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Analysis of Simplex Machine Damage Using Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) Methods

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ABSTRACT

The current industrial landscape is experiencing rapid development, compelling companies to produce high-quality products that meet consumer expectations. The production activities are crucial in the execution of the production process, and smooth operations are highly anticipated by companies in general. This study aims to identify the root causes of frequent breakdowns in the simplex machine that occurred between February and April 2023. The study employs the Fault Tree Analysis (FTA) method to determine the root causes of issues that lead to undesirable events. The results from the Fault Tree Analysis revealed that the primary causes of simplex machine breakdowns are attributed to human factors, machine issues, and material problems. Furthermore, the findings from the Failure Mode and Effect Analysis (FMEA) identified the highest Risk Priority Numbers (RPN) for each component: lack of scheduled machine maintenance (RPN = 192), old machinery (RPN = 64), and waste material getting stuck in the flayer (RPN = 210).

Keywords: *Fault Tree Analysis, Failur Mode and Effect Analysis, RPN,* 5W+1H

INTRODUCTION

The rapid development within the industry today necessitates that companies produce high-quality products that meet consumer targets. Production activities are crucial in the execution of the production process, and smooth operations are highly anticipated by companies in general. One of the factors ensuring production meets targets and runs smoothly is the optimization of production machinery, which must always be in good condition. This includes effective maintenance and machine requirements.

PT. Indo-Rama Synthetics Tbk. Indo-Rama Technologies Complex is a textile company engaged in the processing of cotton to produce yarn. The company consists of two departments: the cotton department and the polyester department. The cotton department produces yarn from 100% cotton material, while the polyester department mixes cotton with other materials to produce polyester yarn. Among the many machines in these two departments, the cotton department is more heavily utilized since its cotton output is also used in the polyester department. Consequently, the simplex machines in the cotton department frequently encounter serious issues. Due to the extended production processes, the company also endeavors to inspect and maintain all machines, implementing a schedule for each, including preventive maintenance.

According to (Kurniawati Agustina Dwi and Putra Pramujaya Vandy A. 2019), preventive maintenance is scheduled maintenance, generally periodic, where a series of maintenance tasks such as inspection, repair, replacement, cleaning, lubrication, and adjustment are carried out. With machines operating 24 hours nonstop in three shifts, the risk of damage increases. Therefore, the role of maintenance becomes critically important. Maintenance activities are performed to ensure that equipment functions as expected. Companies are also required to maintain the performance of their machines and the quality of the products they produce.

Table 1. Simplex Machine Downtime Data for the Month of February

No	Month	Amount of Problems	*Downtime* (Minute)
1	February	12	1526
2	March	13	4484

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3	April	34	12135
Total		**59**	**18145**

The significant downtime of the simplex machines during the period from February to April resulted in frequent failures to meet production targets. The company's current efforts to address this issue include implementing maintenance on each machine to ensure they operate efficiently.

This study aims to identify the root causes of the frequent failures in simplex machines, despite the implementation of preventive maintenance, to facilitate improvements that ensure optimal and efficient machine performance.

To address potential failures in simplex machines, the Fault Tree Analysis (FTA) method can be employed to identify the production process flow. According to (Khrisdamara and Andesta, 2022), Fault Tree Analysis (FTA) is a method used to identify the root causes of problems that lead to undesirable events. This method involves representing the sources of issues in the form of a fault tree model. Subsequently, an analysis using Failure Mode and Effect Analysis (FMEA) is conducted.

Failure Mode and Effect Analysis (FMEA), as described by (Budi Puspitasari et al.,2017), is a systematic method for identifying failures or defects in an object to determine their causes and effects, and to propose actions to address the problems. In this approach, problematic components are further analyzed to obtain the Risk Priority Number (RPN). The RPN is calculated by multiplying the severity, occurrence, and detection ratings, which can be used to determine appropriate corrective actions based on the obtained values.

METHODS

The research object is a machine in a textile company that converts cotton into yarn. The company has a specific machine called the simplex machine, which experiences more frequent breakdowns compared to other machines, making it the focus of this study.

