU	unit	0.4837
TOP	opportunities	9,072
DPO	opportunities	0.1209
DPMO	million	120,922
Level Six Sigma	sigma	2.67
Scrap Cost	IDR	27,863,800
Repair Cost	IDR	55,997,600
COPQ	IDR	83,861,400

The simulation calculations (Table 3) can be calculated using formulas (2), (3), (4), (5), and (6). Then measure COPQ before improvement using formulas (7), (8), and (9).

$$DPU = \frac{1.097}{2{,}268} = 0.4837$$

$$TOP = 2{,}268 \text{ x } 4 = 9{,}072$$

$$DPO = \frac{0.4837}{9{,}072} = 0.1209$$

$$DPMO = 0.1209 \text{ x } 1{,}000{,}000 = 120{,}922$$

$$Level\ sigma = NORM.S.INV\left(\frac{1{,}000{,}000 - 120{,}922}{1{,}000{,}000}\right) + 1.5$$

$$Level\ sigma = 2.670$$

$$Scrap\ Cost = 1{,}097\ x \frac{0.1\text{kg}}{\text{pcs}} \text{ x Rp } 254{,}000$$

$$Scrap\ Cost = \text{Rp } 27{,}863{,}800$$

$$Repair\ Cost = 1{,}097 \text{ x} \frac{0.2\text{kg}}{\text{pcs}} \text{x Rp } 254{,}000 + \text{Rp } 270{,}000$$

$$Repair\ Cost = \text{Rp } 55{,}997{,}000$$

$$COPQ = \text{Rp } 27{,}863{,}000 + \text{Rp } 55{,}997{,}600 =$$

$$COPQ = \text{Rp } 83{,}861{,}400$$

3.3. Analyze stage

This analysis stage has resulted in data processing of several defects, as evidenced by the

Pareto diagram. This Pareto diagram shows dominant defects, shown in the diagram on the left or the red block [28]. The Pareto diagram of several painting defects in automotive companies can be seen in Fig. 3. The dominant type of defect is the orange peel defect at 39.4%, meaning that this defect is the largest compared to other defects. The results of this study also reveal the existence of CTQ with 4 types of defects, which are visible on the Pareto diagram.

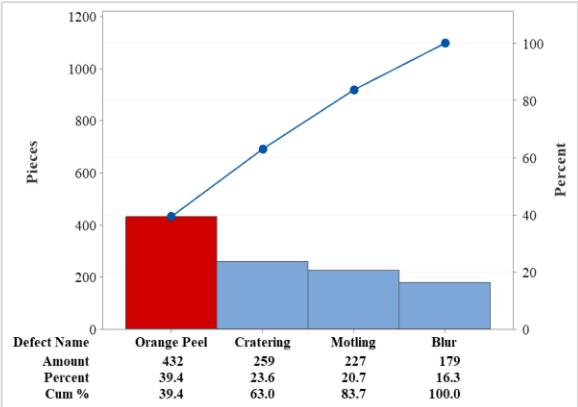

Fig. 3. Pareto diagram before improvement

Fishbone diagrams produce several root cause analyses of several factors, including Man-Machine-Material-Method (4M) and Environment (1E) factors [29], [30]. The fishbone diagram in This study has analyzed the main problem, namely the orange peel defect, where in this diagram, the causes and consequences of the appearance of these defects are analyzed to produce 20 CTQs based on the results of the Fishbone diagram, which are included in the causes and effects of quality reduction (Fig. 4).

3.4. Improve stages

This section produces a mapping of the current condition process stages or CSM in the painting section with Cycle Time (C/T) for one unit of a four-wheeled vehicle (Fig. 5). The improvement involves several corrective actions relevant to the root of the problem through the 5W+1H method [31]. The 5W+1H method can be said to be an effort to overcome all problems that arise in a company. The implementation of 5W+1H with the root causes discussed by the improvement team (Table 4). After Kaizen implementation, the next step is mapping the process time stages in the Future State Mapping (FSM).

The total process time for the painting section is 68 minutes, where the dominant process stages are in the mixing and top coating sections. After carrying out the 5W+1H improvement plan activities as a reference for implementing improvements, the author and the improvement team carried out several Kaizen to improve the root cause of the orange peel painting defect on the body painting part of the four-wheeled vehicle. The Kaizen that has been carried out can be seen in Table 5. After implementing Kaizen, the next step is creating an FSM diagram (Fig. 6). The total painting process time is 57 minutes, which means a decrease from the previous time of 68 minutes. The processing time for painting the body cover of a four-wheeled vehicle has decreased by 16% after repairs.

