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Reliability, Availability, Maintainability, and Safety Analysis of Finger Joint Fu-King Furnimate Machine in Wood Manufacturing Industry

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Abstract. *The objective of this research was to investigate the performance of the Finger Joint Fu-King Furnimate machine, especially for the most critical component of this machine. Based on historical data of machine damage, the Finger Joint Fu-King Furnimate is the machine that has the highest-level frequency of damage. Reliability, Availability, Maintainability, and Safety (RAMS) methods are proposed to analyze the machine's historical data. The result shows that the reliability of machine performance at t = 160 hours is only 27.42%, but the availability of machines is quite high, which passed the standard of 95%. Meanwhile, the maintainability of the machine is relatively fast, which the repair time of its critical component is 8 hours. The low-reliability critical machine spare part affected the safety of the spare part which the Safety Integrity Level (SIL) in the lowest standard (level 1). In general, the novelty of this research is to combine the application of the RAM method as the basis for analyzing machine performance with a safety analysis of the selected critical machine subsystems.*

Keywords: *availability; key performance indicator; maintainability; reliability; safety.*

I. Introduction

Machine maintenance is a very important activity for the success of the production process. Companies that use machine technology must always maintain the condition of the machines used, such as maintaining machine stability, maintaining cleanliness, and machine effectiveness to minimize the risk of damage that may occur and produce quality products. Good machine maintenance activities can improve machine reliability and performance. A well-organized maintenance system is needed to support the smooth production of all machines used. Because, for medium and small-scale companies, maintenance of production equipment, plants, or machines is often less of a concern for the company (Atmaji, 2015).

Machine maintenance is an action that is performed to keep a system or piece of equipment in good working order or to restore its previous state (Dhillon, 2006). According to (Afiva et al., 2019) Machine and equipment maintenance are an activity that returns the function of a machine, equipment, or system to its original operating level for optimal results. Maintenance management is a systematic approach to maintenance that includes planning, scheduling, and monitoring maintenance activities to keep components or systems in good condition or repair damaged components to get them back to working order (Garg & Deshmukh, 2006). The company's management should make a concerted effort to set equipment reliability and maintenance goals. The availability of resources, workforce management, and maintenance planning methods are all factors in maintenance management (Tsarouhas, 2018).

The machine maintenance system is generally divided into two main parts: preventive maintenance and corrective maintenance (Atmaji & Putra, 2018). Preventive and corrective maintenance are the two forms of machine maintenance that are classified depending on their function (Koussaimi et al., 2016). The goal of machine maintenance is to extend the life of components, maintain optimal machine levels, and support the machine's capacity to satisfy its

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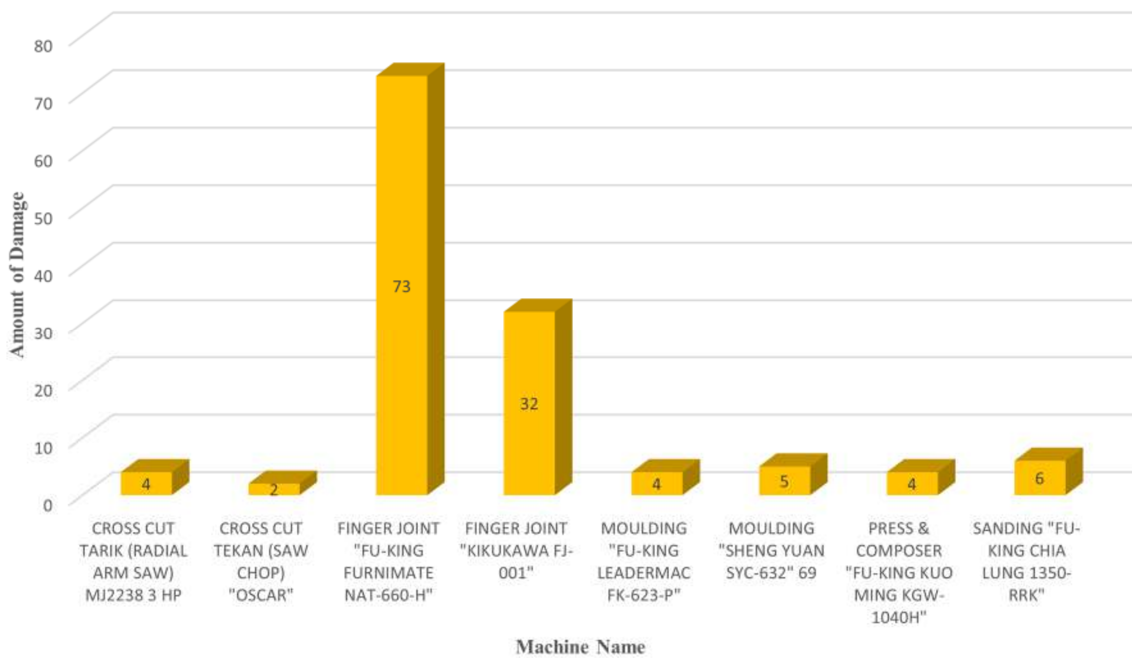

