

Defect Analysis in the Aircraft Painting Process at PT XYZ using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) Methods

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Abstrak

PT XYZ merupakan perusahaan yang bergerak di bidang manufaktur pesawat terbang dan helikopter. Dalam proses produksi pesawat, terdapat tahapan pengecatan yang dilakukan di hanggar Painting Shop. Pengecatan pesawat berfungsi untuk melindungi dari karat dan korosi sekaligus menjadi identitas perusahaan maupun negara. Namun demikian, masih ditemukan berbagai cacat pada proses ini yang tidak sesuai dengan standar kualitas. Berdasarkan data final inspection pengecatan pesawat tahun 2020–2023, tercatat 307 cacat dari lima unit pesawat yang telah dicat. Penelitian ini menggunakan metode Failure Mode and Effect Analysis (FMEA) untuk mengidentifikasi moda kegagalan (failure mode) pada cacat yang terjadi beserta penyebabnya, serta menentukan tingkat keparahan (severity), kemungkinan kejadian (occurrence), deteksi (detection), dan nilai Risk Priority Number (RPN) guna menetapkan prioritas perbaikan. Jenis cacat miss dan runs termasuk kategori berisiko tinggi karena memiliki nilai RPN >200, sehingga diprioritaskan untuk segera diperbaiki. Metode Fault Tree Analysis (FTA) juga digunakan untuk mengetahui akar penyebab cacat yang terjadi. Hasil analisis menunjukkan bahwa faktor penyebab cacat berasal dari aspek manusia, mesin, metode, dan lingkungan.

Kata kunci: cacat, FMEA, FTA, kualitas, RPN

Abstract

PT XYZ is a company that is competent in the manufacturing of aircraft and helicopters. In the aircraft production process, an aircraft painting process is carried out in the Painting Shop hangar. Painting on aircraft serves a dual purpose: protecting the aircraft from rust and corrosion, and representing the identity of a company or country. However, many defects are still found during this process that do not meet quality standards. This can be seen from the aircraft painting final inspection defect data for 2020-2023, 307 defects were found from 5 painted aircraft. This research employs the Failure Mode and Effect Analysis (FMEA) to identify failure modes in defects, their causes, and the severity, occurrence, detection, and Risk Priority Number (RPN) values of these defects, thereby determining repair priorities. The types of defects, misses, and runs fall into the high-risk category because they have an RPN value of >200, so they will be prioritized for immediate improvement. Fault Tree Analysis (FTA) is also used to identify the root causes of defects that occur. The causes of defects are attributed to human, machine, method, and environmental factors.

Keywords: defect, FMEA, FTA, quality, RPN

1. Introduction

At this time, rapid technological changes are driving the industry to develop and advance rapidly. The changes that occur cause competition between companies to become tighter, so every company must face it to remain competitive. One of the efforts that a company can make is to improve the quality of its products. A product is considered to be of high quality if it's able to meet customer expectations (Mentang et al., 2021). The quality of a company's products is determined by the measurements or standards that have been set by the company based on customer needs or demands. If a

product produced by a company does not meet the established measurements or standards, it is considered defective or damaged (Shiyamy et al., 2021).

According to Sitanggang et al. (2019), quality is a condition that continually evolves in response to changing customer tastes or expectations, necessitating ongoing maintenance and improvement of product quality. Companies that can provide products that meet or exceed customer expectations will create strong relationships and trust with their customers. This can help the company build its reputation and expand its customer

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base without significant additional marketing costs, ultimately benefiting the company.

One of the companies that prioritizes quality is PT. XYZ. The company excels in aircraft design and development, aircraft structure and component manufacturing, helicopter and aircraft production, as well as training and maintenance for aircraft and helicopter engines. In the aircraft production process, a painting process is carried out in the painting shop hangar. Aircraft painting serves to protect against rust and corrosion, and to establish the identity of a company or country. The quality standards for aircraft painting require that every part of the aircraft be painted, the paint thickness be between 15 and 23 microns, the paint surface be smooth, and the color match the customer's request.

In the aircraft painting process, many defects are still found, which do not meet quality standards. Based on the final inspection data of aircraft painting at PT. Between 2020 and 2023, 307 defects were found in the five painted aircraft. The types of defects commonly found in the aircraft painting process include parts with thin or unpainted paint (misses), melted paint (runs), spotted paint (inclusions), rough paint, blistering, peeling, cracking, overspray, and wrinkling (orange peel). The classification of defect types is provided by the company, based on their production standards and quality control guidelines.

