

Article

Tractor Paint Quality Control By Integrating The Six Sigma Method And Fail Mode And Effect Analysis (FMEA) PT. XYZ

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Abstract: PT. XYZ is a company engaged in assembling agricultural machinery, namely four-wheeled tractors. The components of the four-wheeled tractor itself consist of the front wheels, rear wheels, engine, engine cover, chassis/frame, steering floor, steering seat, fenders, pedals and roof. For parts that will be assembled, the painting process is carried out within the company itself. Therefore, during the painting process, several problems arise, namely differences in color, paint thickness and paint strength. The painting process at this company has not yet reached zero defects, because several defects were still found in the fenders, floor (steering floor), and engine cover. Situations like this can result in increased production costs and decreased product quality, which ultimately reduces profitability. The aim of this research is to find out the main factors that cause defects in painting parts and make appropriate suggestions/improvements to reduce and prevent defects in the painting process. The method used is the Six Sigma method and the FMEA (Failure Mode Effect and Analysis) method. Six Sigma in technical methods is oriented towards a statistical approach to calculating product defects. The goal is to reduce process variance by eliminating defects that interfere with customer satisfaction. FMEA is a technical analysis which, if carried out correctly and at the right time, will provide great value in helping the decision making process. The research results show that the average DPMO value for tractor product production on weekdays from January 1 2023 to April 30 2023 is 107618.46 with an average sigma value of 2.74. The recommendation for improvement from the FMEA method is that the cause of the defect with the highest RPN value is painting that does not comply with the SOP of 576. The proposed improvement for the cause of this defect is supervision of painting employees.

Keywords: Product Quality, Six Sigma, Failure Mode Effect Analysis (FMEA)

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1. Introduction

PT. XYZ, located at PIER Pasuruan, is a company engaged in the production of agricultural equipment, with its main product being four-wheeled tractors. For the domestic market, the products of this company are not yet well-known because they have not been marketed, and the company focuses on international markets such as Thailand, Vietnam, Europe, and North America. Currently, the company is capable of producing 138 units per day. As an automotive manufacturing company, PT XYZ prioritizes quality above all else. Therefore, for exterior parts such as the Hood Comp (engine cover), Floor (footrest while driving), and Fender (wheel cover) on the tractor itself, special treatment is applied [1].

The production processes in this company are incoming inspection or raw material (spare part) checks, production preparation, sub-assembly, painting, main assembling, final product inspection, and packing [2]. From these processes, defects often occur in the

exterior painting and generate waste that is detrimental to the company [3]. Defects caused by paint can affect the durability of tractor products, as the paint on tractors serves to protect the parts from corrosion or rusting [4]. As a result, the company experiences a decline in production quality due to the high defects during the painting of tractor products [5]. Several factors causing defects in the production process are errors in part selection, damaged raw materials, and non-compliance with the company's established SOP.

Defects in the tractor painting process have received complaints from subsequent processes within the company, as these defects can determine the longevity of the tractor's exterior parts [6]. In the last 4 months (January, February, March, and April), defects were found in 3 part items, namely the fender, engine cover, and floorboard/steering floor [7]. From the data obtained, the total defects were 1421 for color differences, 1530 for paint thickness, and 1975 for paint durability [8]. Thus, the function of quality control plays a very important role for the company in improving and enhancing product quality to meet the planned standards, because the quality of a product is a determining factor in the rapid or slow development of a company that implements quality control [9].

Research related to the use of the six sigma and FMEA methods refers to previous studies, namely, Quality control of clarisa products using the lean six sigma method and the FMECA method [10]. Analysis of the characteristics of carbon residue and sulfur content in biosolar oil products using the six sigma approach [11]. Proposal for the implementation of lean six sigma, FMEA, and fuzzy to improve the quality of liquid soap bottle products [12]. The six sigma, FMEA, and kaizen approaches as efforts to improve the quality of metal casting production at PT. Mitra Rekatama Mandiri [13]. Model for determining quality control in plate production using the six sigma and fuzzy FMEA methods [14].