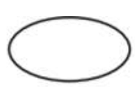
The data collection techniques for this research include direct observation, interviews, questionnaires, and literature review from books or journals. The observation method involves visiting the company to observe and record existing problems as research material. The interview method is used to obtain clearer information about the issues, aiming to identify the root causes of the simplex machine problems. Interviews were conducted with three individuals: two machine operators and one simplex machine leader who understand the machine's condition. The questionnaire method involves distributing questions to respondents related to this research. The questionnaires are useful for providing ratings on each failure mode based on occurrence, severity, and detection.

There are two types of data used in this research: primary and secondary data. Primary data is used to identify critical components and potential failures of the simplex machine, as well as to determine the causes and effects of these failures. Secondary data serves as supporting information obtained from various sources such as the company, journals, books, the internet, and other sources. The secondary data in this research includes information on simplex machine failures and downtime data for the simplex machine from February to April 2023.

Fault Tree Analysis **(FTA)**

According to (Lestari et al. ,2021), the Fault Tree Analysis method is effective in identifying the core issues as it ensures that an undesirable event or resulting loss does not originate from a single point of failure.

Table 2. FTA Terms

Simbol	Arti	Simbol	Arti
	*Basic Event* Dasar inisiasi kesalahan yang tidak membutuhkan pengembang yang lebih jauh		*External Event Event* yang diekspektasikan muncul
	*Conditioning Event* Kondisi *specify* yang dapat diterapkan ke berbagai gerbang logika		Gerbang *AND* Kesalahan manual akibat semua input masalah yang terjadi
	*Undevelopment Event Event* yang tidak dapat dikembangkan lagi karena informasi tidak tersedia		Gerbang *OR* Kesalahan muncul akibat salah satu input masalah yang terjadi

Source: (Khrisdamara & Andesta, 2022)

Failure Mode and Effect Analysis **(FMEA)**

Failure Mode and Effect Analysis (FMEA) is a structured approach to eliminate potential failure modes that may occur in the future. FMEA is a methodology used to

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evaluate failures within a system, design, process, or service. Potential failure modes are identified by assigning scores based on occurrence, severity, and detection ratings (Anthony, 2018).

a. Severity Value
Severity is the initial step in analyzing risk, measuring the magnitude or intensity of how an event affects the final outcome of a process. This impact is rated on a scale from 1 to 10, where 10 represents the most severe impact. The determination of ratings is detailed in the table below.

Table 3. Criteria and Severity Level

Criteria and *Severity* Levels		
Ranking	**Effect**	**Consequences on the Production Process**
1	No effect	In this case the form of failure does not matter
2	Very mild effect	There was no immediate effect , a small number of components had to be repaired
3	Mild effect	A small number of machines/equipment must be repaired, there is a limited effect .
4	Very low effect	Machines/tools must be sorted before use, requiring a little rework/repair on some machines/tools
5	Low effect	The machine/equipment can operate but some additional items do not/do not operate properly, the machine/equipment can be used but its performance is reduced
6	Medium effect	Problems with machines or tools, machines/tools can operate but some additional items cannot function
7	High effect	The problem with the machine/tool is quite serious, the machine can operate but its performance is reduced quite a lot

Criteria and *Severity* Levels		
Ranking	**Effect**	**Consequences on the Production Process**
8	Very high effect	Resulting in interference with the machine/tool so that it cannot be operated and loses its main function.
9	Dangerous effects with warning signs	May be dangerous, affect operational security or not comply with regulations
10	Dangerous effects without any warning signs	Can endanger operator safety, failure to affect operational safety standards set by the government, failure that occurs without warning

Source: (Aprianto et al., 2019)

b. *Occurance Value*

Once the severity rating for the process has been determined, the next step is to assess the occurrence rating. Occurrence represents the likelihood that the failure cause will occur and manifest as a failure during the production of the product. The determination of occurrence ratings can be referenced in the table below.

