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

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ABSTRACT

Objective: *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.* ***Methods:*** *The Method employed is that 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.* ***Results:*** *The Results show that 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.* ***Novelty:*** *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. The Novelty is derived from the specific application and findings of the Six Sigma and FMEA methods in addressing the painting defects at PT. XYZ.*

INTRODUCTION

PT. XYZ, located at PIER Pasuruan, is a company engaged in the production of agricultural equipment, the main product of which is a four-wheel tractor. Domestically, the company's products are not yet well known because they have not been marketed, this company focuses on international markets such as Thailand, Vietnam, Europe and North America. Currently, the company is able to produce 138 units/day. As an *automotive manufacturing company,* PT XYZ places quality as its main priority, therefore for *exterior parts* such as *Hood Comp* (engine cover), *Floor* (footrest when driving) and *Fender* (wheel cover) on the tractor itself, the treatment is more special [1] .

The production processes in this company are *incoming inspection* or checking of raw materials (*spare parts*), *production preparation, sub-assembly, painting, main assembly, final product inspection* and *packing* [2] . From these processes, defects often occur *in exterior paint* and create *waste* that *is* detrimental to the company [3] . Defects caused by paint can impact the durability of the tractor product, because the paint on the tractor has the function of protecting the parts on the tractor so that they do not corrode or rust easily [4] . So the company experienced a decline in production quality due to high levels of defects in the painting of tractor products [5] . Several causal factors occurrence defects in the production process is error taking parts, materials standard damaged, and not in accordance with the established SOP company.

Defects in tractor painting can result in complaints from the company's subsequent processes, as this 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 parts, namely *the fender,* engine cover and steering floor [7] . From the data obtained, the total number of defects *was* 1421 for color differences, 1530 for paint thickness and 1975 for paint durability [8] . Thus, the quality control function plays a very important role for companies in improving and increasing product quality so that it is in accordance with what has been planned, because the quality of a product is a factor that determines the speed or slowness of a company's development that applies quality control [9] .

Study related with use Six Sigma and FMEA methods refer to research previously namely, Quality control of Clarisa products using the *lean six sigma method* and the FMECA method [10] . Analysis of the characteristics of residual carbon and sulfur content of biodiesel oil products using the *six sigma approach* [11] . Proposed application 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 an effort to improve the quality of metal casting production at PT. Mitra Rekatama Mandiri [13]. Determination model production *quality control plate* using method *six sigma* and *fuzzy FMEA* [14] .

So in this research, the appropriate method for controlling product quality and reducing the number of defective products is to use the *Six Sigma method* and *Failure Mode And Effect Analysis (FMEA)* method, because the *Six Sigma method and the Failure Mode And Effect Analysis (FMEA)* method focus more on improving, reducing errors, and minimizing defective products. Study This using data for 4 months namely from January to April 2023. This method can also provide recommendations to companies to improve production quality, especially during the tractor part painting process [15] .

RESEARCH METHOD

This research was conducted at PT. XYZ Jl. Kraton Industri Raya No.11 PIER Pasuruan. This research will be conducted for 4 months from January to April 2023. The research method This can seen in figure 1 as following.

According to Fidha (2019) the formula used in six sigma is count *Central Line* (CL), *Upper Control Limit* (UCL), and *Lower Control Limit* (LCL) This is as following [16] :

Calculate CL using the following formula:

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

Where:

$\sum Np$ = Total Number of Defects

$\sum n$ = Total number checked

Calculate 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 throughout the period

Calculate LCL using the following formula:

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

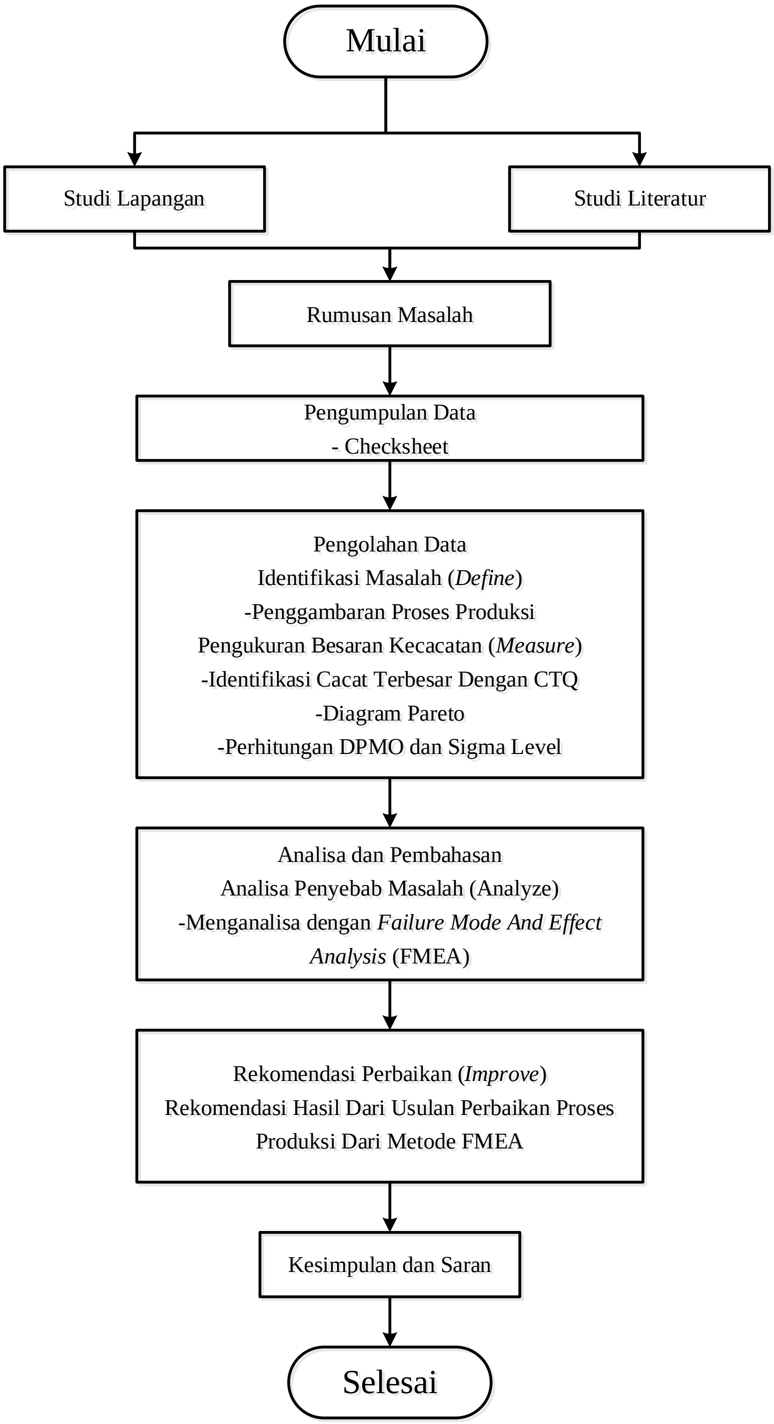

Figure 1. Flowchart.

In Figure 1, the research flow diagram explains the research process that takes place, namely by identifying problems by conducting field studies and literature studies, after which data is collected and data processing is carried out, the first data processing is processing defect data (*Measure*), identifying the biggest defects using *Critical to Quality* (CTQ), making a Pareto diagram and calculating *Defect Per Million Opportunity* (DPMO) and Sigma Level, from the results of the *Six Sigma method calculations*, analyzing defective products by implementing *Failure Mode and Effect Analysis (FMEA) to obtain the Risk Priority Number (RPN)* value to find out the root cause of defects with weighting. So that recommendations are obtained which can be used as suggestions for continuous improvement to the company and increasing product quality.

In FMEA, to determine the improvement is done by calculating the RPN (*Risk Priority Number*) value obtained from the multiplication of the severity level, occurrence level, detection level, each of which is given a value or score [17] . RPN (*Risk Priority Number*) This RPN shows the priority level of a failure obtained from the analysis results in the analyzed process. According to the RPN value, the failure mode is the corrective action that is prioritized and appropriate will be proposed for the highest RPN value after the implementation of the corrective action, the new RPN value will be calculated for each failure, then the priority order is getting higher. Classification from SOD can seen in table 1 below.