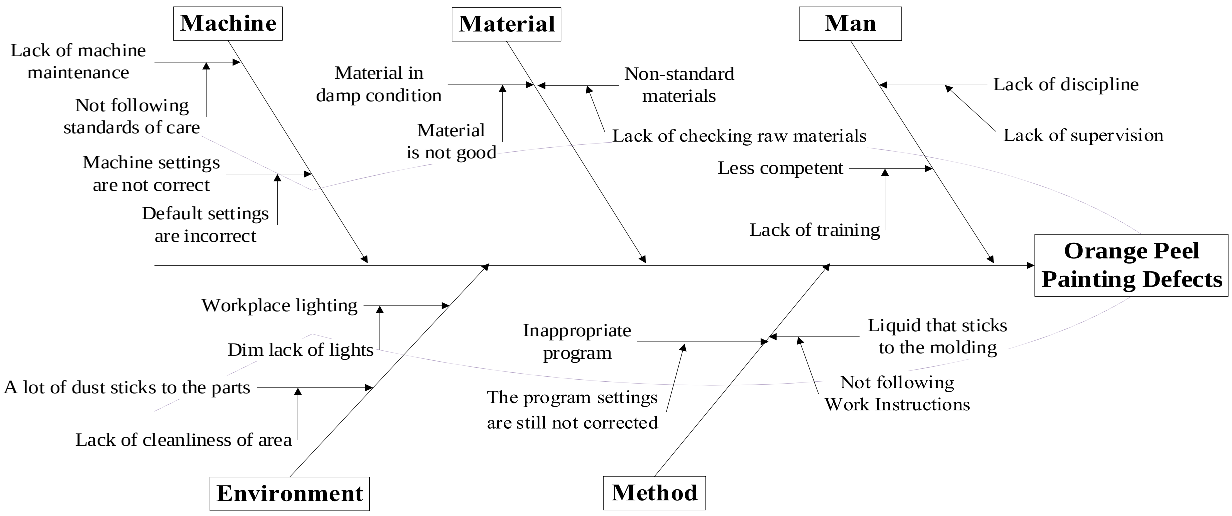

Fig. 4. Fishbone diagram orange peel defects

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Table 4. 5W+1H improvement plan

What	Why	Where	When	Who	How
Material in damp condition	Lack of checks on raw materials	Mixing room	When manpower mixes the paint material	Mixing operator	Carry out work instructions, be more careful when checking paint material mixing, do not use expired paint products, and use new products or new materials.
Manpower is less competent.	Operators are poorly trained.	Mixing room	When manpower mixes the material into the paint	Mixing operator	Carry out daily monitoring regarding operator performance results in the form of a skills competency matrix, which is reported every day before work.
The operator does not follow work instructions	Supervision of operator performance is lacking	Painting area	When manpower paints the vehicle body	Painting operator	Supervise manpower during the mixing process to work according to standard operational procedures set in the mixing process to be more efficient in maintaining quality.
The setting method is not correct.	The spray distance to the vehicle body is too close, and the paint overlap accumulates.	Painting area	When manpower paints the vehicle body	Painting operator	The addition of establishing a standard spray distance between the spray and the vehicle body and a good overlapping position