The problem of many defects found in the painting process can cause delays in delivery or progress because repairs or rework are needed, which can cause losses for the company. Therefore, quality control and improvement are necessary to minimize the occurrence of defects.

Methods that can be used for quality control are the Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA) methods. Failure Mode and Effect Analysis (FMEA) is a method used to identify potential failures that may occur in the design or production process until the product is produced, as well as to analyze the consequences of each failure (Hisprastin & Musrifoh, 2021). The FMEA method aims to determine the level of risk for each type of failure obtained by assessing severity, occurrence, and detection (Suryaningrat et al., 2019). Fault Tree Analysis (FTA) is a method used to identify the potential root causes of failures that occur in a system so that efforts can be made to minimize the occurrence of failures or product defects (Nugraha & Sari, 2021).

The research by Tanto et al. (2023) used the FMEA and FTA methods to analyze defects in the OKT 501 table products at PT. Kurnia Persada Mitra Mandiri. This research provides a comprehensive approach to improving product quality and reducing defects in the production process. Research by Hardianto & Nurianto (2023) also used the FTA and FMEA methods to analyze

defects in paving block production at PT. Duta Beton Mandiri. This research identified the main defects and their root causes, so that improvements were recommended to improve the production process. In this research, FMEA and FTA methods are used to analyze defects in the aircraft painting process at PT XYZ. This research aims to identify the types of defects occurring during the painting process and analyze their root causes.

2. Research Methods

This research was conducted by identifying the problems in the company using field studies and literature reviews. The data was collected for research supporting materials. The data used in this research were the final inspection painting data of aircraft in 2020-2023 and the results of interviews with supervisors, inspectors, and operators in the painting section. Then the data is processed using Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) methods.

In the initiate stage, the Failure Mode and Effect Analysis (FMEA) method is used to observe the process and identify the types of defects that occur. Then, identify the causes of the defects that occur. According to Andriyani & Rumita (2017), the FMEA method is used to identify the sources of quality problems.

Next, determine the values for the criteria of severity (S), occurrence (O), and detection (D). They are rated on a scale of 1-10.

1. Severity (S)

Severity is an assessment of the seriousness of a problem that occurs and affects the process output (Jevon & Rahardjo, 2021). Table 1 shows the severity rating scale.

Table 1. Severity Rating Scale

Impact	Criteria	Rating
Danger occurs without warning	- Does not comply with government regulations - Stopping the operation of the production system	10
Serious, occurs with a warning	- Does not comply with government regulations - Produces a product that endangers the consumer	9
Extreme	- Disrupts the smooth running of the production system - The product cannot be operated (100% scrap)	8
Major	- Customers are very dissatisfied - Slightly disrupts the smoothness of the production process - Product performance is not perfect, but it can still be used	7
Significant	- Still acceptable to consumers - Product performance is reduced because certain functions may not operate	6
Moderate	- Product performance has decreased, but it can still be repaired	5
Modest	- Product performance decreases, but does not require repair	4

Impact	Criteria	Rating
Minor	- Minor impact on the production system or product performance - There are still complaints from some consumers	3
Slight	- Very minor impact on the production system or product performance - There are still complaints from certain consumers	2
No Impact	- No impact on production systems or products	1

(Source: Hardianto & Nuriyanto, 2023)

2. Occurrence (O)

Occurrence is an assessment that indicates how often a failure occurs (Rinoza et al., 2022). Table 2 shows the occurrence rating scale.

Table 2. Occurrence Rating Scale

Occurrence Probability	Incident Level	Rating
Extreme	1 of 2	10
Very High	1 of 3	9
High	1 of 8	8
Relatively High	1 of 20	7
Medium to High	1 of 80	6
Medium	1 of 400	5
Relatively Low	1 of 2.000	4
Low	1 of 15.000	3
Very Low	1 of 150.000	2
Almost Impossible for a Failure to Occur	1 of 1.500.000	1

(Source: Hardianto & Nuriyanto, 2023)

3. Detection (D)

Detection is an assessment that shows the level of control capability currently used to detect the cause or failure mode (Situngkir et al., 2019). Table 3 shows the detection rating scale.

