

Galvalum Roof Quality Control Analysis to Minimize Defects Using the FMECA (Failure Mode Effect and Criticality Analysis) and RCA (Root Cause Analysis) Methods at PT Trisakti Jaya

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ABSTRACT

Objective: This study aims to identify and solve the problem of product defects that occur at PT. Trisakti Jaya, a galvalume production company located in the Margo Mulyo Permai warehouse block C-6 Surabaya, which has 6 long vehicles and approximately 200 employees. These defects have reduced customer satisfaction and caused financial losses for the company. **Method:** The research employs the FMECA (Failure Mode Effect and Criticality Analysis) and RCA (Root Cause Analysis) methods. The FMECA method explains how the percentage of product defects can occur and what percentage arises after using this method, while the RCA method determines how the most effective solutions to problems can be obtained to help the company find the best corrective actions. **Result:** The results show that tears and dents are the highest types of defects, with the highest defect rate occurring in December. This is because the defect data exceeded the upper limit of the control chart, where the tear UCL (Upper Control Limit) is 2470 while the defect data is 2451, and the dent UCL is 3700 while the defect data is 3677. The tear defect is mainly caused by a lack of care when using the machine and minimal lighting in several warehouse corners. **Novelty:** The study provides a practical improvement recommendation by reminding operators about proper cutting machine operation and repairing lighting in less bright warehouse areas, offering a targeted and data-driven approach to reduce recurring defects in the galvalume production process.

INTRODUCTION

Although the economy is often unpredictable, developments in the corporate world are becoming increasingly intense in this era of globalization. Given how fierce competition has become in both domestic and international markets, such developments will make a difference. Consumers determine quality, which means that quality is based on how customers or consumers actually experience a product or service [1]. When a company knows what it wants to achieve, it has achieved quality [2]. An organization's position in the market will increase in direct proportion to the level of customer satisfaction with their offerings [3]. Both FMECA (Failure Mode Effect and Critical Analysis) and RCA methods will be used in this study [4]. Analyzing the causes is known as FMECA, or Failure Mode Effect and Critical Analysis. This is a technique for designing or evaluating system components that involves looking at how they could fail and how that would affect other parts of the system or the overall operating system [5]. The purpose of FMECA, which stands for "Failure Mode Effect and Critical Analysis," is to ensure that manufactured goods will not be released or reintroduced with the same process failure [6]. It is possible to use FMECA (Problem Mode Effect and Critically) to

analyze and identify problems at critical points in the production process, or to address problems at that point in the process [7].

When something goes wrong, one way to fix it is to use RCA, or Root Cause Analysis, to find out what went wrong [8]. Many different industries, including those dealing with health, technology, and business, often use this technique [9]. Instead of focusing on the obvious symptoms or effects of a defect, the RCA (Root Cause Analysis) method can help find the real source of the problem using a systematic approach [10]. The galvalume industry is one in which PT Trisakti Jaya operates [11]. Lightweight roofs, C-channels, and galvalume sheets are just a few of the many products made by this company from galvalume base materials [12]. Galvalume is commonly used in construction, especially for roofing. Margo Mulyo Permai Block C-6 Surabaya is the address of PT Trisakti Jaya. It has around 200 employees and six long vehicles.

It all began in 2005, when the company was founded. Galvalume is the main product of PT Trisakti Jaya, with the majority of their output going to roofing materials for houses [13]. The large volume of products produced in one go does not eliminate the possibility that some of these products will have defects [14]. The problem that arises is the high number of defective products along with the increasing production volume, which causes the company to have difficulty in meeting demand. Defects can reach more than 30% of total production, which is already at a critical stage. As a result, the company has to produce extra products, which means working overtime continuously. This also leads to complaints from consumers. The problems are classified into three types of defects, namely tears, holes, and dents.

Statistical control charts are used to improve process quality, identify process capabilities, assist with effective specifications, track process progress and adjustment times, and identify causes of product rejection [15]. Through the application of statistical methods, statistical quality control serves as a problem-solving tool for monitoring, controlling, analyzing, managing, and improving products and processes [16]. To reduce the product failure rate, data will be declared controlled and analyzed using the FMECA (Failure Mode, Effect, and Criticality Analysis) method in stages [17]. In terms of additional tools, there are seven different types of diagrams: bar, control, histogram, stratification, check sheet, and causal diagrams. When it comes to creating new features for products, these tools are invaluable [18]. The objective of this study is to measure product defects from each production process using the FMECA (Failure Mode Effect and Critical Analysis) method and to minimize product defects using RCA (Root Cause Analysis). The classification of S O D can be seen in Table 1 below.