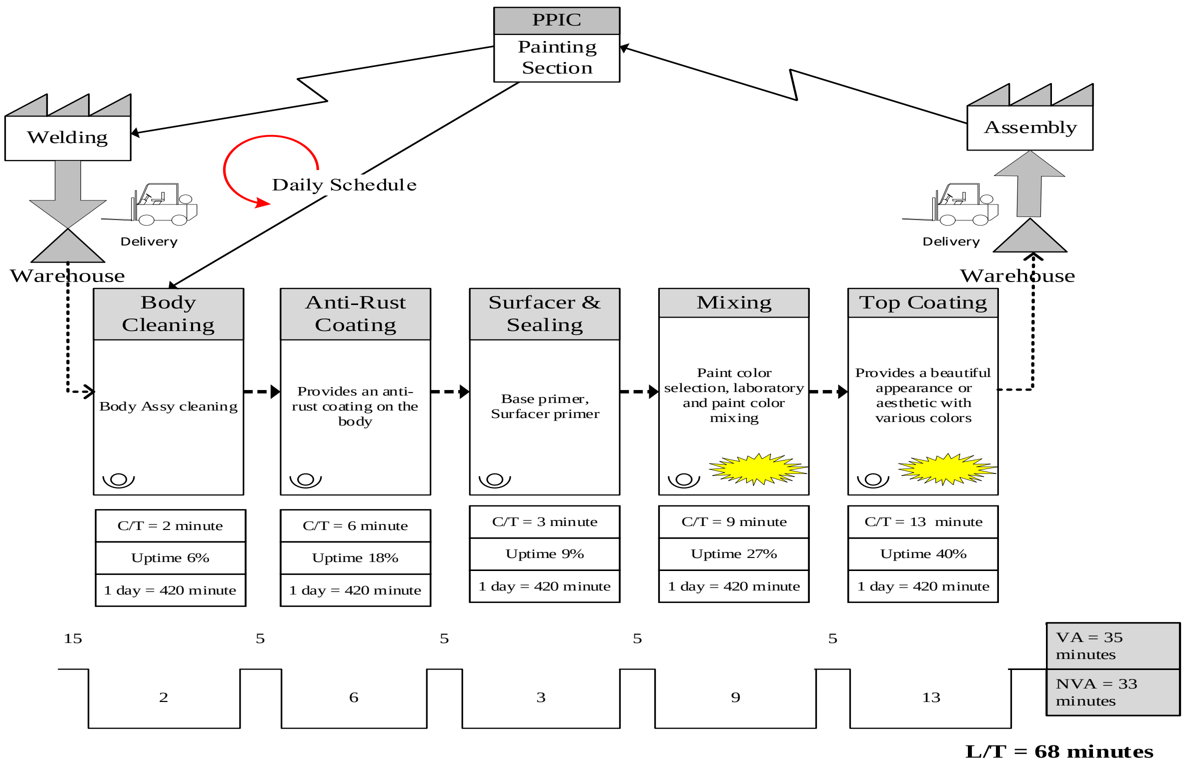
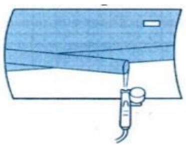
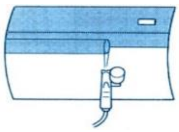
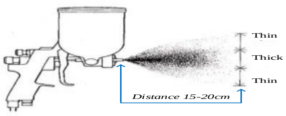


Fig. 5. Current state mapping (CSM)

Table 5. Corrective actions for reducing orange peel painting defects

No	Problem	Before improvement	After improvement	Kaizen remarks
1	Lack of checks on raw materials	 There is no expiration date label on the paint	 Pasting expiry date labels on paint attached to spare parts shelves	Improved methods were adapted to work instructions that the paint material used must not exceed the expiration date of the paint material. Therefore, an expiration date label is made and affixed to each paint material.
2	Operators are poorly trained.	 Training is carried out only when first entering work in the mixing room	 On-the-job training consistently and reporting are informed to employment through the Meiruka board	All paint mixing operators are monitored daily; usually, after mixing, a sample is sprayed onto the body sample. If it is suitable, then production continues. Meanwhile, the mixing operator performance report is documented on the Meiruka board.
3	Supervision of operator performance is lacking.	 There is no sample approval of painting by superiors	 Create a check sheet for painting samples and check them in the sample laboratory before sample approval by superiors	The supervised the performance of mixing operators through a sample approval system, either visual samples or laboratory sample results, so that confirmation of sample accuracy with standards would be controlled.
4	The spray distance to the vehicle body is too close, and the paint overlap accumulates.	 Overlap (overlap) uneven results will result from the layer thickness being also uneven and can cause paint defects.	 The appropriate overlap width is approx. 1/2 to 2/3 spray pattern aimed at maintaining good balance and making consistent overlapping spray pattern	 An addition to the SOP is that the spray gun distance is generally 15-20 cm. For acrylic varnish: 10–20 cm, and for enamel: 15–25 cm. Standard spraying when overlapping paint on the vehicle body