Table 3. Detection Rating Scale

Detection	Criteria	Rating
Almost Impossible	Failure is unlikely to be detected through inspection	10
Very Small	Inspection fails to detect the failure	9
Small	Inspection has a very small chance of detecting the failure	8
Vey Low	Inspection has a little chance of detecting the failure	7
Low	Inspection may detect the failure	6
Medium	Inspection has a high chance of detecting the failure	5
Slightly High	Inspection has a very high chance of detecting the failure	4
High	Inspection can detect the failure	3
Very High	Inspection almost always detects the failure	2
Almost Certain	Inspection always detects the failure	1

(Source: Hardianto & Nuriyanto, 2023)

Next, calculate the Risk Priority Number (RPN) value by multiplying the severity, occurrence, and detection values. The RPN value functions to indicate the priority level for improvements that must be carried out first, and those that cannot be done immediately (Paquita & Laksono, 2022). The failure mode with the highest RPN values will be prioritized for improvement first. The

calculation formula used to find the Risk Priority Number (RPN) value is:

$$RPN = S \times O \times D$$

Description:

S: Severity Value

O: Occurrence Value

D: Detection Value

Risk Priority Number (RPN) values are categorized into three risk levels. Risk Priority Number (RPN) values are categorized into three risk levels. Table 4 shows the risk level categories of the RPN value.

Table 4. RPN Value Risk Level Categories

RPN Level	Category
1 – 99	Low
100 – 199	Medium
≥ 200	High

(Source: Perkasa, & Rahmawati, 2023)

The next stage is to identify and analyze the root causes of failures or defects that have a high RPN category value using the Fault Tree Analysis (FTA) method. According to Kurniawan et al. (2022), the FTA method identifies failures in a system and details the causes of top failures down to basic failures, presented with a visual display. The results from the FTA can determine proposed improvements to reduce or mitigate the problems that occur. Fault Tree Analysis is created using special symbols, including event symbols, gate symbols, and transfer symbols (Mahyar & Supryadi, 2020). Figures 1, 2, and 3 show the FTA symbols used in this research

1. Basic Event Symbol

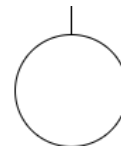


Figure 1. Basic Event Symbol

The basic event symbol is a circle-shaped symbol representing a basic event, primary event, or fundamental failure that does not require cause analysis. This means that the circle symbol represents the final cause of an event.

2. Intermediate Event Symbol

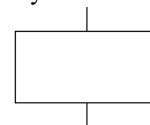


Figure 2. Intermediate Event Symbol

The intermediate event symbol is a rectangular-shaped event symbol used for events resulting from a combination of failed input events entering the gate.

3. OR Gate Symbol

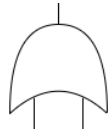


Figure 3. OR Gate Symbol

The gate symbol is used to show the relationship between events in the system (Christian et al., 2020). The OR gate symbol is used to show the events that will occur if one or more failure events that are its inputs occur.

3. Results and Discussion

3.1. Identify the Type of Defect that Occurs

Based on observations and interviews with supervisors, inspectors, and operators in PT XYZ's painting section, data on defect types and numbers in the aircraft painting process from 2020 to 2023 are presented in Table 5.

Table 5. Types and Number of Aircraft Painting Defects in 2020-2023

Type of Defect	Aircraft				
	Medium Aircraft	Small Aircraft A	Small Aircraft B	Small Aircraft C	Small Aircraft D
Orange Peel	4	2	2	1	3
Runs	13	9	10	7	8
Inclusions	12	13	10	11	14
Peeling	5	4	3	3	5
Miss	26	26	18	15	25
Blister/Microbubbling	2	0	0	1	1
Cracking	0	0	0	1	0
Overspray	9	7	8	8	7
Rough Paint	3	2	3	4	2

Based on data on the types and number of aircraft painting defects in 2020-2023, it is known that there are 307 defects consisting of 9 types of defects. The types of defects that occur are orange peel, runs, inclusions, peeling, miss, blister/microbubbling, cracking, overspray, and rough paint. Next, the nine types of defects are identified by failure mode, effect, and cause. Table 6 shows the failure identification.

Table 1. Failure Identification

Failure Mode	Failure Effect	Failure Cause
Incorrect paint mixing composition	Orange Peel	Operators are less careful
Low operator concentration	Miss	Operators are experiencing fatigue
Dirty spray gun	Inclusion	Spray guns are rarely cleaned
Spray distance too close to the object	Runs	The painting process does not follow SOP
The equipment is not functioning properly	Overspray	There is no routine schedule for checking and maintaining equipment
Poor paint mixing	Peeling	Paint mixing is not uniform
Incorrect spraying technique	Rough Paint	Spray pressure is too low or too high
Drying time too short	Cracking	The operator is chasing targets
	Blistering	

3.2. Determination of Severity (S), Occurrence (O), and Detection (D) Values

After identifying the failure modes and causes of the dominant types of defects, the next step is to determine the severity, occurrence, and detection values for each type of defect. Table 7 presents the results of determining severity, occurrence, and detection values.