Figure 1. The frequency of damage in the FJLB production process line.

function's requirements (Ansori & Mustajib, 2013).

The focus of this research is on the manufacturing of pine or Finger Joint Laminating Board (FJLB). Every machine in the company's manufacturing facility is critical to the production process. The firm cannot be separated from the problem of machine damage where machine performance is not optimal and can afflict the company owing to the tight production schedule due to the pursuit of production targets.

The Finger Joint Fu-King Furnimate machine has the highest frequency of machine breakdowns for one year, as shown in Figure 1. The Finger Joint Fu-King Furnimate machine has a significant impact on the FJLB production process, and if it is destroyed, it will harm the output target.

The company currently uses a corrective maintenance strategy, which entails performing maintenance only when the unit is damaged. Machine downtime will rise because of improper maintenance. The machine's reliability value decreases because of the high frequency of failures. So, to keep the machine reliability value stable, research is essential to evaluate the reliability, availability, and maintainability values of the Finger Joint Fu-King Furnimate machine to reduce losses to the company due to high machine downtime.

The study of Tsarouhas (2018) provides the results of complete reliability, availability, and maintainability (RAM) analysis using datasets from the wine packaging line production system. Using an illustrated case study, the author shows how RAM analysis can help determine maintenance intervals and plan to organize appropriate maintenance strategies (Tsarouhas, 2018). In the research of Choudary et al. (2019), India's cement demand is expected to grow rapidly as the government boosts various housing estates on a large scale. This increase in cement demand can be countered, among other things, by increasing the utilization of existing cement plants by improving availability. Cement plant availability can be improved by avoiding failures and reducing maintenance times through reliability, availability, maintainability analysis (RAM) of its subsystems (Choudhary et al., 2019). In the study of Tsarouhas (2019), the purpose is to calculate reliability, availability, and maintenance index (RAM) to measure and improve the performance of automated croissant production lines under real-world working conditions. Based on his research, P. Tsarouhas show how RAM analysis can help determine maintenance intervals and plan and organize appropriate maintenance strategies (Tsarouhas, 2019).

As a result of the RAM approach, the reliability, availability, maintainability, which will be valuable for firms to evaluate machine performance. However, the safety factor of the machine was not yet considered for most of the previous research.

In this study, a safety variable was added to determine the Probability Failure on Demand and Risk Reduction Factor in the subsystems. With the Safety Integrity Level on the critical subsystems, it will reduce the high frequency of machine breakdowns, optimizing a maintenance strategy.

II. RESEARCH METHOD

The critical subsystem of the finger joint fu-king furnimate machine is the focus of this research because the finger joint fu-king furnimate is the machine that has the highest breakdown frequency in the production line. The data used in this research is data on the damage of the finger joint fu-king furnimate machine in the year 2020. Figure 2 shows the flow of the research's methodology.

The first step in researching the Finger Joint Fu-King Furnimate machine, as shown in Figure 2, is to perform a System Breakdown Structure to determine the machine subsystem. According to Fusaro and Viola, (2018) SBS is the first step in identifying the components to be analyzed further. The goal is to divide the system into smaller parts called subsystems and differentiate them based on their function to make it easier to understand the function of these parts (Fusaro & Viola, 2018). Then use the risk matrix to find out the critical subsystems on the machine by classifying the impact and possible risks that may occur during machine failure. Before creating a risk matrix, several risk aspects need to be considered. For each risk, likelihood and severity are assessed, then a risk assessment is carried out to produce a risk matrix (Moss et al., 2019).