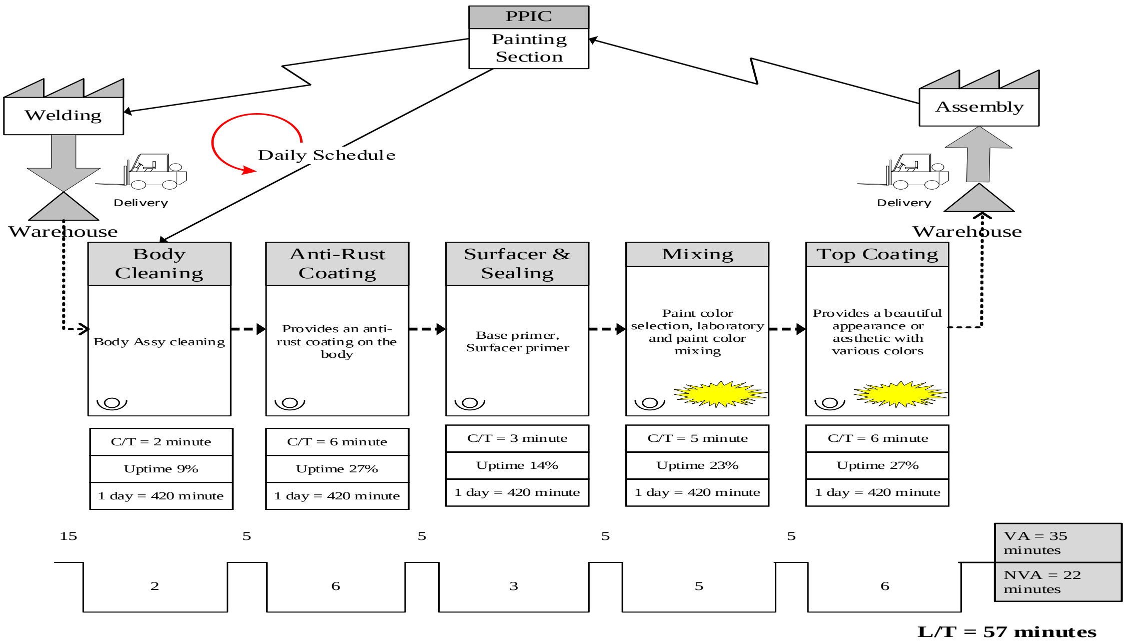


Fig. 6. Future State mapping (FSM)

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3.5. Control stage

This control section has resulted in data processing after improvements due to corrective actions from before this section. Data processing is in the form of production and defect report data for Jan-23 to Jun-23 to obtain the percentage of defects. The evidence of production and defect reports is outlined in a check sheet (Table 6). The percentage of defects was 9.8% for 6 months, showing a reduction of 332.6%. After being improved using the 5W+1H method, every root problem found is immediately improved appropriately and correctly [32].

Table 6. Production and defect results after improvement

Month	Production amount	Defect amount	% defect
Jan-23	397	46	10.4%
Feb-23	386	43	10.0%
Mar-23	410	41	9.1%
Apr-23	423	43	9.2%
Mei-23	399	42	9.5%
Jun-23	382	45	10.5%
Amount	2,397	260	9.8%

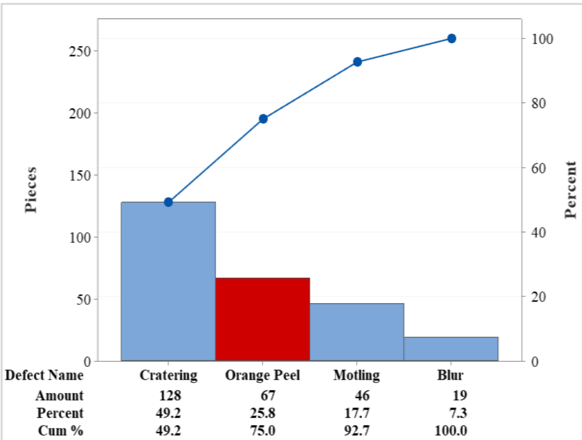

Fig. 7. Pareto diagram after improvement

Based on Fig. 7, there is a decrease in the number of dominant defects from previously orange peel by 39.4% to 25.8% or a decrease of 34.5%. Meanwhile, the dominant defect after this improvement becomes a cratering defect of 49.2% and will be the focus of improvement by the team in the following improvement stage. Meanwhile, the Six Sigma level calculation can be seen in Table 7. The sigma level results obtained are 3.42, meaning there are still 27.117 damages/defects per one million opportunities.