Table 7. Determination of Severity (S), Occurrence (O), and Detection (D) Values

Type of Defect	Defect Freq.	% Defect	% Cum.	S	O	D
Miss	110	35.83%	35.83%	7	8	5
Inclusions	60	19.54%	55.37%	5	6	5
Runs	47	15.31%	70.68%	7	6	5
Overspray	39	12.70%	83.39%	4	6	5
Peeling	20	6.51%	89.90%	5	5	5
Rough Paint	14	4.56%	94.46%	6	5	5
Orange Peel	12	3.91%	98.37%	3	4	5
Blistering	4	1.30%	99.67%	6	4	5
Cracking	1	0.33%	100%	6	2	5

3.3. Calculation of Risk Priority Number (RPN) Value

The next step is to calculate the Risk Priority Number (RPN) value by multiplying the severity, occurrence, and detection values, and then categorize each defect into an RPN value category. Table 8 shows the calculation of the risk priority number value.

Table 8. Calculation of Risk Priority Number Value

Type of Defect	RPN Values	RPN Category
Miss	280	High
Inclusions	150	Medium
Runs	210	High
Overspray	120	Medium
Peeling	125	Medium
Rough Paint	150	Medium
Orange Peel	60	Low
Blistering	120	Medium
Cracking	60	Low

Based on the RPN calculation in Table 8, the types of defects "miss" and "runs" are classified as high risk due to their RPN values exceeding 200, making them a priority for improvement efforts.

3.4. Analysis of Defect Causes with the Fault Tree Analysis (FTA) Method

The next step is to create a Fault Tree Analysis (FTA) diagram to identify the root cause of defects that fall into the high-risk category, based on the RPN values calculated for misses and runs. Figure 4 shows the FTA diagram for defects missed, and Figure 5 shows the FTA diagram for defect runs.

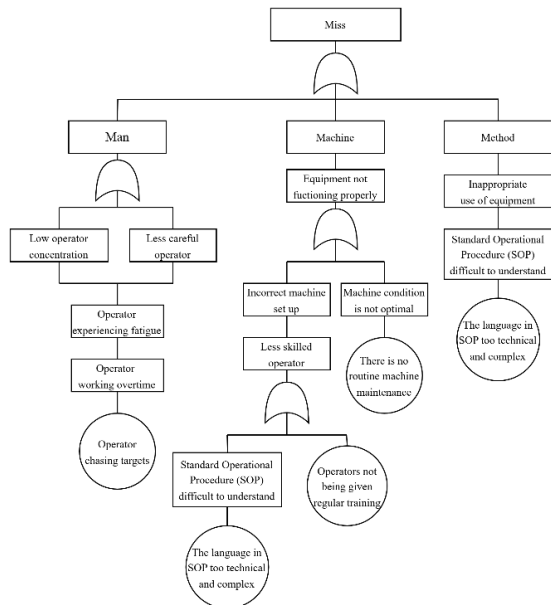


Figure 4. FTA Defect Miss

Based on Figure 4, the defect miss with a high risk (RPN value of 280) is attributed to several factors: low operator concentration, less careful operators, equipment malfunction, and inappropriate equipment use. The factors of low operator concentration level and less careful operation are caused by operators experiencing physical or mental fatigue due to working overtime to chase targets. The equipment's malfunction is primarily due to incorrect machine setup, resulting from the lack of skilled operators who struggle to understand the Standard Operating Procedure (SOP). Additionally, operators receive no regular training, and machines lack maintenance due to the absence of a routine schedule. The factors contributing to the inappropriate use of equipment are that operators struggle to understand SOPs due to the use of overly technical and complex language.