Table 1. RPN Assessment Classification.

Severity Value	Classification	Occurrence Value	Classification	Detection Value	Classification
10	Extreme	10	Almost certain to occur	10	Almost impossible
9	Serious	9	Very high	9	Almost none

8	Very significant	8	High	8	Very low
7	Significant	7	Fairly high	7	Tends to be low
6	Moderate	6	Moderate	6	Low
5	Low	5	Fairly moderate	5	Moderate
4	Very low	4	Small	4	Tends 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: [19]

RESEARCH METHOD

The research was conducted at PT. Trisakti Jaya, a company operating in the production of various types of galvalume. It is located in the Margo Mulyo warehouse block C-6, Surabaya City, East Java Province. This research focused on minimizing the level of product defects that often occur in terms of product quality. Observation and data collection were carried out directly by visiting the field and collaborating with the production department, namely the production process department. The research was conducted from October 2022 to November 2022.

1. Quality Control

The purpose of quality control is to ensure that production or operational activities comply with planned specifications [20]. If there are deviations, they can be addressed to bring the results back in line with expectations or execute the plan as intended. The company's competitive advantage can be enhanced through quality distribution.

2. Control Chart

A control chart is a visual tool that can be used to track and assess whether a process or activity is within statistical quality control, which in turn helps in troubleshooting and improving quality [21].

$$p = \frac{np}{n} \quad (1)$$

Description:

p : percentage of nonconformity (defects)
 np : number of nonconformities in the subgroup
 n : number inspected in the subgroup

$$CL = p = \frac{\sum np}{\sum n} \quad (2)$$

Description:

$\sum np$: total number of nonconformities (defects)
 $\sum n$: total number inspected

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

$$LCL = p - 2 \frac{\sqrt{p(1-p)}}{n} \quad (4)$$

Description:

P : average product nonconformity

n: number of products per group

3. FMECA (Failure Mode Effects and Criticality Analysis)

The FMECA (Failure Mode Effects and Criticality Analysis) method is designed to identify failure models of a product or process, with the aim of calculating the risks associated with human energy sources that become modes of failure, ignoring the ranking of valuable problems, and identifying and implementing corrective activities to address serious problems [22].

$$RPN = (S) \times (O) \times (D) \quad (5)$$

Description:

S : severity

O : occurrence

D : detection

4. Pareto Diagram

A Pareto diagram is a bar graph (histogram) that illustrates problems that occur, grouped by the number of occurrences in descending order. Starting from the bar graph with the highest ranking on the left, we can see problems with many occurrences, to the bar graph with the lowest ranking on the right, which shows errors with a small number of occurrences [23].

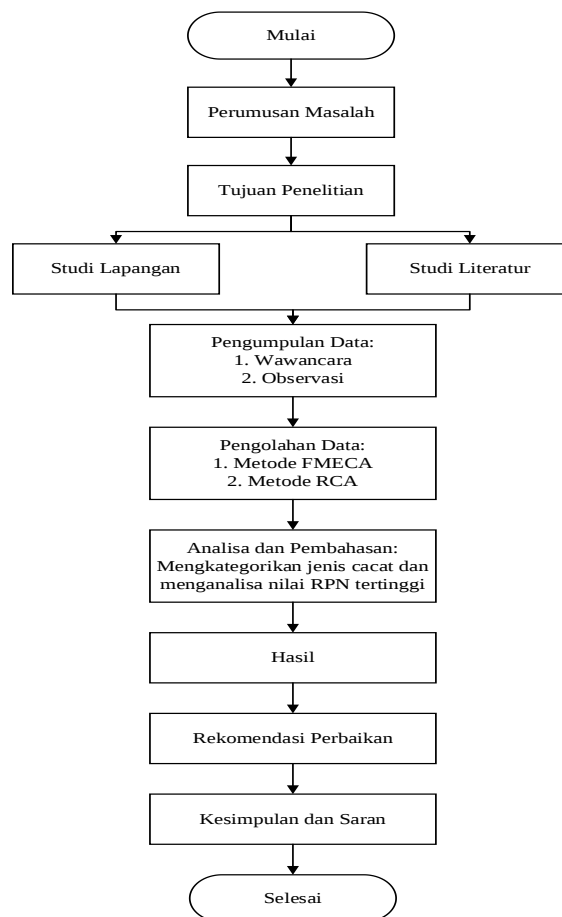


Figure 1. Research Flow Chart.

