Preventive maintenance scheduling using the periodic replacement and repair count limit policy approach on the vacotin water heaters machine at PT XYZ

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ABSTRACT

Manufacturing companies often face challenges in maintaining machine performance to avoid operational losses. PT. XYZ is a company engaged in the flat glass production sector. The company experienced problems from water heater engine damage caused by several factors, the main problem found was the frequent occurrence of extended failures due to maintenance errors that increased the risk of damage to the engine and stopped production. Therefore, the use of the Intensity Function is a concept that can predict engine failure by involving historical analysis of the damage using Weibull and exponential distributions to predict the time of failure. Thus, this analysis results in two maintenance policies that are compared, namely the Periodic Replacement Policy (Policy 4) and the Repair Count Policy (Policy 5). The results of the study show that Policy 4 with an optimal time to replace the engine every 923 hours or 39 days, results in lower maintenance costs (Rp 11,447,000) compared to Policy 5 (Rp 15,500,000) and an estimate where engine damage will begin to occur every T=200 and it is recommended to repair and replace the Main Unit every T=800. In conclusion, updating the preventive maintenance schedule with the implementation of Policy 4 can minimize maintenance costs and the risk of machine damage, thereby increasing the company's operational efficiency.

1. Introduction

Industrial companies are required to work effectively and efficiently in producing a quality product or service (Simanungkalit et al., 2023). This is becoming increasingly important in the era of globalization and increasingly fierce competition, where consumers have many choices and expect products or services that meet high-quality standards. One of the production factors that needs to be increased in its use is production machinery. The machine used in the production process must be able to run optimally (Sajaradj et al., 2019). Machine operation is considered efficient when its downtime is low. To ensure efficient machine operation, a suitable machine care and maintenance system is required. An optimal machine maintenance system is a system that is able to develop a maintenance schedule with minimum downtime to produce minimum total costs, damage to a component that is not detected during the production process can affect performance and even damage other components related to the component concerned (Syaripudin et al., 2022). Generally, the improvement of a machine that is higher or more often used in a production system, the role of maintenance management in a system becomes more and more important (Nasution et al., 2021).

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Machine maintenance in the manufacturing industry plays a crucial role in maintaining production efficiency and output quality. In the era of increasingly fierce global competition, a company's ability to maintain machine reliability through planned maintenance is one of its competitive advantages (Huang et al., 2020). One of the most common maintenance approaches is preventive maintenance, where equipment is maintained regularly before damage occurs to reduce downtime and repair costs (Siregar & Munthe, 2019).

PT. XYZ is a company that produces flat glass with an installed aggregate production capacity of 720,000 tons for sheet glass, 5,800,000 square meters for safety glass, and 6,800,000 square meters for mirrors. This large annual capacity makes it not only the largest glass producer in Indonesia but also in Southeast Asia. The process in the production of flat glass that needs to be considered is one of the most important things in the glass cooling process which is considered quite crucial in the success of production. This glass cooling process aims to reduce the temperature of the glass which was initially at 100-140 degrees Celsius to 80 degrees Celsius by spraying water with a temperature of 60 degrees Celsius. This process is a process that cannot be missed because cooling this glass is needed for the glass breaking process so that there is no failure or defect during the glass breaking process. The company is facing significant challenges in managing the maintenance of the Vacotin Water Heater NTEC machine. These machines often suffer unexpected damage, causing a decrease in production efficiency and potential financial losses due to high downtime. Mishandling in the implementation of maintenance is often the root of the problem that causes extended failure.