Table 7. Six sigma measurement results after improvement

Parameters	Unit	Results
Total Productions	pcs	2,397
Total Defects	pcs	260
CTQ	defects	4
DPU	unit	0.1085
TOP	opportunities	9,588
DPO	opportunities	0.0271
DPMO	million	27,117
Level Six Sigma	Sigma	3.42
Scrap Cost	IDR	6,604,000
Repair Cost	IDR	13,478,000
COPQ	IDR	20,082,000

This study also resulted in a decrease in COPQ, which, before improvements, the company incurred costs of IDR 83,861,400 to IDR 20,082,000. The company has saved painting repair costs of IDR 63,779,400, or a decrease of 76%.

After knowing the sigma level before and after improvement, the next step is calculating the four-block diagram. This four-block process diagram shows the company's performance in each section, especially in the painting section of this study. A process that states the direction of improvement on two sides, namely the technology direction and the control direction, represents the process capability (Z) of a currently running process. The process capability calculation can be taken from the sigma level results before improvement, namely 2.67 sigma, and the sigma level results after improvement, namely 3.42 sigma.

Four block diagrams can be calculated with the Zshif value as control capability and the Zst value, which reflects technological knowledge, and then plotted in four block diagrams which show the ongoing process capability (Z). Zshif and Zbench before improvement can be calculated with a four-block diagram using the formulas (7) and (8).

$Zst = Zbench.lt + 1.5$

$2.67 = Zbench.lt + 1.5$

$Zbench.lt = 2.67 - 1.5 = 1.17$

$Zshif = Zbench.st - Zbench.lt$

$Zshif = 2.67 - 1.17 = 1.5$

After improvement, Zshif and Zbench can be calculated with a four-block diagram using the

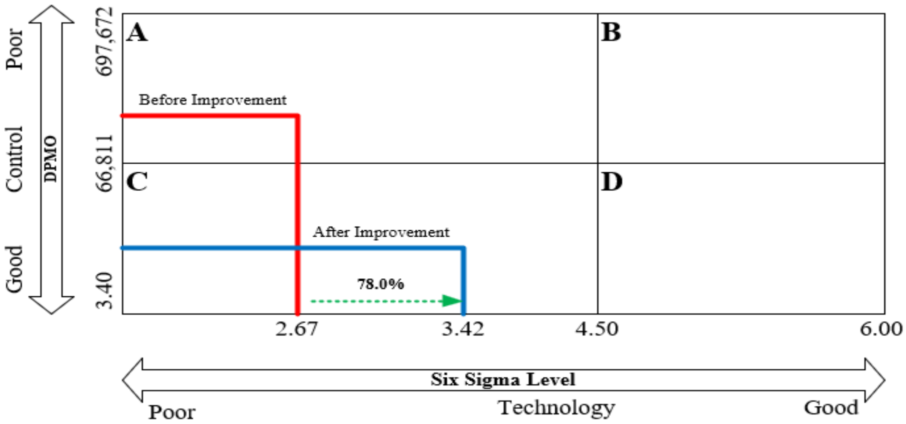

Fig. 8. Results of the four-block process diagram before and after improvement

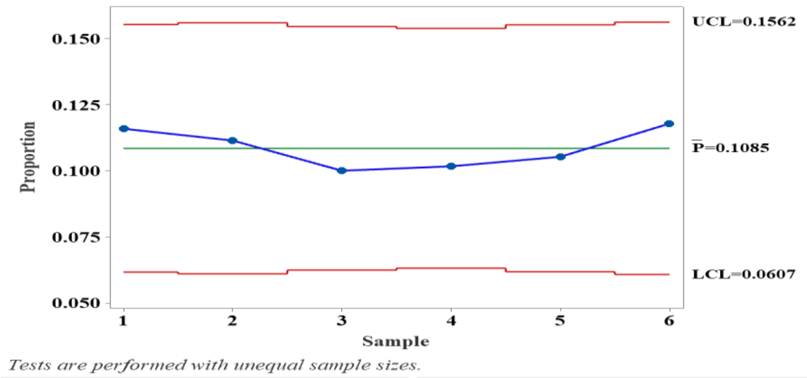

Fig 9. Chart of defects after improvement

formulas (7) and (8).