Table 4. Criteria and *Occurrence* Rating

Criteria and Occurrence Rating *in* FMEA		
Ranking	**Incident**	**Damage Occurrence Rate**
1	*Probability of failure* is remote	Less than 1 incident per month.
2	Low *probability of failure*	About 2 incidents per month
3	Low *probability of failure*	About 4 incidents per month

Criteria and Occurrence Rating *in* FMEA

Ranking	Incident	Damage Occurrence Rate
4	*Probability of failure* is moderate	About 6 incidents per month
5	*Probability of failure* is moderate	About 8 incidents per month
6	*Probability of failure* is moderate	About 10 incidents per month
7	*Probability of failure* is high	About 14 incidents per month
8	*Probability of failure* is high	About 16 incidents per month
9	*The probability of failure* is very high	About 18 incidents per month
10	*The probability of failure* is very high	About more than 20 events every month

Source: (Aprianto et al., 2019)

c. *Detection Value*

After obtaining the occurrence rating, the next step is to determine the detection rating. Detection serves as an effort to prevent production processes and reduce failure rates in production processes. The determination of detection ratings can be seen in the table below.

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Table 5. *Detection* Criteria and Ratings

Detection Criteria and Ratings (*Detection*)		
Ranking	**Detection**	**Verbal Criteria**
1	Detection is almost certain	The control device/system can almost certainly detect the cause/mechanism and method of failure
2	Very high detection	There is a very high probability that the control tool/system will detect the cause/mechanism of failure
3	High detection	Current control tools/systems have a high probability of detecting the cause/mechanism of failure
4	Detection is quite high	Current control tools/systems have a high probability of detecting the cause/mechanism of failure
5	Medium Detection	Control tools/systems are likely to detect moderate failures
6	Low detection	Control tools/systems to detect causes/mechanisms of low failure
7	Detection is very low	Control tools/systems to detect causes/mechanisms of failure are very low
8	Remote detection	Current control tools/systems are far less likely to detect the cause/mechanism of failure

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Detection Criteria and Ratings (*Detection*)		
Ranking	**Detection**	**Verbal Criteria**
9	Very far detection	It is very unlikely that the control device/system will detect the cause/mechanism of failure
10	Detection is completely uncertain	The control tool/system cannot detect the cause/mechanism and method of failure

Source: (Aprianto et al., 2019)

RPN = *Severity x Occurance x Detection*

RESULTS AND DISCUSSION

The data collected and used for data processing include the total machine damage data and total downtime of simplex machines in the cotton-to-yarn production from February to April 2023, as presented in Table 6.

Table 6. Simplex machine damage data

SIMPLEX MACHINE DAMAGE DATA				
No	**Date**	**Problem**	**Damage Amount**	**Time (Minutes)**
1	4.Feb.2023	Lapping Bottom Roll	1	96
2	05.Feb.2023	Lapping Bottom Roll	1	94
3	06.Feb.2023	Maintenance Repair	1	150
4	09.Feb.2023	Flayer Repair	1	77
5	13.Feb.2023	Maintenance Repair	1	85
6	17.Feb.2023	Creel Repair (2), Sensor Problem (1)	3	172
7	18.Feb.2023	Change Materials	1	313
8	20.Feb.2023	High Tension	1	83

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SIMPLEX MACHINE DAMAGE DATA				
No	**Date**	**Problem**	**Damage Amount**	**Time (Minutes)**
9	27.Feb.2023	Change Materials	2	456
10	01.March.2023	Spindle Repair	3	645
11	11.March.2023	Spindle Repair (3), Jammed Flayer (2)	5	1932
12	16.March.2023	Maintenance Repair (1), Flayer Repair (2)	3	219
13	19.March.2023	Doffing Problem	2	1688
14	02.April.2023	Spindle Repair	1	263
15	05.April.2023	Lapping Top Roll	1	98
16	06.April.2023	Lapping Top Roll	1	105
17	07.April.2023	Doffing Problem	3	2239
18	11.April.2023	Doffing Problem	2	1735
19	13.April.2023	Sensor Problem (1), Flyer Jammed (2)	3	601
20	17.April.2023	Doffing Problem	3	2326
21	18.April.2023	Doffing Problem	2	1627
22	19.April.2023	Idle Repair (2), Hight Tension (1)	3	585
23	21.April.2023	Scouring (1), Low Tension (2)	3	420
24	22.April.2023	Problem Doffing (3), Lapping Top Roll (1)	4	164
25	24.April.2023	Spindle Repair (3), Spindle Brodol (1)	4	1259
26	26.April.2023	Brodol Spindle	2	352