Research that has been conducted by (Harja & Nugraha, 2019), using the Weibull distribution method and calculating the MTBF value by proposing an update to the PM schedule of the curing machine to consider the addition of new PM activities that accommodate the expected life time duration value of the components that cause engine breakdowns, so as to minimize unplanned downtime. Other research conducted by (Alfionita & Alifin, 2023), using preventive maintenance with MTBF and MTTR obtained results that suboptimal maintenance by company staff and other root causes have the potential to affect the implementation of PM as indicated by a high Risk Priority Number (RPN) score. Other research was also conducted by (Muzakki, 2021), using preventive maintenance with age replacement obtained results that showed that one of the optimal replacement intervals was for 23 days for sensor components with a replacement cost of Rp. 77,625,000 which reduced the previous maintenance cost of Rp. 99,900,000. The research was also conducted by (Dzulyadain et al., 2020), using a maintenance policy with Reability Centered Maintenance (RCM) obtained results with the RCM method, a maintenance policy was obtained for the critical brake subsystem, namely 2 scheduled on condition tasks and 2 scheduled restoration tasks. Meanwhile, the research conducted by (Riki & Murnawan, 2023), using preventive maintenance with MTBF obtained the result that the cost of maintaining the machine using preventive maintenance resulted in a smaller total maintenance cost of Rp.7,100,000, per year compared to the previous breakdown maintenance cost which reached Rp.12,070,741, the total cost expenditure was smaller if implementing preventive maintenance so that this method was right for use by the company. However, most existing studies treat periodic replacement and minimal repair as separate strategies without evaluating their combined cost-effectiveness in a real industrial context. To the best of our knowledge, no previous research has applied and compared both Policy 4 and Policy 5 on aging-critical heating equipment like the Vacotin Water Heater, using real failure data. This study fills this gap by integrating both approaches and identifying the optimal preventive maintenance interval based on Weibull-distributed failure behavior.

Although many studies have discussed the optimization of maintenance schedules, there is still a gap in the application of methods that comprehensively consider a combination of cost factors, repair time, and frequency of breakdowns in machines with unique characteristics such as Vacotin Water Heater. Previous research has tended to focus on just one aspect, such as cost or time, without considering the synergy of the two in the context of a specific company. Based on the problems that occur in the company's existing condition and the gaps that occur. Therefore, it is necessary to propose an update of the preventive maintenance schedule to reduce the risk of damage and maximize engine performance (Dhamayanti et al., 2016). This study aims to propose an update of the preventive maintenance schedule on the Vacotin Water Heater machine at PT. XYZ using the Weibull distribution method and the optimal maintenance policy approach. The proposed solution is expected to reduce the total cost of maintenance, reduce downtime, and improve the company's overall operational efficiency. The proposal for a more optimal preventive maintenance schedule will help PT.

XYZ reduces the downtime of the Vacotin Water Heater machine which has been a major obstacle in the production process, by adopting the right maintenance policy, the company can minimize the cost of sudden repairs (corrective maintenance) and reduce the frequency of damage, thereby reducing overall operational costs, and the proposed solution is expected to improve machine reliability, extend machine life, and ensure that the production process runs without interruption Significant. The purpose of this research is to propose an update of the preventive maintenance schedule on the Vacotin Water Heater machine at PT XYZ by analyzing historical damage data using Weibull and exponential distributions. By comparing Policy 4 (Periodic Replacement) and Policy 5 (Repair Count), this study determines the optimal maintenance interval that minimizes costs, reduces downtime, and improves machine reliability.

2. Methods

The research object in this study is the NTEC Vacotin Water Heater machine used at PT XYZ. This machine functions as a large-scale water heater used in the glass cooling process at the production stage. This machine is very crucial to maintain product quality because it affects the glass cutting process after cooling. The focus of this research is to propose an updated preventive maintenance schedule for the Vacotin Water Heater machine by considering the minimum cost and reducing the frequency of damage by using the Weibull and exponential distribution methods in damage analysis as well as maintenance policies based on cost and number of damage. This study is descriptive quantitative, using historical data of engine failures to determine the optimal preventive maintenance schedule (Lepenioti et al., 2020). The following is the flow of this research can be seen in Fig. 1.

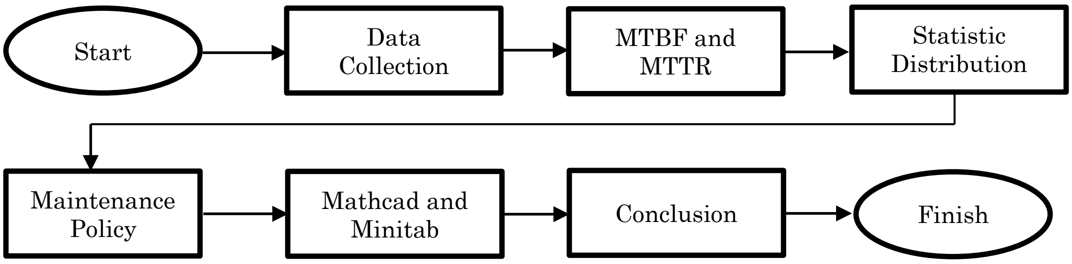

Fig. 1 Research flow.

Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR)

Mean Time Between Failure (MTBF) is a metric used to measure the average time it takes before a device or system fails. The higher the MTBF of a device or system, the more reliable it is. MTBF indicates the average amount of time expected between two failures on that product or system. The higher the MTBF value, the more reliable the product or system. MTBF can be mathematically calculated by the formula:

$$MTBF = \frac{(\text{Total operational time} - \text{Downtime})}{(\text{Number of failure})} \quad (1)$$

Mean Time to Repair (MTTR) is a measure used in equipment maintenance management to assess the average time it takes to repair equipment that is experiencing damage or interference. MTTR is one of the key performance indicators used to measure efficiency in repairing equipment so that companies can maintain productivity and reduce unplanned downtime. MTTR can be mathematically calculated by the formula:

$$MTTR = \frac{\text{Downtime}}{(\text{Number of failure})} \quad (2)$$

To calculate MTTR, it is necessary to collect data on the start and completion times of equipment repairs and the number of repairs carried out during a certain period. Furthermore, the total repair time is divided by the number of repairs made to get the average repair time per repair.

Statistic Distribution

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Damage distribution is a pattern followed by damage data where each damage data has different characteristics. There are several types of distributions that are often found, namely Weibull distributions, exponential distributions, normal distributions, lognormal distributions, gamma and so on. In the distribution research that will be used is the Weibull and exponential distribution.

Exponential Distribution

Exponential distribution is a type of probability distribution that is typically used to model the time between two events that occur randomly and independently. An exponential distribution has a single parameter, referred to as the degree of damage, that controls the level of damage that occurs to a system. In the context of damage distribution, exponential distribution is used to model the time between component or system failures. This distribution is often used in system reliability analysis and can provide an estimate of how often failures can occur in a system. By using exponential distribution on damage distribution, reliability analysis can be performed to identify the level of failure of a system, estimate the average time between failures, and plan effective maintenance policies to minimize damage and extend the life of the system. In an exponential distribution, there is a parameter used, namely the scale parameter (θ), the following are the functions that this exponential distribution (Alifin, 2024):

a. Cumulative Distribution Function

$$\text{CDF} = F(t) = 1 - e^{\left(\frac{-t}{\theta}\right)},\ t>0 \quad (3)$$

b. Probability Density Function

$$PDF = f(t) = \frac{1}{\theta} e^{\left(\frac{-t}{\theta}\right)},\ t>0 \quad (4)$$

c. Survival/Reliability Function

$$Survival\ Function = \bar{F}(t) = 1 - F(t), t > 0 \quad (5)$$

d. Intensity Function

$$(t) = \frac{f(t)}{\bar{F}(t)} = \frac{\frac{1}{\theta} e^{\left(\frac{-t}{\theta}\right)}}{e^{\left(\frac{-t}{\theta}\right)}} = \frac{1}{\theta} \quad (6)$$

Weibull Distribution

The Weibull distribution is one of the probability distributions used to describe the time of failure or the life time of a product or system. Weibull distributions are often used in reliability analysis to model damage distributions and predict future damage times. Weibull distributions can be used to estimate various parameters, such as mean time between failures (MTTF), failure rate (hazard rate), and reliability level. This distribution has the advantage of its ability to accommodate data that is both asymmetric and abnormal. By using Weibull distribution, companies or organizations can make smarter decisions in maintenance planning, risk management, and product or system quality improvement.