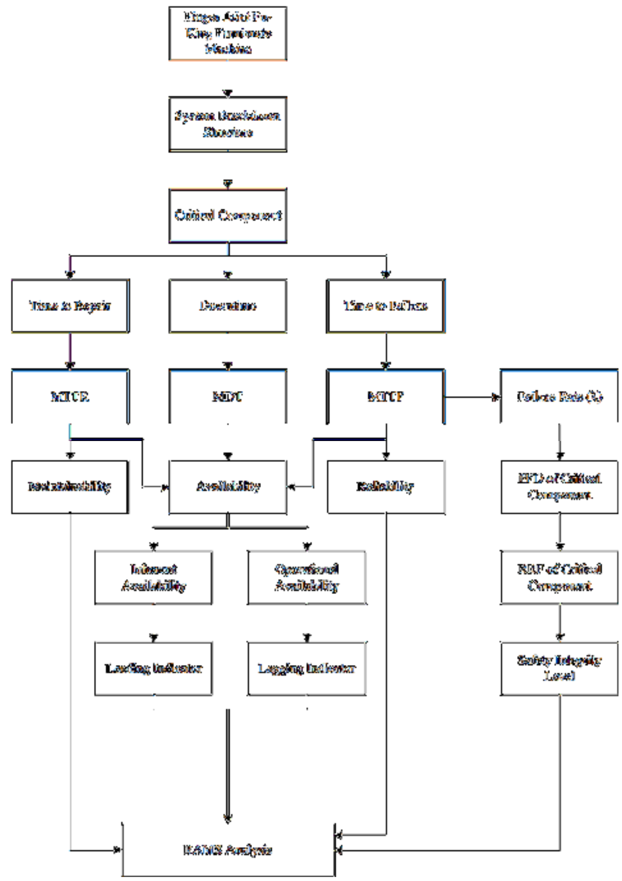

Figure 2. Research Methodology

They move to quantitative measurements, such as calculating the machine's Time to Repair (TTR), Downtime (DT), and Time to Failure (TTF), after obtaining the crucial subsystem of the FJ Furnimate machine. The calculation then proceeds on to the Mean Time to Repair (MTTR), Mean Downtime (MDT), and Mean Time to Failure (MTTF). The average time it takes for a component or system to fail is known as the Mean Time to Failure (MTTF). The mean time to failures (MTTF) is a common metric for assessing reliability. (Larrucea et al., 2017), while MTTR is the average time required to repair a component or system to restore its function (El-Metwally et al., 2018). The following equation shows the MTTR, MDT, and MTTF distribution types:

Normal distribution:

$$MTTR = \mu \quad (1)$$

Exponential distribution:

$$MTTR = \frac{1}{\lambda} \quad (2)$$

Weibull distribution:

$$MTTR = \eta \times \Gamma(1 + \frac{1}{\beta}) \quad (3)$$

Where:

η = Distribution parameters
λ = Failure rate
Γ = Gamma
β = Weibull distribution parameter

The reliability calculation is performed using MTTF after getting MTTR, MDT, and MTTF. The probability of a component or system performing its tasks correctly during operation time for a given period is known as reliability (Choudhary et al., 2019). According to Hasan, Ahmed, & Tahar, (2015) The Reliability Block Diagram (RBD) model is used to model complex failure relationships between the system and its subsystems. It can be widely used to analyze the reliability, availability, dependability, and maintainability of many machining systems (Hasan et al., 2015).

MTTR, MDT, and MTTF are used to calculate the availability value. Defining availability is a measure of the time it takes for a component or system to perform its function (Larrucea et al., 2017). In Tsarouhas's research, (2019) Availability can be increased by increasing the value of reliability and maintainability of a component or system (Tsarouhas, 2019).

MTTR is used to calculate the maintainability value. Sikos & Klemeš Research, (2010) Explaining maintainability is the probability of success of a system or component that will operate again in its original state within a certain period (Sikos & Klemeš, 2010).

Furthermore, the calculation of safety is carried out using MTTF and lambda values or the rate of damage. Fusaro & Viola Studies, (2018) said safety is freedom from conditions that can cause the failure of the whole system. Within the scope of maintenance, safety analysis on the system can be defined by the Safety Integrity Level (SIL). SIL is the range of system security levels. SIL represents probability failure on demand (PFD) and risk reduction factor (RRF) (Fusaro & Viola, 2018). According to IEC 61508, SIL has 4 levels, as seen at Table 1.