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SIMPLEX MACHINE DAMAGE DATA				
No	**Date**	**Problem**	**Damage Amount**	**Time (Minutes)**
27	29.April.2023	Sensor Problems (1), Idle Repair (1)	2	361
AMOUNT			59	18145

From Table 6 above, it can be observed that the maintenance carried out by the company on the simplex machines has not been effectively and efficiently implemented. Critical component failures in the simplex machines occurred frequently, totaling 59 times during the period from February to April 2023, resulting in a total downtime of 18,145 minutes. Furthermore, based on Table 6, a histogram diagram was created, as depicted in Figure 1.

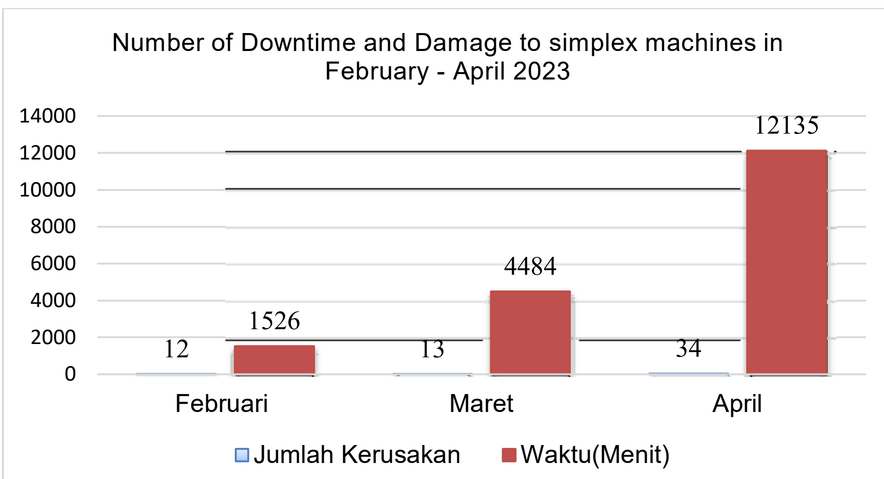

Figure 1. Histogram diagram

To find out which components are dominant in research on potential failures on simplex machines in February-April 2023, a Pareto diagram was created based on table 7.

Table 7. Number of damage to each component

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NO	Component	***Downtime*** **(Minute)**	Percentage %	cumulative
1	Doffing Problem	9615	52.99%	52.99%
2	Spindle Repair	3699	20.39%	73.38%
3	Flayer Jammed	1244	6.86%	80.23%
4	Brodol Spindle	676	3.73%	83.96%
5	Idle Repair	597	3.29%	87.25%
6	Lapping Top Roll	339	1.87%	89.12%
7	High Tension	316	1.74%	90.86%
8	Maintenance Repair	300	1.65%	92.51%
10	Sensor Problems	291	1.60%	94.11%
11	Flayer Repair	231	1.27%	95.39%
12	Scouring	226	1.25%	96.63%
13	Low Tension	194	1.07%	97.70%
14	Lapping Bottom Roll	190	1.05%	98.75%
15	Change Materials	135	0.74%	99.49%
16	Creel Repair	92	0.51%	100.00%
Amount		18145	100%	

Based on the processing from table 7, the dominant sequence of known components is in figure 2.