Therefore, the appropriate methods for controlling product quality and reducing the number of defective products in this study are the Six Sigma method and the Failure Mode and Effect Analysis (FMEA) method, because the Six Sigma method and the Failure Mode and Effect Analysis (FMEA) method focus more on improvement, error reduction, and minimizing defective products. This research uses data over a period of 4 months, specifically from January to April 2023. The method can also provide recommendations to the company to improve production quality, especially during the painting process of tractor parts [15].

2. Materials and Methods

This research was conducted at PT. XYZ Jl. Kraton Industri Raya No.11 PIER Pasuruan. This research will be conducted over a period of 4 months from January to April 2023. The method in this study can be seen in Figure 1 as follows.

According to Fidha (2019), the formulas used in six sigma to calculate the Central Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) are as follows [16]:

Calculating CL using the following formula:

$$CL = \bar{p} = \frac{\sum Np}{\sum n} \quad (1)$$

Where:

$\sum Np$ = Total number of disabilities

$\sum n$ = Total number checked

Calculating UCL using the following formula:

$$UCL = \bar{p} + 3 \frac{\sqrt{p(1-p)}}{n} \quad (2)$$

Where:

\bar{p} = Proportion of defects/ defective products

n = Average number of products over the entire period

Calculating LCL using the following formula:

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

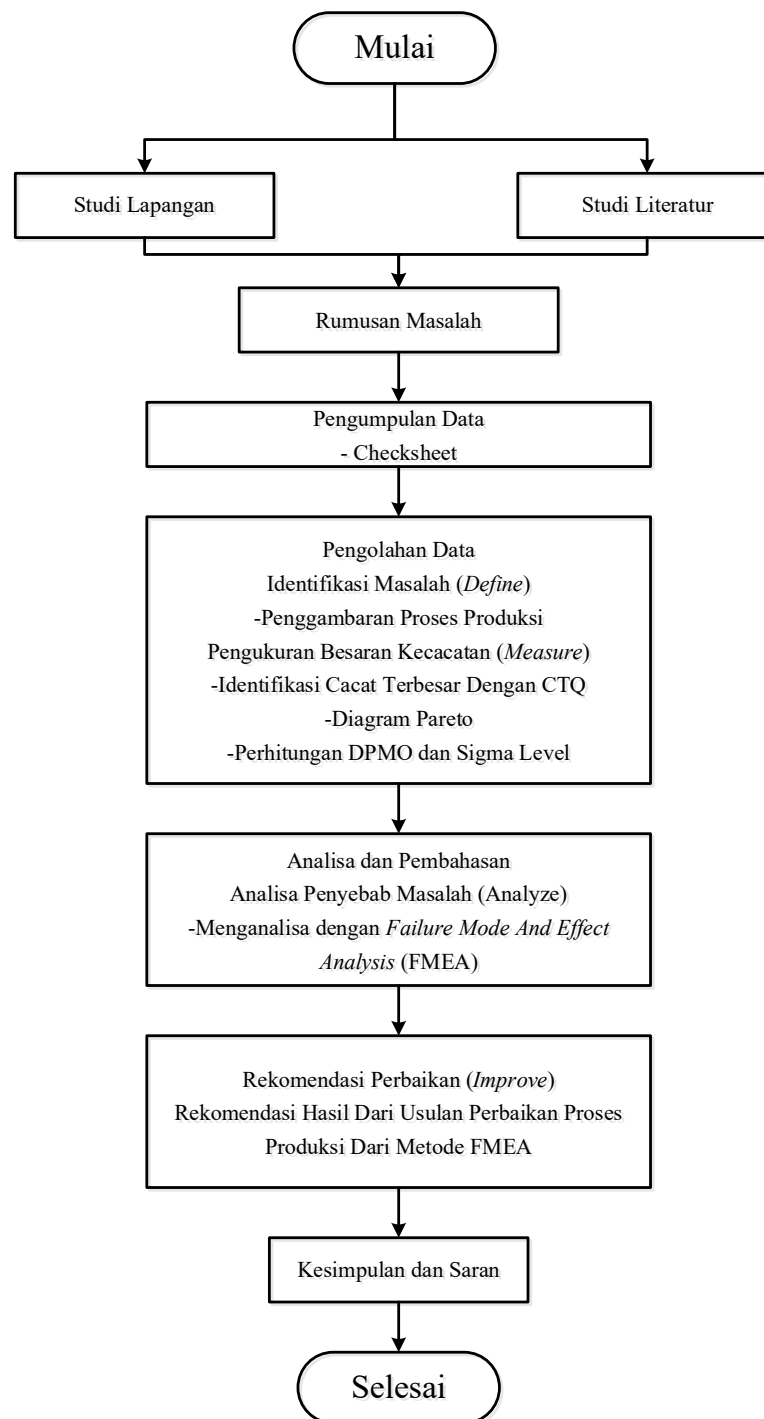


Figure 1. Research Method

In Figure 1, the research flowchart explains the research process, which begins with problem identification through field studies and literature reviews. After that, data is collected and processed. The first step in data processing is defect data processing (Measure), identifying the largest defects using Critical to Quality (CTQ), creating a Pareto diagram, and calculating Defect Per Million Opportunity (DPMO) and Sigma Level. Based on the Six Sigma method calculations, defective products are analyzed by implementing Failure Mode and Effect Analysis (FMEA) to obtain the Risk Priority Number (RPN) value to identify the root cause of defects through weighting. Thus, recommendations are obtained that can be proposed for continuous improvement to the company and product quality enhancement. In FMEA, to determine improvements, the RPN (Risk Priority Number) is calculated by

multiplying the severity, occurrence, and detection levels, each of which is assigned a value or score [17]. RPN (Risk Priority Number) This RPN indicates the priority level of a failure obtained from the analysis results of the analyzed process. According to the RPN value, the failure mode is the prioritized corrective action and will be proposed for the highest RPN value. After the implementation of corrective actions, the new RPN value will be calculated for each failure, thus increasing the priority order. The classification of S O D can be seen in the following table 1.

Table 1. RPN Assessment Classification

Severity Value	Value Classification	Severity Value	Classification	Occurrence Value	Detection Value Classification
10	Extreme	10	Almost certain to happen	10	Almost impossible
9	Serious	9	Very high	9	Almost none
8	Very significant	8	High	8	Very low
7	Significant	7	Quite High	7	Tends to be low
6	Moderate	6	Medium	6	Low
5	Low	5	Moderately enough	5	Medium
4	Very low	4	Small	4	Tending to be high
3	Minor	3	Very small	3	High
2	Very minor	2	Almost never	2	Very high
1	None	1	Rare	1	Almost certainly detected

Source: [18]

In Table 1, the classification of the RPN (Risk Priority Number) assessment is presented using the calculation values from S O D. The values are divided as follows:

1. S is the severity rating.
2. O is the occurrence level value.
3. D is the value of the detection level.

3. Results

A. Define

The production processes at this company are incoming inspection or raw material (spare part) checks, production preparation, sub-assembly, painting, main assembling, final product inspection, and packing. From these processes, defects often occur in the exterior paint and generate waste that is detrimental to the company. Defects caused by paint can affect the durability of tractor products, as the paint on tractors serves to protect the parts from corrosion or rust. As a result, the company experiences a decline in production quality due to the high defect rate during the painting of tractor products. In this study, the type of defect used is the defect in the paint on the tractor. Classification of the types of defects in tractor paint quality as shown in Table 2 is as follows.

Table 2. Classification of Types of Disabilities

Period	Total Production	Total Disability	Type of Disability		
			Color Difference	Paint Thickness	Paint Durability
January	3835	1191	357	364	470
February	3856	1270	360	392	518
March	3730	1180	330	370	480
April	3511	1285	374	404	507

Source: Data PT. XYZ

In Table 2, the classification of defects in tractor production at PT. XYZ includes 3 types of defects, namely: color differences, paint thickness, and paint durability. The results are data obtained from January to April 2023. The classification data in Table 2 is used to identify the sigma value, pareto chart, and control chart in the production of the company.