Figure 1 shows the research flow chart explaining the research process, which consists of field studies and literature studies, followed by formulating the research problems and objectives, then collecting data through interviews with production supervisors, observations, and requesting company data with the supervisor's permission. The next stage is data processing, the first of which is a control chart to calculate the upper and lower control limits, and the second is FMECA to determine the failure rate by calculating the Risk Priority Number (RPN). The results of the calculations can be analyzed to determine the level of defect risk. Meanwhile, the cause of failure is determined using the Root Cause Analysis (RCA) method. This yields improvement suggestions that can be continuously considered to improve product quality.

RESULTS AND DISCUSSION

Results

A. Data Collection

In 2022, according to company data, there were significant variations in the number of galvalume product defects received from different suppliers. The following is the galvalume defect data in this study in Table 2.

Table 2. Details of Galvalume Product Defects.

Month	Total Production	Reject Production	Defect Percentage (%)	Type of Defect		
				Torn	Holes	Dents
December	44.745	8.170	33%	2451	2042	3677
January	39.052	3.852	15%	1156	963	1733
February	16.653	778	3%	233	195	350
March	20.207	1.537	6%	461	384	692
April	30.232	4.852	19%	1456	1213	2183
May	36.590	5.870	23%	1761	1468	2641
Total	187.479	25.059	100%	7518	6265	11276

Table 2 shows that the highest defect rate occurred in December, accounting for 33% of the total defects in the data, with 8,170 units. The second highest defect rate occurred in May, accounting for 23% or 5,870 units. The third highest occurred in April, accounting for 19% or 4,852 units.

The following diagram is one of the tools used to help visualize the defect data in Table 1. The data entered in the diagram is the defect data and the average of each defect that occurred each month. The following is a diagram of galvalume defect data as shown in Figure 1.

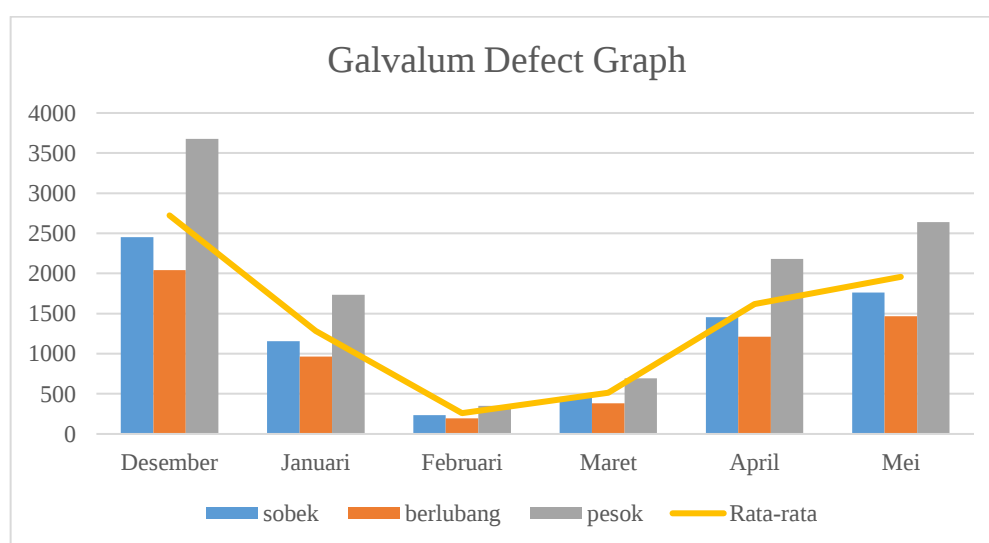


Figure 2. Galvalume Defect Graph.

Based on Figure 2, it can be seen that December has the highest average galvalume defect rate compared to other months. Meanwhile, the month with the lowest average defect rate is February. This serves as a benchmark that production in December needs to be monitored more closely to prevent this from continuing.