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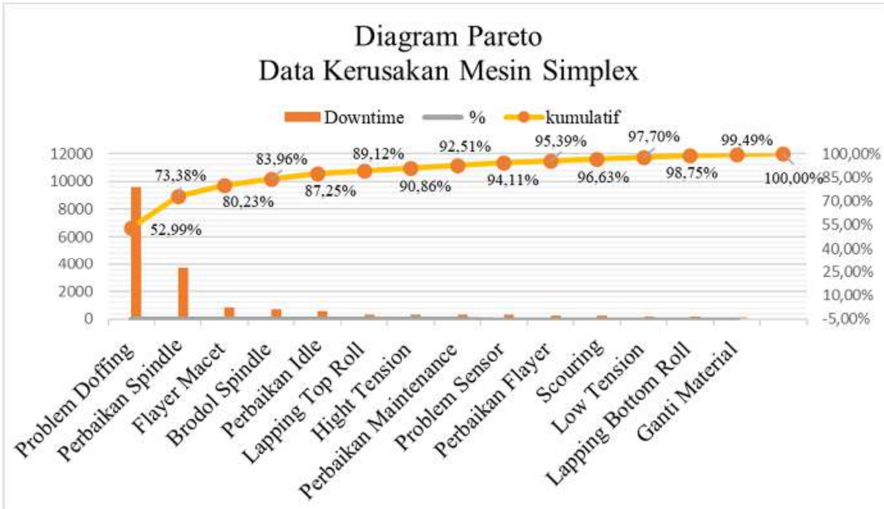

Figure 2. Pareto Diagram

According to (Koriyanti & Lia, nd) based on the *Pareto Chart* principle , known as the 80/20 principle, which means that 80% of the effects are caused by 20% of the causes. So, of the 16 engine failures, there are 3 engine damage components with a total cumulative *percentage* of 80.23%, namely *problems doffing* with a weight of 20.39%, *spindle* repair of 21%, and *flayer* jamming of 6.86% so that the main repair was focused on the damaged components .

The next step is to create a fault tree (FTA) which functions to explain the causes of damage problems of the 3 components in the form of a tree diagram. The following is a picture of *Fault Tree Analysis* (FTA):

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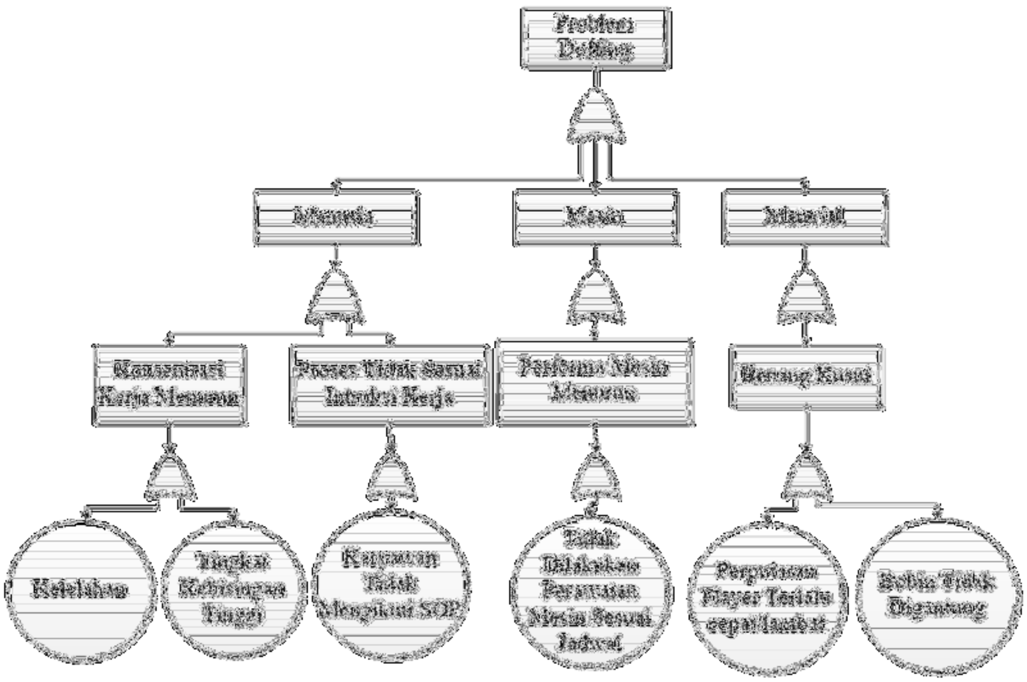