B. Measure

Measure stage The first step is to input the proportion value into the control chart (P-Chart) to measure the control level over the defects experienced by the company. The step that must be taken is to first calculate the values of CL, UCL, and LCL, which are useful as control value determinants. Here are the mathematical formulas and an example calculation using data from this research. The CL calculation is as follows:

$$\begin{aligned} \text{CL} &= \bar{p} \\ &= 4926 / 14932 \\ &= 0,3299 \end{aligned}$$

The UCL calculation is as follows:

$$\begin{aligned} \text{UCL} &= 0,3299 + 3 \frac{\sqrt{0,3299(1-0,3299)}}{3733} \\ &= 0,3299 + (3 \times 0,01343) \\ &= 0,3299 + 0,0403 \\ &= 0,3702 \end{aligned}$$

Perhitungan LCL adalah sebagai berikut:

$$\begin{aligned} \text{UCL} &= 0,3299 - 3 \frac{\sqrt{0,3299(1-0,3299)}}{3733} \\ &= 0,2685 - (3 \times 0,01343) \\ &= 0,2685 - 0,0403 \\ &= 0,2896 \end{aligned}$$

The next step is to classify the calculation results of determining the values of Central Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) as shown in Table 3 below.

Table 3. Determination of Central Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) values

No	Period	Production Quantity	Disabled	Propose	UCL	LCL	CL
1	January	3835	1191	0,3106	0,3702	0,2896	0,3299
2	February	3856	1270	0,3294	0,3702	0,2896	0,3299
3	March	3730	1180	0,3164	0,3702	0,2896	0,3299
4	April	3511	1285	0,3660	0,3702	0,2896	0,3299
	Total	14932	4926	1,3223			
	Average	3733,0	1232	0,3299			

In Table 3, the results of the calculations for the Central Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) values are obtained. After the values of CL, UCL, and LCL from the table above are known, the data will then be presented on the P-Chart to determine whether the data being studied is in control or not. Here is the P-Chart control map that can be seen in Figure 2 below.

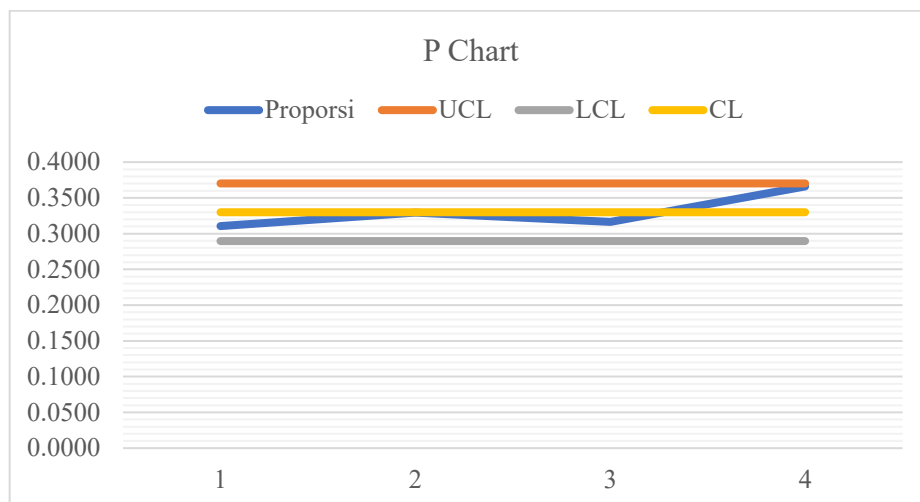


Figure 2. P-Chart

In the control chart P-Chart in Figure 2 above, it is known that all data fall within the control limits, so all data processing can continue to the next processing stage. All proportion values are within the normal limits, which do not exceed the UCL and LCL boundaries. So, to determine which month has higher production process issues, we need to calculate the sigma value.

At the measurement stage, potential Critical To Quality (CTQ) is determined as a characteristic that affects quality and is directly related to customer satisfaction, and the performance baseline is measured through DPMO (Define Per Million Opportunities) measurement, which is then converted into sigma levels.