Table 1. Safety Integrity Level

Safety Integrity Level	Probability Failure On-Demand (PFD)	Risk Reduction Factor (RRF)
4	< 0.0001	>10000
3	0.001-0.0001	1000-10000
2	0.01-0.001	100-1000
1	0.1-0.01	10-100

III. RESULT AND DISCUSSION

The first step in calculating RAMS is to perform a system breakdown structure. The breakdown system structure of the FJ Furnimate machine can be seen in Figure 3.

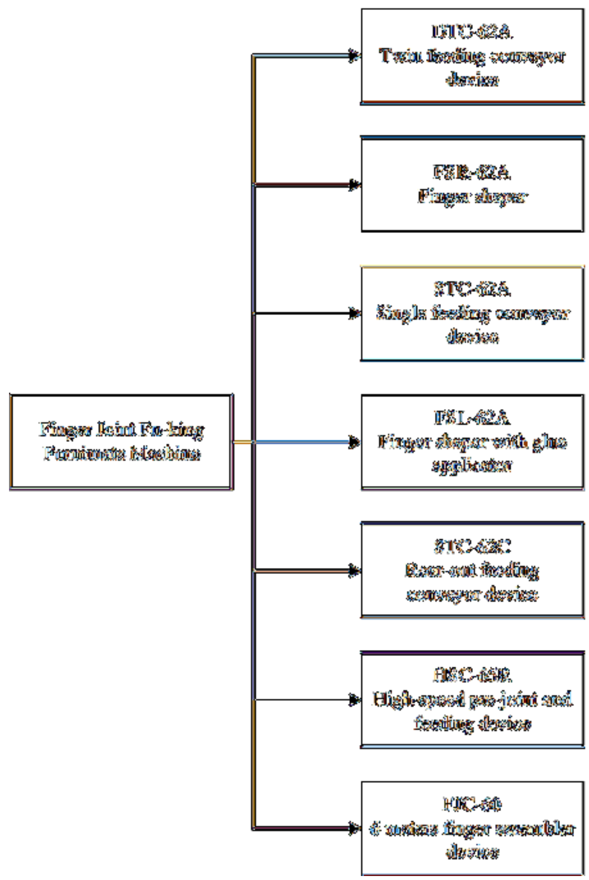

Figure 3. System Breakdown Structure

The goal of identifying critical subsystems is to find the ones that pose the biggest risk of harm during machine operation. An evaluation of severity and likelihood scales is used to identify critical subsystems, which is then transformed into a risk matrix to explain the selected critical subsystems. Severity and likelihood are the two matrix values in the risk matrix.

Table 5. Risk Matrix Subsystem FJ Furnimate Machine

Likelihood	Severity				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost Certain (5)			FSL-62A, FJC-60		
Likely (4)			HSC-65R		
Possible (3)		FSR-62A			
Unlikely (2)		STC-62C			
Rare (1)	DTC-62A	STC-62A			

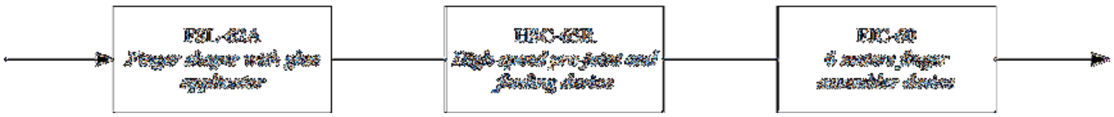

Figure 4. Reliability Block Diagram Critical Subsystem

In Table 2, it can be concluded that there are 4 types of colors in the risk matrix. That is, green indicates low risk, yellow indicates moderate risk, orange indicates a high risk that requires immediate improvement and red indicates high risk and urgently needs improvement. Based on table 2, there are three important subsystems in the red area, namely the FJC-60, FSL-62A, and HSC-65R subsystems. After getting the critical subsystem, the calculation proceeds to the next stage.

The application of the reliability block diagram is intended to show the relationship between reliability and availability characteristics on the critical subsystem of the FJ Furnimate machine. The following figure shows the operating system of the critical subsystem of the FJ Furnimate machine.