Table 1. Classification RPN Assessment.

Severity **Value**	**Classification**	*Occurrence* **Value**	**Classification**	*Detection* **Value**	**Classification**
10	Extreme	10	Almost certainly happening	10	Almost impossible
9	Are you serious	9	Very high	9	Almost No There is
8	Very significant	8	High	8	Very low
7	Significant	7	Quite High	7	Tends to low
6	Medium	6	Medium	6	Low
5	Low	5	Moderate enough	5	Medium
4	Very low	4	Small	4	Tend tall
3	Minor	3	Very small	3	Tall
2	Very minor	2	Almost never	2	Very high

1	There isn't any	1	Rare	1	Almost Certain detected

Source : [18]

In table 1 is classification from RPN (*Risk Priority Number*) assessment with use mark calculation from SO D. The value divided become as following :

1. S is mark *severity* level
2. O is mark *occurrence* rate
3. D is mark *detection* level

RESULTS AND DISCUSSION

A. *Define*

The production processes in this company are *incoming inspection* or checking of raw materials (*spare parts*), *production preparation, sub-assembly, painting, main assembly, final product inspection* and *packing.* From these processes, *defects often occur* in *exterior painting* and cause *waste that is detrimental to the company. Defects caused by* paint can impact the durability of tractor products, because paint on tractors has a function to protect parts on tractors from corrosion or rust. So the company experienced a decline in production quality due to defects during the painting of high tractor products. In this study, the type of defect used is defects in paint on tractors. Classification type defects in the quality of tractor paint as in table 2 as following.

Table 2. Classification of Disability Types.

Period	Total Production	Total Defects	Type of Defect		
			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 from PT. XYZ

Table 2 shows the classification of defects in tractor production at PT. XYZ, including three types of defects: color differences, paint thickness, and paint durability. These results represent data obtained from January to April 2023. The classification data in Table 2 was used to identify sigma values, *Pareto charts*, and *control charts* in the company's production.

B. *Measure*

T astage measure The first step is to enter the proportion values into a control chart (*P-Chart*) to measure the company's level of control over defects. The first step is to calculate the CL, UCL, and LCL values, which are used to determine the control values. The following are mathematical formulas and calculation examples using the data from this study.

The calculation of CL is as follows:

CL $=\bar{p}$

= 4926 / 14932

= 0.3299

UCL calculation is as follows:

UCL = 0.3299 + $3\frac{\sqrt{0,3299(1-0,3299)}}{3733}$

= 0.3299 + (3 x 0.0 1343)

= 0.3299 + 0.0403

= 0.3702

LCL calculation is as follows:

UCL = 0.3299 - $3\frac{\sqrt{0,3299(1-0,3299)}}{3733}$

= 0.2685 - (3 x 0.0 1343)

= 0.2685 - 0.0403

= 0.2896

next step is classify the calculation results from determining *the Central Line* (CL), *Upper Control Limit* (UCL), and *Lower Control Limit* (LCL) values which can be seen in table 3 below.

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

No	Period	Amount Production	Disabled	Proporsi	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			
Avarage		3733.0	1232	0.3299			

In table 3 it is found that results calculation from *Central Line* (CL), *Upper Control Limit* (UCL), and *Lower Control Limit* (LCL) values. After the CL, UCL, and LCL values are known from the results of the table above, the data will then be presented on *a P-Chart* to determine whether the data being studied is under control or not. The following is a *P-Chart control map* which can be seen in Figure 2 below.