The next step is to assess the sigma level, which requires knowing the DMPO value first. The DPMO (Defects Per Million Opportunities) value is the proportion of errors per million opportunities. This DPMO measurement is an excellent measure for determining product quality because it is directly related to defects, costs, and wasted time during the production process. Here is an explanation of the DPMO calculation, which can be seen in the formula and example calculations for January:

1. DPU calculation formula (*Deffect Per Unit*) January

$$\text{DPU} = \text{Total defects} / \text{total units} \quad (4)$$

$$\text{DPU} = 1191 / 3835 = 0,3106$$

2. Calculation formula *Yield* January

$$\text{Yield} = 1 - \frac{\text{Jumlah produksi cacat}}{\text{Hasil produksi}} \times 100\% \quad (5)$$

$$\begin{aligned} \text{Yield} &= 1 - (1191/3835) \times 100\% \\ &= 1 - (0,3106) \times 100\% = 68,94\% \end{aligned}$$

3. Calculation formula DPO (*Deffect Per Opportunities*)

$$\text{DPO} = \frac{\text{Total kecacatan}}{\text{Total unit} \times \text{CTQ}} \quad (6)$$

$$\text{DPO} = 1191 / (3835 \times 3) = 0,1035$$

4. Calculation formula DPMO (*Deffect Per Million Opportunities*)

$$\text{DPMO} = \text{DPO} \times 1.000.000 \quad (7)$$

$$\text{DPMO} = 0,1035 \times 1.000.000 = 103520,21$$

Table 4. Sigma Value Classification

Month	Production Quantity	Disabled	DPU	Many CTQs	% yield	DPO	DPMO	Sigma level
January	3835	1191	0,3106	3	68,94%	0,1035	103520,21	2,76
February	3856	1270	0,3294	3	67,06%	0,1098	109785,62	2,73
March	3730	1180	0,3164	3	68,36%	0,1055	105451,30	2,75
April	3511	1285	0,3660	3	63,40%	0,1220	121997,53	2,67

Average

107618,46

2,74

In the results of table 4, different sigma values were obtained. The higher the sigma value, the lower the likelihood of a product defect occurring. Conversely, the smaller the sigma value, the higher the likelihood of defects occurring. In April, the sigma value was 2.67, which means that the defect rate for that month was higher compared to other months. Therefore, in April, attention needs to be given to the production process because it has the lowest sigma level, indicating a higher defect rate compared to other months.

Next is to identify the potential Critical To Quality (CTQ) that most affects the total defects each month. Here is the percentage of defects from the total defects produced over three months of production as shown in Table 5.

Table 5. Percentage of Disabilities

Type of Defect	January	February	Marvh	April	Total	Percentage	Cumulative percentage
Colour Gradient	357	360	330	374	1421	29%	29%
Thickness	364	392	370	404	1530	31%	60%
Paint Durability	470	518	480	507	1975	40%	100%

In Table 5, the defect percentages for each CTQ were obtained to generate a Pareto diagram from the table results. The percentage has a cumulative percentage used to determine which defect rate is significantly high. After creating the defect percentage, the next step will be determining the critical to quality (CTQ) using a Pareto diagram. Here are the results of the Pareto diagram that can be seen in Figure 3 below.