Furthermore, a Pareto chart is a quality tool used to determine cumulative defect data that can identify the highest type of defect. Before creating a Pareto chart, a cumulative table must first be created. The following is a cumulative table as shown in Table 3.

Table 3. Cumulative Types of Defects.

Type of Defect	Number	Percentage	Cumulative
Tears	7518	30%	30%
Holes	6265	25%	55%
Dents	11276	45%	100%

Table 3 shows that from the calculations performed, it can be concluded that galvalume product defects are divided into three main types. First, the dent type defect is the top priority with a percentage of 45%. Second, the tear type defect is the second priority with a percentage of 30%. Meanwhile, the handle type defect is the third priority with a percentage of 25%. Analysis of the table shows that the most dominant defect is the pesok type. This data can be represented in a Pareto diagram as shown in Figure 3.

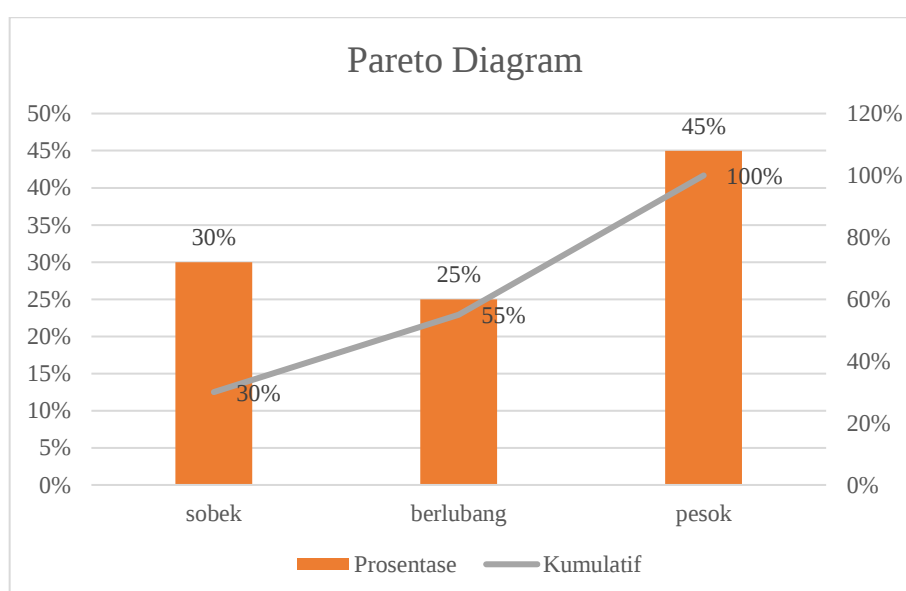


Figure 3. Pareto Diagram.

Figure 3 shows that the Pareto diagram above reveals that the defects that occurred in production from December to May were dominated by three types of defects, namely dents with a percentage of 45%, tears with a percentage of 30%, and holes with a percentage of 25% of the production sample. Therefore, improvements can be made by focusing on the two types of defects, namely dents and tears.

B. Control Chart

A control chart is used to see the upper control limit and the lower control limit. If the data is still within the control limits, the data is declared to be under control. Figure 3 shows two types of defects that are the main priorities, namely denting and tearing. At this stage, to measure whether quality control is under control or not, calculations are performed using a control chart. The following is the control chart calculation for defects in galvalume products. The following is the table and graph of the control chart for tear defects in galvalume products, as shown in Table 4 and Figure 4.

Table 4. UCL, CL, and LCL.

Month	Total Production	Tears	Proportion	UCL	CL	LCL
December	44.745	2451	0,055	2470	1257	200
January	39.052	1156	0,030	2470	1257	200
February	16.653	233	0,014	2470	1257	200
March	20.207	461	0,023	2470	1257	200
April	30.232	1456	0,048	2470	1257	200
May	36.590	1761	0,048	2470	1257	200
Total	187.479	7518	0,040			

The following is the processing of tear defect data to find CL, UCL, and LCL in 2022 production as follows.