Figure 4 shows that the working system of the FJ Furnimate machine is arranged in series because each subsystem of the work system is integrated. Failure in one subsystem can affect the performance of other subsystems.

Time to Failure, Time to Repair, and Downtime Distribution

Through the Anderson-Darling test, it can be determined a representative distribution of time to failure, time to repair, and downtime data on a critical subsystem of the finger joint Fu-King Furnimate machine. This distribution test compares the distribution between the normal, exponential, and Weibull distributions. Determination of distribution is done by examining the Anderson-darling (AD) and P-

Table 2. Result of TTF Distribution Test

Subsystems	Distribution	AD Value	P-Value	Selected Distribution
FJC-60	Normal	1,861	<0,005	Weibull
	Exponential	1,047	0,097	
	Weibull	0,412	>0,250	
FSL-62A	Normal	1,087	0,006	Weibull
	Exponential	0,290	0,828	
	Weibull	0,250	>0,250	
HSC-65R	Normal	0,540	0,122	Exponential
	Exponential	0,245	0,883	
	Weibull	0,274	>0,250	

Table 3. Result of TTR Distribution Test

Subsystems	Distribution	AD Value	P-Value	Selected Distribution
FJC-60	Normal	0,553	0,136	Normal
	Exponential	5,824	<0,003	
	Weibull	0,604	0,107	
FSL-62A	Normal	0,166	0,930	Weibull
	Exponential	5,680	<0,003	
	Weibull	0,164	>0,250	
HSC-65R	Normal	0,559	0,114	Weibull
	Exponential	2,514	<0,003	
	Weibull	0,543	0,156	

Table 4. Result of DT Distribution Test

Subsystems	Distribution	AD Value	P-Value	Selected Distribution
FJC-60	Normal	0,669	0,070	Normal
	Exponential	6,158	<0,003	
	Weibull	0,979	0,012	
FSL-62A	Normal	0,432	0,279	Normal
	Exponential	6,255	<0,003	
	Weibull	0,511	0,196	
HSC-65R	Normal	0,435	0,244	Weibull
	Exponential	2,298	0,003	
	Weibull	0,409	>0,250	

Value. The AD value shows a representative distribution in the distribution of the data, where the smaller the AD value, the more representative the distribution of the tested data. While the value of P-Value is used as a parameter of acceptance of H0 provided that if the P-Value > α, then H0 is accepted. This test was carried out using Minitab 19 software with a 95% confidence level.

Tables 3, 4, and 5 shows selected distribution for time to failure, time to repair, and downtime data.

Calculation of MTTF, MTTR, and MDT

MTTF, MTTR, and MDT of the selected critical component distributions were tested with Minitab 19 software. The next step is to use AvSim+ 9.0 software to find parameters for each distribution. In Table 6, the MTTF value for the FJC-60 subsystem is 403,705 hours, the FSL-62A subsystem is 431,476 hours, and the HSC-65R subsystem is 770,154 hours. In Table 7, the MTTR value of the FJC-60 subsystem is 0.9605 hours, the FSL-62A subsystem is 0.9439 hours, and the HSC-65R subsystem is 1.5038 hours. In Table 8, the MDT value of the FJC-60 subsystem is 1.2159 hours, the FSL-62A subsystem is 1.1096 hours, and the HSC-65R subsystem is 1.8495 hours.

Reliability

Reliability calculation requires TTF data. The time variable determined is the independent variable with a time duration of between 8 hours to 160 hours with an interval of 8 hours. Based on the reliability calculation using an analytical approach from the critical subsystem, it is found that the probability of the subsystem to function properly for 8 to 160 hours. Figure 5 is a graph of the results of reliability calculations using an analytical approach.

Based on the calculation of the value of system reliability, the company can see that the reliability of the system at t = 8 hours is 88.40% and has decreased quite far at t = 160 hours, which is 27.42%. The largest decrease in system reliability occurred at t = 16 hours, which was 7.41%, and based on the IVARA standard, system reliability was set at 80%. So that the optimal time for the finger joint fu-king furnimate machine is at t = 16 hours with a system reliability value of 80.99%.