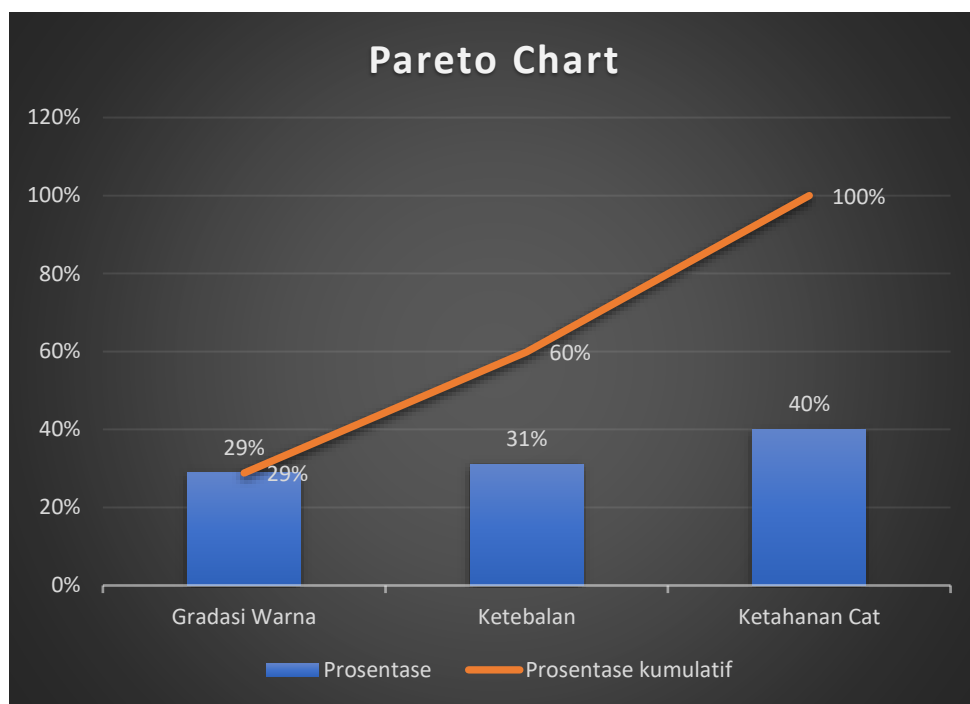


Figure 3. Pareto Chart

In Figure 3, the Pareto diagram shows that out of 4 defects, there are 2 types of defects that have a very significant impact on the defect rate in the garment production process, namely loose stitches and uneven stitches. It can be said that the CTQ or Critical to Quality values are loose stitches and uneven stitches.

C. Analyze

In the analyze stage, it is the process of finding the causes of defects in tractor production, specifically in tractor paint. The method used at this stage is Failure Mode and Effect Analysis (FMEA), which serves to determine the ranking of defect causes from highest to lowest. The results can be used for the improvement process to determine alternative solutions. The FMEA method as shown in Table 6 is as follows.

Table 6. Failure Mode and Effect Analysis (FMEA)

Production Process	Cause of Failure Mode	S	O	D	RPN	Clasificación
Raw Material Inspection	Some of the raw materials are defective and were missed.	7	5	5	175	8
	The raw materials were damaged during inspection.	4	5	5	100	13
Production Preparation	The inspection of the production machine was not thorough.	4	6	5	120	12
	Incomplete raw materials	5	6	5	150	11
Sub Assy	Small part does not match	7	6	5	210	7
	Small part is not enough	7	7	6	294	4
Painting	The paint does not meet the standard.	7	7	8	392	3
	The machine is malfunctioning.	8	8	8	512	2
	Painting does not comply with SOP.	9	8	8	576	1
Main Assembling	Main part is not compliant	6	7	5	210	6
	Main part is insufficient.	6	6	6	216	5
Final Inspection	Product inspection is not optimal.	7	5	5	175	9
Product Packing	Damaged packaging	6	5	5	150	10

In Table 6, the RPN (Risk Priority Number) results for each failure occurring in the tractor production processes at PT. XYZ were obtained. From each production process, different failures were experienced. In Table 6, it is used to find the RPN value for each failure. Observations were conducted to determine S (Severity), O (Occurrence), and D (Detection), resulting in different RPN values. In Table 6, the highest RPN value was obtained for painting not following SOP, which was 576. The second highest RPN value is on the problematic machine at 512. The third highest RPN value is for paint not meeting standards, at 392.

Based on the reference from Table 1, for example, the first failure in Table 6 has S O D values of 7, 5, and 5 respectively, with an RPN of 175. This means that the failure has a severity value or seriousness level that is significant, leading to potential performance degradation due to suboptimal function, potential occurrence of defective products, and potential stoppage due to other failures. The occurrence value is the frequency of the failure's occurrence, which is at a moderate level, resulting in a moderate occurrence rate. Meanwhile, the detection value is a measure of the ability to control failures at a moderate level, which means the control is not yet effective. Here is an example of RPN calculation using the formula:

$$\begin{aligned} \text{RPN1} &= S \times O \times D \quad (8) \\ \text{RPN1} &= 7 \times 5 \times 5 \\ &= 175 \end{aligned}$$

D. Improve

In Table 6, the values have been sorted from highest to lowest to determine the level of risk faced by the company if improvements are not made immediately. The results in that table show that the RPN values above 200 are ranked from 1 to 7. The highest ranking is in the washing process with an RPN of 576, specifically in the painting not following

SOP, which causes a delay in tractor production. The description of the RPN value category is based on the detailed values in Table 7:

Table 7. RPN Value Category

Risk Level	RPN Value Scale
<i>Very Low</i>	$x < 20$
<i>Low</i>	$20 \leq x < 80$
<i>Medium</i>	$80 \leq x < 120$
<i>Hight</i>	$120 x < 200$
<i>Very Hight</i>	$x \geq 200$

Source: [19]

The categorization of RPN values in Table 3 helps the company to choose which risks should be addressed first based on the highest/most critical risk values. Out of the 13 identified risks, there are 7 factors that have a very high risk value. Therefore, these 7 risks will be provided with improvement alternatives to give the company options to find solutions for maintaining or even enhancing the quality value of the product. Here are the improvement suggestions as shown in Table 8.