Use on Weibull's distribution method to obtain components that cause frequent breakdowns (Sulistyo & Mutiawati, 2021). In this distribution, there are several parameters, namely the scale parameter (α) and the shape parameter (β). The following are the functions of this weibull distribution, which are as follows (Alifin, 2024).

a. Cumulative Distribution Function

$$\text{CDF} = F(t) = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\beta}},\ t>0 \quad (7)$$

b. Probability Density Function

$$PDF = f(t) = \frac{dF(t)}{dt} = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} e^{-\left(\frac{t}{\alpha}\right)^{\beta}},\ t>0 \quad (8)$$

c. Survival/Reliability Function

$$Survival\ Function = \bar{F}(t) = 1 - F(t), t > 0 \quad (9)$$

d. Intensity Function

$$\lambda(t) = \frac{f(t)}{\bar{F}(t)} = \frac{\frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} e^{-\left(\frac{t}{\alpha}\right)^{\beta}}}{e^{-\left(\frac{t}{\alpha}\right)^{\beta}}} = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} \quad (10)$$

Maintenance Management

According to (Alifin, 2024), in System Maintenance about repairable systems, there are several policies, one of which is policies 4 and 5. In the repairable system maintenance policy, namely policy 4 regarding the periodic replacement policy, the policy is as follows:

1. The product has a fixed maintenance schedule for T that cannot be changed.
2. If there is product damage before the T schedule, the product will be minimally repaired or minimally repaired.

If damage occurs before the predetermined maintenance schedule, then, in a repairable system, the form of corrective maintenance is in the form of minimal repair with minor repairs such as cleaning dust, dirt on the engine, oil spills and others. Every product change will return the product to prime condition or a new product because in this policy 4 the preventive maintenance time is fixed for a period (0.t). So, the Expected Cycle Length (ECL) is as follows:

$$ECL = T \quad (11)$$

Description:

ECL = Expected Cycle Length

T = Fixed time

In modeling maintenance policies, it must pay attention to the potential or possibility that will occur. In this policy 4, there are 2 possibilities, namely the product is definitely replaced at the time or point of PM or the product is damaged before the PM schedule. If the product is damaged before the preventive schedule will be repaired immediately with minimal repair, then there will be PM and CM fees. In addition, the time when the product is damaged or replaced preventively is considered 0 or ignored. So the total maintenance cost expectation for policy 4 is with the following formula:

Total maintenance cost expectations= $C_{mr} + C_{r2}$

$$ECC(T) = C_{r2} + C_{mr} \wedge (T) \quad (12)$$

Description:

C_{mr} = Corrective maintenance cost (minimal repair)

C_{r2} = Preventive maintenance costs with replacement,

$\wedge (T)$ = Amount of damage

Based on the ECL and ECC equations, the expected maintenance cost per unit time (J(t)) is:

$$E[J(T)] = \frac{ECC(T)}{ECL(T)} = \frac{C_{r2}+C_{mr}\wedge(T)}{T} \quad (13)$$

The optimal maintenance policy in policy 4 is when the periodic preventive schedule can minimize the value of J(T). Therefore, the policy 4 optimization problem is as follows:

$$\underset{T}{Min}\{E[J(T)]\} \quad (14)$$

In the repairable system maintenance policy, namely policy 5, namely repair count policy with product maintenance policy as follows:

a. If the product is damaged, it will be repaired immediately in a corrective manner with minimal repair.
b. The product will be replaced at the time of the kth damage or repair during the time span (0,t).
c. As long as the number of damage or repairs has not reached the kth number, policy number 1 still applies.

Each product replacement will return the product to its prime condition because in policy 5 the occurrence of replacement depends on whether the product reaches the kth time damage or not. All damage up to k-1 will be repaired minimally, then the first damage pattern will have a Non-Homogeneous Poisson Process (NHPP) probability distribution with the following formula:

$$q_k(T) = \frac{[\wedge (T)]^{k-1} e^{-\wedge(T)}}{(k-1)!} \lambda(T)$$

$$ECL(T,k) = \int_0^{T=\infty} x\, q_k(x) dx \quad (15)$$

Description:

∧(T) = Expected amount of damage

λ(T) = Intensity of damage

e = Exponential number

k = Damage limit

If the damaged product will be repaired immediately with minimal repair as long as the number of damage is k-1, there will be corrective maintenance costs (minimal repair), then the total maintenance cost expectation for policy 5 is as follows:

$$ECC(k) = C_{r2} + C_{mr}(k-1) \qquad (16)$$

Note:

ECC = Expected total maintenance cost

C_{r2} = Expected cost of CM (Replacement)

$C_{mr}(k-1)$ = Expected CM cost (minimal repair)

Based on the ECL and ECC equations, the expected maintenance cost per unit time (J(t)) is as follows:

$$E[J(T,k)] = \frac{ECC(k)}{ECL(T,k)} = \frac{C_{r2}+C_{mr}(k-1)}{\int_0^{T=\infty} xq_k(x)dx} \qquad (17)$$

The optimal maintenance policy in policy 5 is when the number of breakdowns (k) determined can minimize the value of J(k) because the main decision variable in policy 5 is the value of k not t (time). Therefore, the optimization problem is as follows:

$$\min_{k}\{E[J(k)]\} \qquad (18)$$

If the data is Weibull distributed, then the optimal k can be used by using the formula:

$$k^* = \left\lfloor \frac{\left(\frac{C_{r2}}{C_{mr}}\right)-1}{\beta-1} \right\rfloor + 1 \qquad (19)$$

3. Results and Discussion

At PT XYZ has a batch of damage to the vacotin water heater machine that is uncontrollable, so it is categorized as an extended failure, this damage can be classified as Catastrophic damage, which is caused by mishandling maintenance, because it greatly affects production performance. The following is an image of the vacotin water heater main unit that controls the heater on the machine can be seen in Fig. 2.

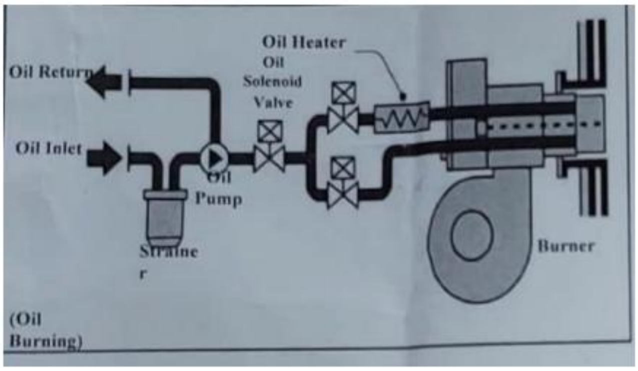


Fig. 2 Main unit vacotin water heater.

Fig. 2 above is an illustration of the main unit vacotin water heater that controls the heater on the machine which often experiences damage and must be given full attention. Based on the staff's statement, it is known that for pre-ordering it is enough to spend 5 million rupiah, but if the order is made for the same day's needs, it must pay an additional fee of 7.5 million rupiah because the unit comes from the 2nd party. For minimal machine repair costs, it is enough to use the services of a company engineer at a cost of 200 thousand rupiah, but for more in-depth repairs it is necessary to call a specialist engineer who costs 500 thousand rupiah. Thus, a batch of damage has been found on the vacotin water heater machine number 2 in the Cold 2 Department and a sample of historical damage data is taken in Table 1.

Table 1 Historical damage sample data

Nth damage	Time of damage	Date
0	13:45:00	18/11/2023
1	14:35:00	19/11/2023
2	14:45:00	20/11/2023
3	15:30:00	21/11/2023
4	17:25:00	22/11/2023
5	16:00:00	23/11/2023
6	19:30:00	24/11/2023
7	12:10:00	26/11/2023
8	19:30:00	28/11/2023
9	11:30:00	28/11/2023
10	03:30:00	28/11/2023

The known damage time and if converted into Time to Failure and Time Between Failure will be as in the Table 2.