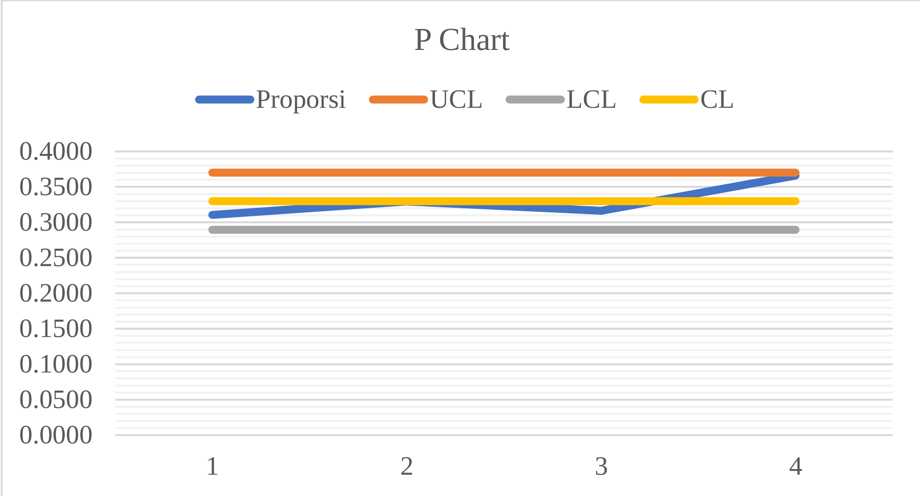

Figure 2. *P-Chart.*

In Figure 2 of *the P-Chart* control map above, it is known that all data is within the control limits, so all data processing can be continued to the next processing process. All over mark proportion be on the limit normal which is not pass UCL and LCL limits. Therefore, to determine which months have higher production process problems, calculate the sigma value.

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

The next step is to assess the sigma level. The DMPO value must first be known. The DPMO (*Defects Per Million Opportunities*) value is the proportion of errors per million opportunities. This DMPO measurement is an excellent measure for determining product quality because it directly relates to defects, costs, and wasted time during the production process. The following is a description of the DPMO calculation, which can be seen in the formula and an example of how it was done in January :

1. DPU (*Defect Per Unit*) calculation formula for January

DPU = Total defects/total units (4)

DPU = 1,191 / 3835 = 0.3106

2. *Yield* calculation formula January

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

Yield = 1 – (1 191 / 3835) x 100%

= 1- (0, 3106) x 100% = 68, 94 %

3. *Defect Per Opportunities*) calculation formula

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

DPO = 1191 / (3835 x 3) = 0.1035

4. *Defect Per Million Opportunities*) calculation formula

DPMO = DPO x 1,000,000 (7)

DPMO = 0.1 035 x 1,000,000 = 1 03520, 21

Table 4. Classification of Sigma Values.

Month	Amount Production	Amount 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
Avarage							107618,46	2.74

Table 4 shows varying sigma values. The higher the sigma value, the lower the likelihood of product defects. Conversely, the lower the sigma value, the higher the probability of defects. April had a sigma value of 2.67, indicating a higher defect rate compared to other months. Therefore, April requires attention to the production process because it has the lowest sigma value, indicating a higher defect rate compared to other months.

The next step is to identify the potential *Critical To Quality* (CTQ) items that most influence the total number of defects each month. The following is the percentage of defects from the total number of defects resulting from three months of production, as shown in Table 5.

Table 5. Percentage of Disabilities.

Type of Defect	January	February	March	April	Amount	Percentage	Percentage cumulative
Color Gradation	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 it is found that percentage defects in each CTQ in order to be able to generate a Pareto diagram from results table said. Percentage the own percentage cumulative used For know level which disability has the highest percentage? Enough significant. After making percentage disability Next, *the critical to quality (CTQ)* will be determined using a Pareto diagram. The following is the result of the Pareto diagram, which can be seen in Figure 3 below.