Table 8. Improvement Proposals

No	<i>Cause of Failure Mode</i>	Proposal for Improvement
1	Small part does not match	Supervision during the production process
2	Small part is not enough	Inspection before the production process
3	The paint does not meet the standard	Supervision in paint selection
4	The machine is malfunctioning.	Regular machine maintenance
5	Painting does not comply with SOP.	Supervision of painting employees
6	Main part is not compliant	Supervision during the production process
7	Main part is insufficient.	Inspection before the production process

E. Control

The control stage is the final stage of the DMAIC (Define, Measure, Analyze, Improve, and Control) cycle. At this stage, control is carried out on what has been analyzed in the Analyze stage and after the implementation of improvement proposals in the Improve stage. Control is carried out with re-measurement like the Measure stage but after the improvements have been made. What needs to be done in this stage is:

1. Recalculate the DPMO (Defects Per Million Opportunities) value on the waste that has been improved.
2. After the results are obtained, if there is an increase in the sigma level, it needs to be continuously monitored. However, if there is still no change, the Analyze phase needs to be conducted again and the Improve phase needs to be determined. Similarly, it should be done repeatedly.

F. Recommendations to the Company

Recommendation for PT. XYZ on tractor production regarding paint quality is to improve the supervision of the production process in April. In that month, the sigma value

was the lowest among all months in this study. The smaller the sigma value, the greater the occurrence of defects. In the painting process, the highest defect type is paint durability, which has a percentage of 40%. Therefore, the paint durability requires close monitoring by PT. XYZ to improve. The improvement recommendation from the FMEA method is that the cause of defects with the highest RPN value is painting not according to SOP, which is 576. The proposed improvement for the cause of the defect is supervision of the painting employees.

4. Discussion

The Six Sigma DMAIC methodology successfully identified key quality issues in PT. XYZ's tractor painting process. Analysis of the data from January to April 2023 revealed that the paint defects were highest in April, with a sigma level of 2.67, indicating poor process performance.

The defects were primarily due to three factors: color inconsistency, paint thickness, and paint durability, with paint durability being the most significant, accounting for 40% of defects. This directly impacts the tractor's ability to resist corrosion and weathering.

Using tools like the P-Chart and Pareto analysis, it was evident that the painting process was within control limits but still underperforming. FMEA analysis revealed that the highest risks were related to non-compliance with SOPs, faulty equipment, and improper paint selection, which contributed to the defects.

The proposed improvements focus on enhanced supervision, equipment maintenance, and stricter adherence to SOPs to address these issues and reduce defects in future production.

5. Conclusion

The average DPMO value for tractor product production on working days from January 1, 2023, to April 30, 2023, is 107,618.46 with an average sigma value of 2.74. For Critical to Quality (CTQ) in tractor product production with values above 10%, namely color difference (29%), paint thickness (31%), and paint durability (40%). Recommendation for PT. XYZ in tractor production regarding paint quality is to improve production process supervision in April. In that month, the sigma value was the lowest among all months in this study. The smaller the sigma value, the greater the defects occur. In the painting process, the highest defect type is paint durability, which has a percentage of 40%. Therefore, the paint durability requires close monitoring by PT. XYZ to reduce it. The improvement recommendation from the FMEA method is that the cause of defects with the highest RPN value is painting not according to SOP, which is 576. The proposed improvement for the cause of the defect is supervision of the painting employees.

The suggestion in this research is to further incorporate the process capability formula used to measure the ability of a process to show how close a particular process can deliver results to the required specifications in the six sigma process, and in FMEA, to add other tools such as kaizen to design strategies for improving production quality.

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