Figure 3. FTA on The _Doffing Problem Component_

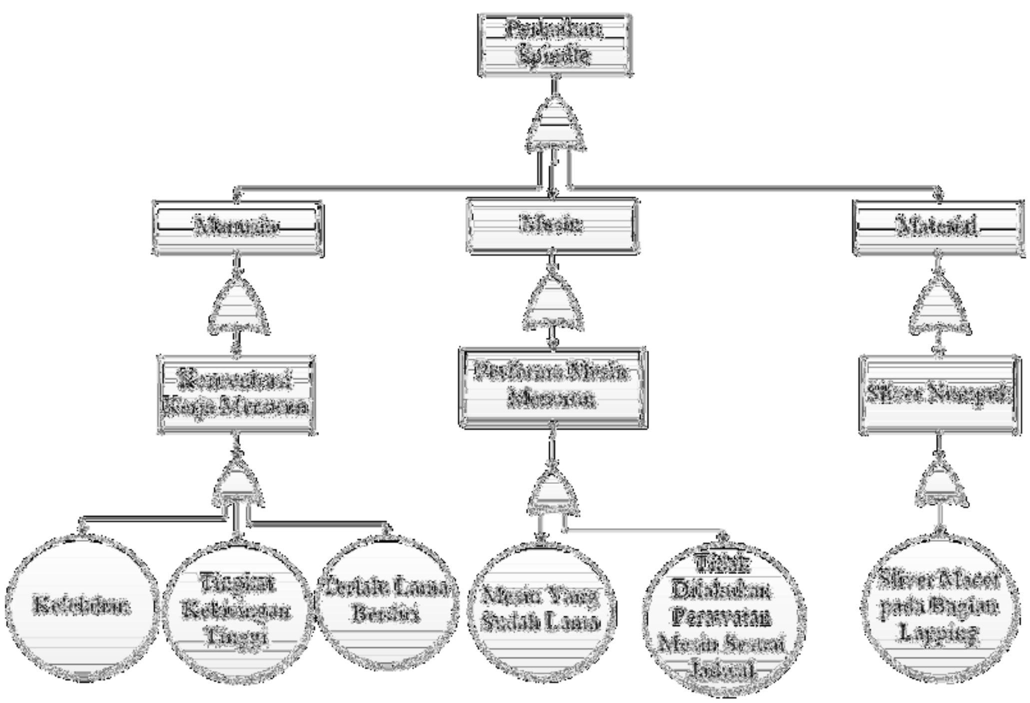

Figure 4. FTA on Spindle Repair Components

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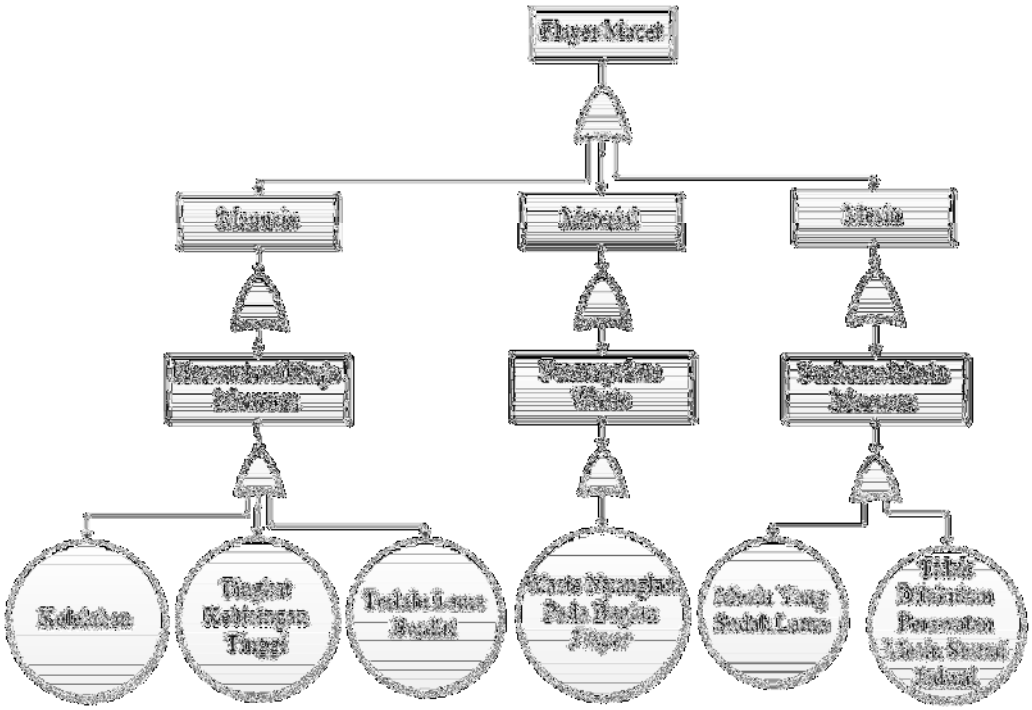