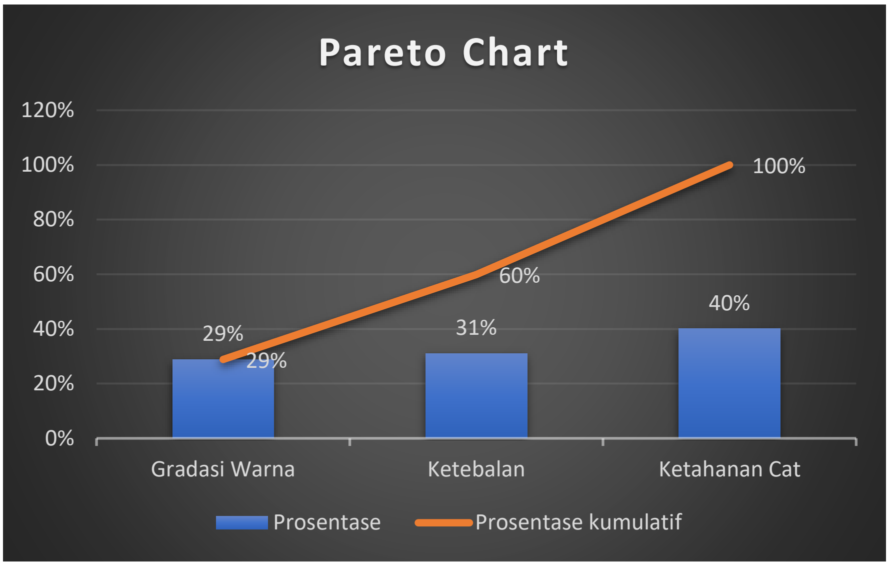

Figure 3. Pareto Chart.

On Figure 3 Pareto diagram can be seen from 4 defects there are 2 types of disabilities which has a very significant value in influencing the level of defects in the clothing production process, namely loose stitches and loose stitches No neat. So it can be said that the CTQ or *Critical to Quality value is* loose stitches and tight stitches. No neat.

C. *Analyze*

At the analyze stage, this is the process of searching reason defects in tractor production specifically for tractor paint. The method used at this stage This is Functioning *Failure Mode and Effect Analysis* (FMEA). For determine the ranking of causes disability highest until lowest. The results can used for the improve process for determine alternative improvement. The FMEA method is as in table 6 as following.

Table 6. *Failure Mode and Effect Analysis* (FMEA).

Production process	*Cause of Failure Mode*	S	O	D	RPN	Ranking
Raw Material Checking	Raw material there is something missing that is defective	7	5	5	175	8
	Raw material damaged when checked	4	5	5	100	13
Production Preparation	Checking machine production not enough maximum	4	6	5	120	12
	Raw material No complete	5	6	5	150	11
Sub Assy	small parts No in accordance	7	6	5	210	7
	small parts No Enough	7	7	6	294	4
Painting	Cat no in accordance standard	7	7	8	392	3
	Machine problematic	8	8	8	512	2
	Painting No according to SOP	9	8	8	576	1
Main Assembling	Main part No in accordance	6	7	5	210	6
	Main part No Enough	6	6	6	216	5

Final Product Inspection	Checking product No maximum	7	5	5	175	9
Packing	Damaged packaging	6	5	5	150	10

In table 6 it is found that RPN (*Risk Priority Number*) results for each failures that occur in each production process tractor at PT. XYZ. From each production process experience different failures. In table 6 used For look for RPN value for each failure. It is done observation in order to be able to determine S (*Severity*), O (*Occurance*), and D (*Detection*) so that produce different RPN values. In table 6 it has been obtained highest RPN value in painting No according to SOP of 576. The highest RPN value second be on the machine problematic of 512. The highest RPN value third is on the paint not in accordance standard amounting to 392.

Based on reference from table 1, as example of failure first in table 6 has SOD values are 7, 5, and 5 respectively with RPN of 175. This means failure the own mark *severity* or mark seriousness arising at a significant level so that potential for decreased performance a because there are functions that not optimal, potential arises defective products, There is potential termination due to failure others. At the value *occurrence* is frequency findings occurrence failure those who are at a sufficient level currently so that number occurrence of an event at a moderate level. While mark *detection* is mark measurement ability control failure at a moderate level means control Not yet effective. The following example RPN calculation with formula :

RPN1 = S x O x D (8)

RPN1 = 7 x 5 x 5

= 175

D. *Improve*

Table 6 lists the values from highest to lowest to determine the level of risk the company will face if improvements are not made immediately. The results are shown in Table 6. the RPN value that has mark above 200 is ranked 1 to with 7. Highest ranking found in the washing process with RPN of 576, namely at painting No according to the SOP which causes production tractor become hampered. The description of the RPN value categories is based on the description values in table 7 :

Table 7. RPN Value Categories.