- a. Calculating the error proportion:

$$p = \frac{np}{n}$$

$$= \frac{2451}{44745} = 0,055$$

- b. Calculating the average or CL:

$$CL = p = \frac{\sum np}{\sum n}$$

$$= \frac{7518}{6} = 1257$$

- c. Calculating *UCL* (*Upper Control Limit*)

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

$$= 1257 + 1053$$

$$= 2470$$

- d. Calculating the *LCL* (*Lower Control Limit*)

$$LCL = p - 2 \frac{\sqrt{p(1-p)}}{n}$$

$$= 1257 - 1053$$

$$= 200$$

After knowing the results of the CL, UCL and LCL calculations, the types of tear defects can be seen in Figure 4 below:

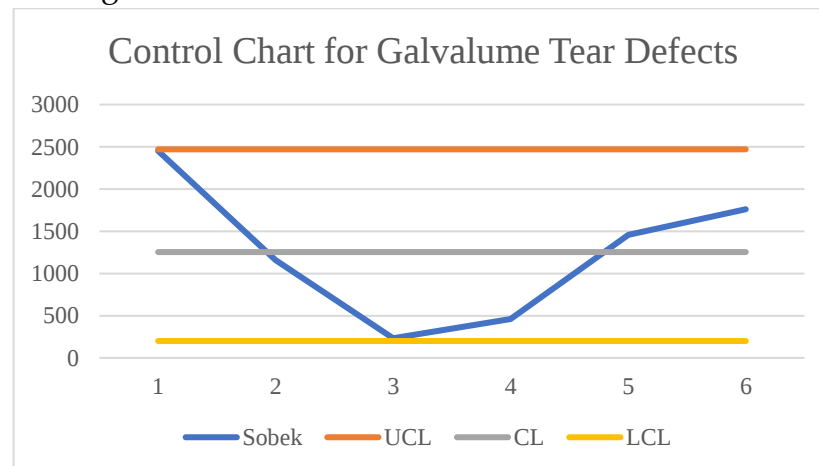


Figure 4. Control Chart for Galvalume Tear Defects.

Based on Figure 4, the control chart for galvalume tear defects shows that the UCL (Upper Control Limit) = 2470, while the CL or average = 1257 and the LCL (Lower Control Limit) = 200. It can be seen that the data obtained is within the specified control limits, so it can be said that the data is under control. The UCL and LCL lines are not crossed by the CL line, so there is no process variation that is out of control. However, in December, tear defects need to be significantly improved so that they do not occur again in the future.

Next is to create a control chart for pesok defects in galvalume products. The following is a table and graph of the control chart for pesok defects in galvalume products, as shown in Table 5 and Figure 5.

Table 5. UCL, CL, and LCL.

Month	Total Production	Dent	Proportion	UCL	CL	LCL
December	44.745	3677	0,082	3700	1881	300
January	39.052	1733	0,044	3700	1881	300
February	16.653	350	0,021	3700	1881	300
March	20.207	692	0,034	3700	1881	300
April	30.232	2183	0,072	3700	1881	300
May	36.590	2641	0,072	3700	1881	300
Total	187.479	11276	0,060			

The following is the processing of defect data to find CL, UCL, and LCL in 2022 production as follows.

a. Calculating the error proportion:

$$p = \frac{np}{n}$$

$$= \frac{3677}{44745} = 0,082$$

b. Calculating the average or CL:

$$CL = p = \frac{\sum np}{\sum n}$$

$$= \frac{11276}{6} = 1881$$

c. Calculating *UCL (Upper Control Limit)*

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

$$= 1881 + 1579$$

$$= 3700$$

d. Calculating the *LCL (Lower Control Limit)*

$$LCL = p - 2 \frac{\sqrt{p(1-p)}}{n}$$

$$= 1881 - 1579$$

$$= 300$$

After knowing the results of the CL, UCL and LCL calculations, the type of galvalume defect can be seen in Figure 5 below:

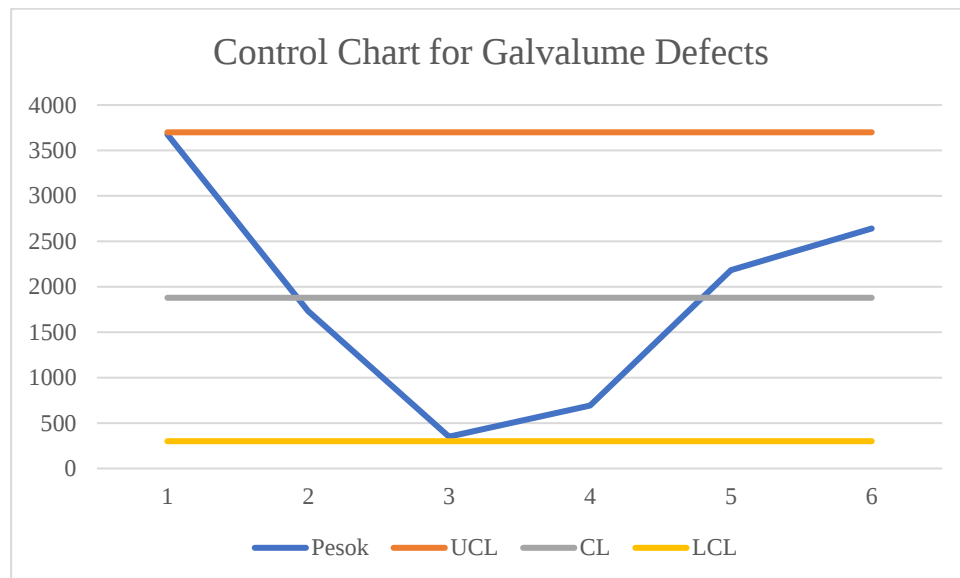


Figure 5. Control Chart for Galvalume Defects.

Based on Figure 5, the control chart for Galvalum defects shows that the UCL (Upper Control Limit) = 3700, while the CL or average = 1881 and the LCL (Lower Control Limit) = 300. It can be seen that the data obtained is within the specified control limits, so it can be said that the data is under control. The UCL and LCL lines are not crossed by the CL line, so there is no variation in the process that is out of control. However, in December, the defect rate needs to be significantly improved so that it does not occur again in the future.

Discussion

Analysis and Discussion

Critical Analysis is the process of assessing and classifying the risk of failure. At this stage, the causes of defects that occurred due to failures in December will be classified. Critical analysis uses a critical matrix, as shown in Table 6, which is used to determine the priority of critical analysis.

Table 6. *Critically.*

Criticality Level	Value	Risk
Minor	0-30	Acceptable
Medium	31-100	Tolerable
High	101-180	Unacceptable
Very High	181-252	Unacceptable
Critical	>252	Unacceptable

Based on Table 6, there are 5 assessments to evaluate the failure score using the Risk Priority Number (RPN). The RPN value is determined by multiplying the Severity, Occurrence, and Detection values, which are the results of identification after conducting

observations and interviews with production supervisors. The calculation of the Risk Priority Number (RPN) is shown in Table 7 below.

Table 7. RPN Calculation Results.

Type of defect	Failure Mode	Failure Effect	S	O	D	RPN
Tearing	Imprecise installation on the cutting machine	Tearing after cutting	5	4	7	140
Dent	Proses Rough storage process	Dent on one galvalume rack	5	6	7	210

Table 7 shows that the highest risk is the dent defect type with failure in the rough storage process and the effect of a dent on one galvalume rack with an RPN value of 210. The classification of the first highest RPN results has S O D values of 5, 6, and 7, respectively. This means that the failure has a low severity value, so there is a potential for performance decline due to suboptimal functions, the potential for defective products, and the potential for stoppages due to other failures. The occurrence value is the frequency of occurrence of the failure, which is at a moderate level, meaning that the number of occurrences is moderate (< 3 times per day). Meanwhile, the detection value is a measurement of the ability to control failures at a relatively low level, meaning that control is not effective and does not maximally detect the causes of defects early on. After that, the second highest risk is the type of tear defect with installation failure in the cutting machine that is not precise and the effect is tearing when cutting is complete with an RPN value of 140. Then, in the next stage, the RPN value was obtained from the Failure Mode Effect and Analysis (FMEA) calculation, followed by further analysis based on the Critically table, whether it falls into the category of (acceptable) no obstacles, (Tolerable) not a priority for improvement, or (Unacceptable) needs improvement. The following is an example of RPN calculation:

$$\begin{aligned} \text{RPN Tear} &= S \times O \times D \\ &= 5 \times 4 \times 7 = 140 \end{aligned}$$

The RPN calculation results show different total values between tear defects and pitting defects. Pitting defects have the highest value at 210, followed by tear defects at 140. A high RPN can lead to inconsistencies in the production process if not addressed immediately. As in the case of the pesok defect, which has an RPN value of 210 with a tendency for low detection, this indicates that the company has minimized the detection of the causes of defects. This can lead to higher defects, which will affect production quality and increase the cost of handling defective products.