Figure 5. *FTA on The Flayer Component is Stuck*

Based on *the Fault Tree Analysis* (FTA) that has been created, the next thing to do is create a *Failure Mode and Effect Analysis* (FMEA) table which functions to provide weighting to *Severity, Occurance* and *Detection values* based on potential failure effects, causes of failure and current control processes to produce a *Risk Priority Number* (RPN) value.

Table 8. FMEA Problem Doffing Table

No	Potential Causes of Failure	S	O	D	RPN
1	Machine maintenance not carried out according to schedule	8	4	6	192
2	*Spindle* Rotation Too Fast/Slow	3	4	6	72
3	Employees Do Not Follow SOPs	6	2	5	60
4	Bobbins Not Hanging	6	2	4	48
5	Fatigue	2	2	3	12

6	High Noise Level	2	1	4	8

Table 9. Spindle Repair FMEA Table

No	Potential Causes of Failure	S	O	D	RPN
1	Old Machine	4	4	4	64
2	*Sliver Jammed In Lapping* Part	5	4	3	60
3	Machine maintenance not carried out according to schedule	4	3	4	48
4	Standing Too Long	3	4	3	36
5	High Noise Level	3	3	3	27
6	Fatigue	2	2	2	8
Total					243

Table 10. Flayer Jam FMEA Table

No	Potential Causes of Failure	S	O	D	RPN
1	*Waste* Stuck in the *Flayer*	7	6	5	210
2	Old Machine	5	4	5	100
3	Machine maintenance not carried out according to schedule	5	4	4	80
4	Standing Too Long	3	4	5	60
5	High Noise Level	3	2	4	24
6	Fatigue	1	2	3	6
Total					480

RPN calculation number 1 (*Waste* stuck in the *flayer section)* :

RPN = S x O x D

RPN = 7 x 6 x 5 = 210

Based on the largest RPN value according to the reaction that must be carried out (*recommended action*). The next step is to provide an analysis of proposed improvements using the 5W+1H (*What, Where, When, Who, Why* + *How*) method (Knop & Mielczarek, 2018) (Krisnaningsih et al., 2021) .

Improvements that will be carried out for this process are carried out based on the causes of failure which have been analyzed based on *Fault Tree Analysis* (FTA) and *Failure Mode Effect Analysis* (FMEA) so that the problems that occur are known for repairs.

Table 11. 5W + 1H Analysis of Proposed Improvements to the Doffing Problem

Jenis Kerusakan	Penyebab Kegagalan	*What* (Apa Rencana Perbaikan)	*Why* (Mengapa Perlu Dilakukan Perbaikan)	*Who* (Siapa Yang Melakukan)	*Where* (Dimana Lokasi Perbaikan)	*When* (Kapan Waktu Perbaikan)	*How* (Bagaimana Langkah Perbaikan)
Problem Doffing	Tidak Dilakukan Perawatan Mesin Sesuai Jadwal	Melakukan Pemeriksaan Berkala Sesuai Jadwal Yang Sudah Ditentukan	Untuk Meminimalisir kerusakan mesin pada mesin simplex	Mekanik bagian mesin simplex	Produksi catton pada bagian mesin simplex	Sebelum Mesin Sudah terjadi kerusakan	Perusahaan memberikan pengawasan dengan ketat dan memberi peringatan atau sanksi untuk mekanik yang tidak melakukan perbaikan atau perawatan mesin yang sudah ditetapkan penjadwalannya oleh perusahaan