Risk Level	RPN Value Scale
Very Low	x < 20
Low	20 ≤ x < 80
Medium	80 ≤ x < 120
Hight	120 x < 200
Very High	x ≥ 200

Source : [19]

The RPN value categorization in Table 3 helps companies determine which risks to address first, based on the highest risk value/highest importance. Of the 13 risks identified, 7 factors have very high risk values. These 7 risks will then be given improvement alternatives to provide the company with options for finding solutions to maintain or improve product quality. Following is proposal repair as in table 8.

Table 8. Proposal Repair

No	*Cause of FailureMode*	**Proposal Repair**
1	small parts No in accordance	Supervision during the production process
2	small parts No Enough	Checking before the production process
3	Cat no in accordance standard	Supervision in paint selection
4	Machine problematic	Maintenance machine in a way periodically
5	Painting No according to SOP	Supervision to employee painting
6	Main part No in accordance	Supervision during the production process
7	Main part No Enough	Checking before the production process

E. *Control*

The control phase is the final phase of the DMAIC (*Define, Measure, Analyze, Improve, and Control*) cycle. This phase involves monitoring the analysis conducted in the *Analyze phase,* followed by implementing the proposed improvements in the *Improve phase.* Control is performed by repeating the same measurements as in the *Measure phase,* but after improvements have been made. This phase involves:

1. Recalculate the DPMO (*Defect Per Million Opportunities*) value for waste that has been repaired.
2. Once the results have been carried out, if there has been an increase in the sigma level then it needs to be continuously monitored, but if there is still no change it is necessary to carry out the *Analyze stage* and determine *Improve* again. Likewise, this is done repeatedly.

F. Recommendations to Companies

Recommendation for PT. XYZ in production tractor on the quality of paint is For repair supervision of the production process in April. In the month of the own smallest sigma value between all months in research this. The more small sigma value then the more big disability occurs. In the painting process type the highest disability is paint durability that has percentage of 40%. So the paint durability is very good need supervision by PT. XYZ to get decreased. Recommendations repair from FMEA method is on the cause disability with highest RPN value is painting No according to SOP of 576. Proposal repair For reason disability the is supervision to employee painting.

CONCLUSION

Fundamental Finding : The average DPMO value for tractor product production on working days from January 1 to April 30, 2023 was 107,618.46 with an average sigma value of 2.74. The Critical to Quality characteristics exceeding 10% were color differences at 29%, paint thickness at 31%, and paint durability at 40%. Among all types of defects in the painting process, paint durability had the highest percentage at 40%, indicating it as the most dominant defect. The lowest sigma value occurred in April, which signifies the highest level of defects during the observed period. Based on the FMEA analysis, the cause of defects with the highest Risk Priority Number was painting not in accordance with standard operating procedures, with an RPN value of 576. **Implication :** The results imply that the quality of the tractor painting process at PT. XYZ is still below optimal performance, particularly during April when defect rates increased significantly. A lower sigma value indicates a higher occurrence of defects, which emphasizes the need for tighter control of the painting process. The dominance of paint durability defects suggests that insufficient adherence to procedures directly affects product quality. Therefore, strengthening supervision of painting activities and employee compliance with SOPs is crucial to reduce defect levels and improve overall production quality. **Limitation :** This study is limited by the absence of detailed process capability analysis to quantitatively measure how well the production process meets required specifications. Without incorporating specific process capability indices, the evaluation of process performance within the Six Sigma framework cannot fully demonstrate the closeness of the process output to established standards. **Future Research :** Future research should incorporate process capability formulas to better assess the ability of the production process to meet quality specifications within the Six Sigma approach. Additionally, the FMEA method can be complemented with other quality improvement tools such as Kaizen to design more comprehensive and sustainable strategies for enhancing production quality.

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