Table 6. Result of MTTF Calculation

Critical Subsystems	Selected Distribution	$\Gamma(\frac{1}{\beta}+1)$	MTTF (Hour)
FJC-60	Weibull	1.25430	403.705
FSL-62A	Weibull	1.10373	431.476
HSC-65R	Exponential	-	770.154

Table 7. Result of MTTR Calculation

Critical Subsystems	Selected Distribution	$\Gamma(\frac{1}{\beta}+1)$	MTTR (Hour)
FJC-60	Normal	-	0.9605
FSL-62A	Weibull	0.90861	0.9439
HSC-65R	Weibull	0.89566	1.5038

Table 8. Result of DT Calculation

Critical Subsystems	Selected Distribution	$\Gamma(\frac{1}{\beta}+1)$	MDT (Hour)
FJC-60	Normal	-	1.2159
FSL-62A	Normal	-	1.1096
HSC-65R	Weibull	0.89328	1.8495

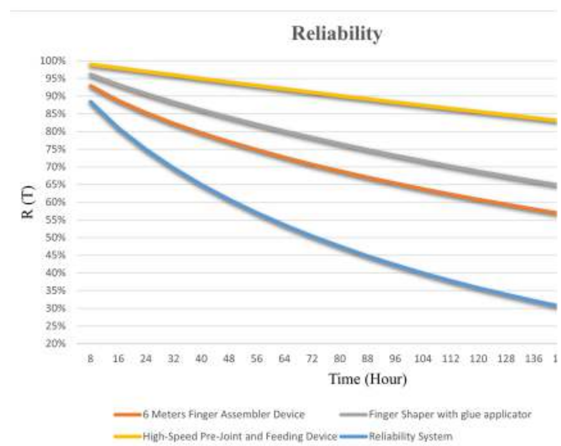

Figure 5. Graphic of Reliability Calculation

Table 9. The Result of Inherent Availability Critical Subsystems

Critical Subsystems	MTTF	MTTR	Inherent Availability
FJC-60	403.705	0.960455	99.76%
FSL-62A	431.476	0.943891	99.78%
HSC-65R	770.154	1.503843	99.81%

Inherent Availability

The calculation of inherent availability uses MTTF and MTTR data for the critical subsystems of the FJ Furnimate machine, namely FJC-60, FSL-62A, and HSC-65R. Table 9 is the result of the calculation of inherent availability.

Operational Availability

Furthermore, the calculation of operational availability is carried out using the operational time of the FJ Furnimate machine for one year and downtime data from the FJ Furnimate machine. Table 10 is the result of calculating operational availability on the FJ Furnimate machine subsystem.

Maintainability

In the calculation of maintainability, the data used is the TTR data for each critical subsystem. In this study, the observations used are within 1 to 10 hours where (t) is the independent time variable to get the optimal time to achieve optimal maintenance or 100%. The following figure shows the maintainability calculations for the critical subsystem of the FJ Furnimate machine

In Figure 6, after calculating the maintainability using the analytical approach in a period of 1 to 10 hours, the FJC-60 subsystem achieved the best performance at t = 6 hours, the FSL-62A subsystem achieved the best performance at t = 6 hours, and the HSC-65R subsystem achieves the best performance at t = 8 hours, then maintainability of the system can reach 100% when repaired is at t = 8 hours. The calculation of the maintainability value is influenced by the MTTR of each subsystem. The smaller the MTTR, the faster the subsystem will achieve the best performance when repaired.

Safety

The SIL calculation process includes several steps, namely calculating the probability failure on demand (PFD), calculating the rate of damage (λ), and calculating the safety integrity level (SIL). Table 10 shows the results of the SIL calculation on the critical subsystem of the FJ Furnimate machine when Ti = 16 (the largest decrease in reliability calculations), so that the following results are obtained.