Table 12. 5W + 1H Analysis of Proposed Spindle Repair Improvements

Jenis Kerusakan	Penyebab Kegagalan	*What* (Apa Rencana Perbaikan)	*Why* (Mengapa Perlu Dilakukan Perbaikan)	*Who* (Siapa Yang Melakukan)	*Where* (Dimana Lokasi Perbaikan)	*When* (Kapan Waktu Perbaikan)	*How* (Bagaimana Langkah Perbaikan)
Perbaikan *Spindle*	Mesin Yang Sudah Lama	Memperbaiki atau mengganti mesin yang sudah lama atau yang sering terjadi kerusakan	Untuk Meminimalisir kerusakan yang sering terjadi pada mesin agar proses produksi berjalan dengan lebih efisien	Mekanik dan *leader* bagian mesin simplex	Produksi catton pada bagian mesin simplex	Sebelum mesin mengalami kerusakan total	Bagian mekanik bisa lebih ekstra melakukan perawatan pada mesin atau bagian leader dan perusahaan melakukan pergantian mesin dengan membeli mesin baru atau melakukan pertukaran mesin dengan mempertimbangkan juga pengeluaran perusahaan.

Table 13. 5W + 1H Analysis of Proposed Flayer Jam

Jenis Kerusakan	Penyebab Kegagalan	*What* (Apa Rencana Perbaikan)	*Why* (Mengapa Perlu Dilakukan Perbaikan)	*Who* (Siapa Yang Melakukan)	*Where* (Dimana Lokasi Perbaikan)	*When* (Kapan Waktu Perbaikan)	*How* (Bagaimana Langkah Perbaikan)
Flayer Macet	*Waste* Nyangkut Pada Bagian *Flayer*	Pembersihan waste secala berkala	Untuk Meminimalisir flayer macet yang sering terjadi pada mesin agar proses produksi berjalan dengan lebih efisien	Operator yang sedang melakukan proses produksi	Produksi catton pada bagian mesin simplex	Sebelum terjadinya komponen flayer macet	Selalu membersihkan waste dengan cara meniupnya dari bagian atas mesin atau di ambil manual lewat bawah mesin

CONCLUSION

Based on the data processing results and discussion regarding simplex machine failures to identify the root causes, the following conclusions can be drawn:

In the cotton yarn production process, there are three frequently occurring component failures in the simplex machines: doffing problems, spindle repairs, and flayer jams.

Based on the Fault Tree Analysis (FTA) conducted, the potential failures in the simplex machines are attributed to three factors: human, machine, and material.

By analyzing component failure issues using the Failure Mode Effect Analysis (FMEA) method, the potential failure causes for each component of the simplex machine can be identified as follows:

1. Doffing problems arise due to the lack of scheduled machine maintenance, caused by insufficient mechanics to perform maintenance or repairs, with an RPN of 192.
2. Spindle repairs are needed due to decreased machine performance caused by aging machinery, with an RPN of 64.
3. Flayer jams occur due to waste accumulation, specifically waste getting stuck in the flayer, with an RPN of 210.

Based on the 5W+1H analysis, the proposed improvements for each component aim to reduce potential machine failure risks as follows:

1. For doffing problems caused by the lack of scheduled maintenance, the company should strictly supervise and issue warnings or sanctions to mechanics who do not perform the scheduled maintenance or repairs.
2. For spindle repairs due to aging machinery, the mechanical department should perform extra maintenance, or the company should consider replacing old machines with new ones or exchanging machines, taking into account the company's expenses.
3. For flayer jams caused by waste getting stuck, it is recommended to regularly clean the waste by blowing it from the top of the machine or manually removing it from the bottom.

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