$Zst = Zbench.lt + 1.5$

$3.42 = Zbench.lt + 1.5$

$Zbench.lt = 3.42 - 1.5 = 1.92$

$Zshif = Zbench.st - Zbench.lt$

$Zshif = 3.42 - 1.92 = 1.5$

The results of the four-block process diagram in the form of a diagram can be seen in Fig. 8. The four-block process diagram has increased by 78.0%, meaning that the corrective actions taken have been successful and can reduce painting defects. Furthermore, the control chart method is used after improvements to monitor the percentage of defects (Fig. 9).

3.6. Discussion

Production optimization is a process of activities to increase the output or amount of production in an industry [33]. Optimization in increasing production capacity is done in many ways, including reducing product defects or production waste [34]. Research on reducing defects in various industries has been widely conducted to increase employee productivity and performance in producing automotive spare parts in these companies [24], [35]. The use of the Six Sigma method in the DMAIC approach to reduce defects in the manufacture of car panels in the automotive industry in the assembly process has succeeded in increasing the Sigma level from 2.90 to 5.20 due to the consistent implementation of Total Quality Management (TQM) and International Standard Operational (ISO) [36]. Another research that combines the DMAIC approach with the Kaizen approach in the garment industry has increased the sigma level from 3.70 to 3.96, an increase of 7% [21].

This study uses the DMAIC approach, which in each Stage uses several methods, including the LSS method and other methods such as FGD, Pareto diagram, Fishbone diagram, VSM, 5W+1H, control chart, and process capability diagram. This study has reduced the percentage of painting defects in the process of painting four-wheeled vehicle bodies. Apart from reducing the percentage of painting defects, this study has

http://dx.doi.org/10.30656/jsmi.v7i2.7512

narrowed down the process stages that contribute to excessively long processing times, namely the mixing and top coating sections. After improving the processing time, the painting process time was reduced by 16%, and repainting costs were reduced by 76%.

The contribution of this study includes quality and reliability engineering, where the main focus is quality improvement to reduce defects in the painting area. Reducing the percentage of product defects is indicated by an increase in the sigma level so that painting defects can be reduced and employee performance productivity can be increased. This study explains more about an activity to improve the quality of body painting products to reduce painting defects, both reducing the percentage of defects and increasing the sigma level. The success of this study conceptually uses the DMAIC approach combined with several improvement tools, including the LSS method.

The theoretical implications of this study can provide additional insight regarding references for future researchers related to defect improvement using the LSS-DMAIC approach. Meanwhile, the practical implications of this study can be used as a reference by other four-wheeled vehicle industries, where This study has successfully reduced product defects. The industry must always carry out continuous improvement activities, especially improving product quality. Applying the LSS-DMAIC approach is very important for the industry to achieve productivity targets and reduce production defects, lead time process, and COPQ so that the automotive industry, in terms of productivity, remains high to meet increasing customer orders.

4. CONCLUSION

This section discusses the conclusions that can be explained following the results of previous research. This study has found that several defects often appear at 6 months, namely the types that cause a high percentage of painting defects, including orange peel, cratering, melting, and blur. After analyzing and processing the data, the dominant defect in the painting section in the automotive industry was the orange peel defect.

This study resulted in several corrective action solutions, including tightening supervision of the performance of painting section operators so that they are consistent and committed to working according to the SOP or WI that has been created. A competency matrix is used to evaluate operator performance, which is reported to superiors and subordinates by the supervisory department and documented on the Meiruka board. The addition sets standards for the spray distance between the sprayer and the vehicle body and a good overlap position. After taking corrective action, this study increased the process capability from 1.17 to 1.92. The higher the capability value, the higher the sigma level. This study also has increased the sigma level from 2.76 to 3.42, meaning an increase of 78%. This study has also reduced the company's cost to IDR 63,779,400 every six months and has reduced the painting process time by 16%. In this way, the company has benefited from saving repair costs and reducing waste of time in the body cover painting process in the four-wheeled vehicle manufacturing industry.

In the future, the researcher recommends that further research be aimed at reducing wasted time transferring chemical painting material to the spraying cabin and reducing production defects in cratering painting defects by using integration between LSS because there are still opportunities for improvement to be more effective and efficient with use industry 4.0 management in the four-wheeled vehicle industry.

ACKNOWLEDGMENT

Researchers would like to express their gratitude to the four-wheeled vehicle manufacturers who have provided the time and opportunity for research into the automotive industry which has been carried out consistently for 6 months.

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