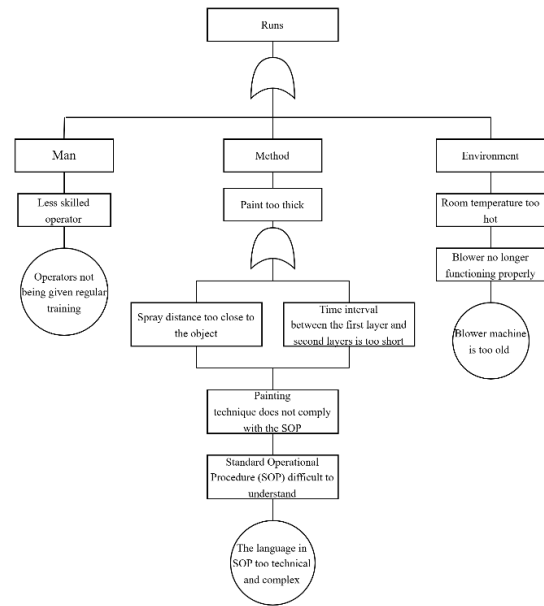


Figure 5. FTA Defect Runs

Based on Figure 5, the defect runs with a high risk, as indicated by an RPN value of 210, and is attributed to several factors, including less skilled operators, excessive paint application, and excessively hot room temperatures. The lack of skill is caused by operators not receiving regular training. Excessive paint thickness occurs because the spray distance is too close to the object, and the interval between the first and second layers is too short. The painting technique also does not comply with the SOP, as the SOP uses overly technical and complex language that is difficult for operators to understand. The hot room temperature is caused by an old blower that no longer functions properly.

3.5. Improvement Suggestion

Based on the results of the Fault Tree Analysis (FTA) presented in figures 4 and 5, the proposed improvement aims to address the issue of operators experiencing fatigue from working overtime to meet targets, which in turn leads to decreased concentration and accuracy. This is achieved by rearranging the operators' work and rest schedules. Operators are expected to utilize their existing rest time effectively, enabling them to work carefully, concentrate well, and avoid mistakes that could lead to failure (Andriani et al., 2021). Additionally, hiring subcontract workers is recommended to eliminate the need for overtime. Another suggestion is to modify and improve the layout of facilities that are far apart to be closer together so that operators do not get tired quickly and can work more effectively and efficiently.

The problem of SOPs being difficult for operators to understand, due to the use of overly technical and complex language, can be solved by revising and updating the SOPs. Clearer language should be used, and diagrams or photos should be added as examples to make them easier for operators to understand (Gabriele, 2018).

In addition, training and socialization of the new SOPs to all workers should be provided so that they can understand and implement the SOP properly. Periodic evaluations are necessary to ensure the new SOP is functioning properly and not introducing new issues. SOPs also need to be revised periodically according to changes in a process or feedback from users or operators.

The problem of operators not receiving regular training, which results in less skilled operators, can be addressed by providing regular training to enhance operator skills and knowledge. With regular training, operators will be quicker and more precise in dealing with defects that occur, which can reduce the percentage of defects that occur (Saputra & Palit, 2021).

The problem of machines not operating optimally, caused by the absence of routine maintenance, can be addressed by creating a fixed schedule for machine maintenance supported by a checklist of maintenance procedures (Nur & Haris, 2019). This scheduling is designed to facilitate monitoring of the condition and performance of the machines and tools used. Maintenance activities may include lubrication and cleaning of machines and tools. Strict supervision is necessary, along with reinforcement of the SOPs and clear sanctions or warnings for operators who fail to follow maintenance procedures. This ensures that the routine maintenance schedule is carried out properly and without delays, thereby reducing the occurrence of defects.

The problem of an old blower can be solved by replacing it with a new one because the old blower is no longer effective in air circulation, which can disrupt the painting process.

4. Conclusion

Based on the results of the research conducted, the following conclusions can be drawn:

1. Based on the results of data processing and analysis of the calculation of the Risk Priority Number (RPN) value using the Failure Mode and Effect Analysis (FMEA) method, the type of defect that is most risky or falls into the high risk category is the type of defect that has an RPN value >200, namely misses with an RPN value of 280 and runs with an RPN value of 210.
2. The causes and root causes of the most risky types of defects, misses, and runs are that operators have to work overtime to meet targets, the language in SOP is too technical and complex, operators are not given regular training, there is no routine schedule for machine maintenance, and the room temperature is too hot.
3. To overcome and reduce defects, several improvements are suggested: rearrange the operators' work and rest schedules, evaluate and revise SOPs, conduct socialization and SOP training, create a maintenance schedule for machines and tools, provide regular training for operators to enhance their knowledge and insight, and replace old blowers with new ones.
4. This research only analyzes product defects in the painting process. Therefore, it is recommended that future research consider all stages of production, so that the causes of defects can be identified more comprehensively and product quality improvements can be carried out more effectively.

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