The results of the FMECA calculation and analysis are shown in Table 8 below.

Table 8. FMECA Calculation Results for Galvalume Production.

Defect Type	Failure Mode	Failure Effect	RPN	Criticality	Risk
Tear	Imprecise installation	Tearing upon completion of cutting	140	High	Unacceptable
Dent	Excessively rough storage process	Dent on one galvalume rack	210	Very High	Unacceptable

Based on Table 8 above, it can be seen that the RPN calculation results in two values that fall into the very high and high categories. The first is the highest value for the dent defect with a failure effect of a dent on one galvalume rack with an RPN value of 210, which falls into the very high criticality degree, so that improvements need to be made (unacceptable). The second defect is tearing with a failure cause of tearing after cutting, with an RPN value of 140, which is classified as high criticality, requiring improvement (unacceptable).

Improvement Recommendations

Analyze the causes of waste using root cause analysis. This analysis is to determine the cause of failure that occurred in the tear and dent defects in December, which caused the number of defective products to be out of control. To find alternatives to eliminate waste, an analysis of the causes was carried out. The following are the root causes of defects in Table 9.

Table 9. Root Cause Analysis.

Type of defect	Description of defect	Why 1	Why 2	Why 3	Why 4	Why 5
Tears	Tears after cutting	Employees are not careful	Cutting is not according to size	Not checking the machine	Not careful when using the machine	
Dents	Dents on one galvalume rack	Employees are not careful and focused	Placement in an area with little light	Some corners of the warehouse have minimal lighting		

From the root cause analysis in Table 9, the root causes of galvalume defects at PT Trisakti Jaya are known. The root cause of tears is a lack of thoroughness when using the machine. Meanwhile, the root cause of dents is poor lighting in some corners of the

warehouse. The following are recommendations for improving the root causes of galvalume defects at PT Trisakti Jaya in Table 10.

Table 10. Recommendations for Improvement.

<i>Waste</i>	Defect Description	Root Cause	Recommendations for Improvement
Tearing	Tearing after cutting	Lack of precision when using the machine	Remind operators of the method for using the cutting machine
Dents	Dents on one galvalume rack	Some corners of the warehouse have minimal lighting	Improve lighting in poorly lit corners of the warehouse

Based on Table 10, it is known that the cause of galvalume tearing defects in December at PT Trisakti Jaya was carelessness when using the machine. Meanwhile, the cause of galvalume denting defects in December at PT Trisakti Jaya was poor lighting in some corners of the warehouse.

The recommended improvement for the cause of galvalume tearing defects in December at PT Trisakti Jaya is to remind operators of the correct method for using the cutting machine. Meanwhile, the recommended improvement for the cause of galvalume pesok defects in December at PT Trisakti Jaya is to improve lighting in poorly lit corners of the warehouse.

CONCLUSION

Fundamental Finding : The conclusion obtained from the research on galvalume product quality control at PT Trisakti Jaya is that the types of defects are tears and dents, with the highest frequency occurring in December as the defect data has approached the upper limit of the control chart. The UCL (Upper Control Limit) for tears is 2470 while the defect data is 2451, and the UCL for dents is 3700 while the defect data is 3677. The discussion focuses on finding the causes of failure and providing recommendations for improvement related to these defects. **Implication :** The FMECA results show that the tear defect has an RPN of 140 and the dent defect has an RPN of 210, both classified as unacceptable, indicating that immediate corrective actions are required. The causes include imprecise installation for tearing and overly rough storage for denting, reflecting the need for better operational discipline and environmental conditions in the production area. **Limitation :** This study primarily analyzes defects using FMECA and RCA, focusing only on two dominant defect types—tears and dents—without integrating broader quality control tools or exploring seasonal production variations that may influence defect rates. **Future Research :** Future studies are suggested to incorporate additional quality tools such as fishbone diagrams and flow charts for more detailed analysis and to employ the Six Sigma method for more comprehensive defect classification and continuous process improvement.

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