Table 10. The Result of Operational Availability Critical Subsystems

Critical Subsystems	Operational Time	DT	Operational Availability
FJC-60	4680	1.21591	99.97%
FSL-62A	4680	1.10955	99.98%
HSC-65R	4680	1.84946	99.96%

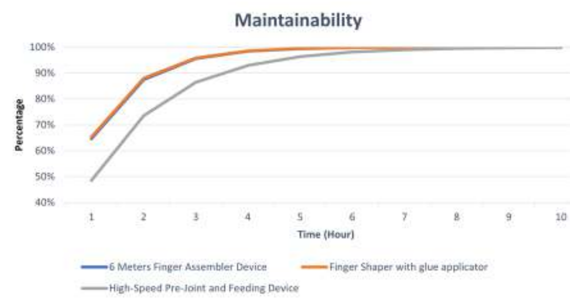

Figure 6. Graphic of Maintainability Calculations

Table 11. The Result of Safety Integrity Level Calculation

Critical Subsystems	t (Hour)	λ	PFD	RRF	SIL
FJC-60	16	0.00248	0.020	50.4632	1
FSL-62A	16	0.00232	0.019	53.9345	1
HSC-65R	16	0.00130	0.010	96.2693	1

Table 12. The Result of Maintenance Key Performance Indicator

Indicator	Value	Target (95%)
Leading Indicator	99.53%	Achieved
Lagging Indicator	99.92%	Achieved

Based on table 11, shows that the FJC-60 subsystem has the highest failure rate or damage rate of 0.00248. In terms of the PFD value, the maximum value obtained is 0.020 on the FJC-60 subsystem. The PFD value will affect the RRF value. The RRF value of the FJC-60 subsystem is lower than the other subsystems. The highest RRF value is 96.2693 on the HSC-65R subsystem. The three critical subsystems get the lowest value in the SIL level, which is 1 where the highest level based on the IEC 61508 standard is 4. A high damage rate can cause a low SIL level and if the damage rate is low it can increase the SIL value.

Maintenance Key Performance Indicator

The calculation of the leading and lagging indicators shows the level of performance of the critical subsystem of the FJ Furnimate machine in

Table 12. In table 12, the value of the leading indicator and lagging indicator in the system has reached the IVARA standard or the company's target of 95%, and the availability of the system has passed the key performance indicator.

Findings based on P. Tsarouhas., (2018) study is the three most important factors that affect the maintainability process of a production line are resource availability, human resource management, and maintenance planning procedures (Tsarouhas, 2018).

Based on Choudary et al., (2019), the analysis shows that cement plant repair times need to be reduced to improve cement plant availability. According to RAM analysis, the case study company's capacity was 17% unused due to maintenance issues and 15% due to management issues (Choudhary et al., 2019).

Tsarouhas (2019) found that the method used was to understand the nature of failure patterns and to accurately quantify the reliability and maintenance characteristics of croissant production systems. The analysis identifies key points on the production line that needs to be further improved through effective maintenance strategies (Tsarouhas, 2019)

The contribution of this research, besides analyzing the RAM of the machine, also adds a safety value that is useful for analyzing the safety integrity level of the machine. When the value of the safety integrity level can be known, then actions to improve the maintenance strategy can also be determined.

IV. CONCLUSION

This research found that FJC-60 is a subsystem that has the lowest reliability value because has the lowest MTTF value among the others. Meanwhile, the calculation of the maintainability value is affected by the MTTR of each subsystem. The smaller the MTTR, the faster the subsystem will achieve the best performance when repaired.

The assessment is carried out using a key performance indicator based on the RAMS calculation, where the leading indicator is inherent availability and the lagging indicator is operational availability, which has exceeded the target indicator by 95 percent based on world-class maintenance key performance indicator standards. However, the machine's reliability is low, and the safety level in the three important subsystems of the Finger Joint Fu-King Furnimate machine is one of four SIL levels. Based on the IEC 61508 standard, this shows that the level of machine safety is at its lowest.

The low-reliability critical machine spare part affected the safety of the overall spare part. A high failure rate can cause the SIL level to be lower and if the failure rate is low, it can increase the SIL value. So, to increase the reliability and SIL value, it is necessary to reduce the rate of damage, or increase the MTTF value, accelerating the repair or decreasing the MTTR value.

This research is supposed to serve as an insightful effort to perform full RAMS analysis in highly facilitated areas of the wood manufacturing industry. It also provides a useful data analysis source for the wood manufacturing industry to improve its maintenance strategy. The roles of reliability, availability, maintainability, and safety are recognized as important strategic variables and are important to be considered in future studies to assess the performance and success of an organization.

This research has not yet considered the cost and availability of spare parts, as well as an appropriate machine maintenance schedule so that in future research can review the availability of spare parts using the RCS (Reliability Centered Spares) method and the machine maintenance schedule using the RCM (Reliability Centered Maintenance) method.

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