Table 2 Historical NTEC vacotin water heater engine damage data (repairable system)

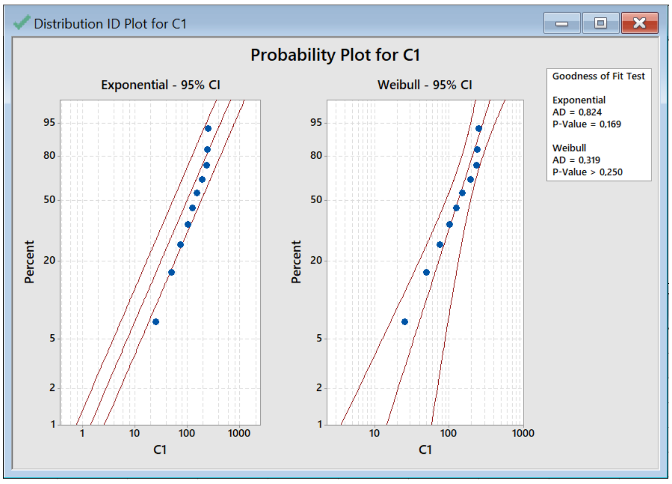
Nth damage	*Time to Failure* (t-unit clock)	*Time between Failure*
1	24.83	24.83
2	49.00	24.17
3	73.75	24.75
4	99.67	25.92
5	122.25	22.58
6	149.75	27.50
7	190.42	40.67
8	229.75	39.33
9	237.75	8.00
10	245.75	8.00
	MTBF	24.58

This MTBF is obtained from the formula, namely:

$$MTBF = \frac{\sum_{i=1}^{n} TBF}{n} \quad (20)$$

MTBF=245.8/10=24.5 hours

Based on that, in order to be able to provide proposals for updating the preventive maintenance schedule when a batch of damage occurs. Statistical distribution identification is carried out using a minitab, it is known that Fig. 3 below shows the estimated distribution to be used:



ML Estimates of Distribution Parameters

Distribution	Location	Shape	Scale	Threshold
Exponential			142,29167	
Weibull		1,89867	160,10694	

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Fig. 3 Estimated distribution to be used

With the help of calculations using the Minitab application, it is known that of the two distributions, it is found that the P-value of both is the same, which is more than 0.05, but what will be used is the Weibull distribution because the P-value of the Weibull distribution is greater than the exponential distribution and based on the graph on the Weibull distribution there is no data that comes out or outliers in contrast to the exponential distribution which has outliers. So, what will be used is the Weibull distribution with scale and shape values from time to failure data from historical machine damage data, and obtained data as in Table 3.

Table 3 Parameter values

Notation	Value	Information
Cr2	Rp 5,000,000	PM Cost for Replacement
Cr1	Rp 7,500,000	CM Cost for Replacement
Cmr	Rp 200,000	CM Cost for Minimal Repair
Cm2	Rp 500,000	CM Cost for Perfect Repair
Tm2	4	Average repair time with perfect repair (hour)
α	160.10694	Weibull distribution scale parameter
β	1.89867	Weibull distribution shape parameters

After knowing some important variables above, we can apply data processing to find the optimal time to repair vacotin water heater machine damage based on minimum cost by comparing the use of Policy 4 (Periodic Replacement Policy) and Policy 5 (Repair Count).

The following is a calculation for policy 4, namely the Periodic Replacement Policy:

Unknown:

$\alpha = 160.10694$

$\beta = 1.89867$

$C_{r2} = 5000$

$C_{mr} = 200$

Answer:

$A(t) = \left(\frac{t}{\alpha}\right)^{\beta}$

$ECL(t) = t$

$ECC = C_{r2} + C_{mr} - \wedge (t)$

$J(t) = \frac{ECC(t)}{ECL(t)}$

$t = 100$

$t *= Minimize(J(t))$

$t *= 922.83$

$J(t *) = 11.447$

$ECC(T *) = 10560$

From the Mathcad solution above, it can be obtained that the optimal time to replace based on policy 4 is at time 922.83 time units, where the minimum cost rate is Rp. 11,447,000.

The following is a calculation for policy 5, namely Repair Count):

Unknown:

$\alpha = 160.10694$

$\beta = 1.89867$

$C_{r1} = 7500$

$C_{mr} = 200$

Answer:

$$k^* = \left\lfloor \frac{\left(\frac{C_{r1}}{C_{mr}}\right) - 1}{\beta - 1} \right\rfloor + 1$$

k_opt = floor (k)

$$\wedge(t) = (\frac{t}{\alpha})^{\beta}$$

$$\lambda(t) = \frac{t}{dt}\wedge(t)$$

$$q(t) = \frac{[\wedge(t)]^{k\_opt-1}e^{-\wedge(T)}}{(k\_opt-1)!}\lambda(t)$$

$$ECL(t) = \int_0^{\infty} x\,q(x)dx$$

$$ECC = C_{r1} + (k\_opt - 1)C_{mr}$$

$$J(t) = \frac{ECC}{ECL(t)}$$

k_opt = 41

J(20) = 6.932 x 10^{15}

ECC = 1.55 x 10^{4}

Based on the results of the Mathcad calculation, the optimal damage limit is k* = 41, which means that if the product is damaged, the product will be replaced without any minimum repair and with a minimum cost of J(k*) = Rp. 6,932,000 per unit time. Meanwhile, the total maintenance cost is Rp.15,500,000. After all parameters are obtained, the results of plotting several failure functions with scale parameters (α) and shape parameters (β) to the Weibull distribution equation are also obtained, as follows:

CDF = $F(t) = 1 - e^{-\left(\frac{t}{\propto}\right)^{\beta}}$, t>0

F(t) = $1 - e^{-\left(\frac{t}{160.1}\right)^{1.89}}$, t>0

$PDF = f(t) = \frac{dF(t)}{dt} = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} e^{-\left(\frac{t}{\propto}\right)^{\beta}}$, t>0

$f(t) = \frac{dF(t)}{dt} = \frac{1.89}{160.1}\left(\frac{t}{160.1}\right)^{1.89-1} e^{-\left(\frac{t}{.60,1}\right)^{1.89}}$, t>0

Survival Function= $\bar{F}(t) = 1 - F(t), t > 0$

$\bar{F}(t) = 1 - F(t), t > 0$

$$\lambda(t) = \frac{f(t)}{\bar{F}(t)} = \frac{\frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} e^{-\left(\frac{t}{\propto}\right)^{\beta}}}{e^{-\left(\frac{t}{\propto}\right)^{\beta}}} = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1}$$

$$\lambda(t) = \frac{f(t)}{\bar{F}(t)} = \frac{1.89}{160.1}\left(\frac{t}{160.1}\right)^{1.89-1}$$

Next is to enter the value of t<0<1000 to see changes in CDF, PDF, Survival Function, and intensity Function values shown in Table 4.

Table 4 Failure function plotting results

T<0<1000				
T	CDF	PDF	Survival Function	Intensity Function
100	0.335792	0.002373	0.664208	0.007769
200	0.782516	0.001352	0.217484	0.014483
300	0.962913	0.000594	0.037087	0.020851
400	0.996616	0.000235	0.003384	0.027002
500	0.999832	0.000088	0.000168	0.032998
600	0.999995	0.000032	0.000005	0.038873
700	1.000000	0.000011	0.000000	0.044648

T<0<1000				
T	CDF	PDF	Survival Function	Intensity Function
800	1.000000	0.000004	0.000000	0.050341
900	1.000000	0.000001	0.000000	0.055962
1000	1.000000	0.000000	0.000000	0.061519

After plotting the failure function, Fig. 3 shows the graph of the intensity function and Fig. 4 shows the graph of changes in the cumulative distribution function, probability distribution function, and survival function.

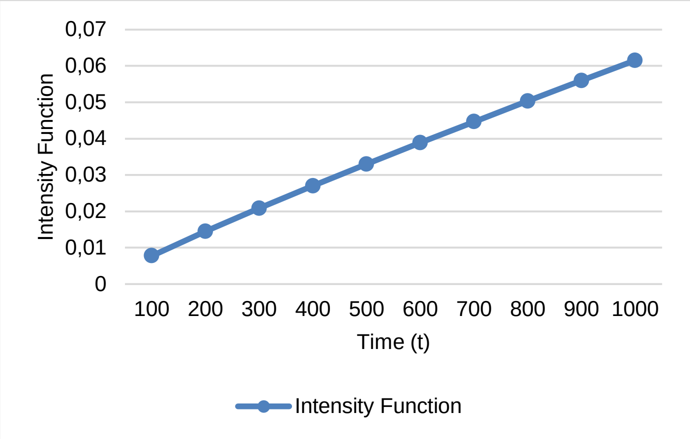

Fig. 4 Intensity function graph.

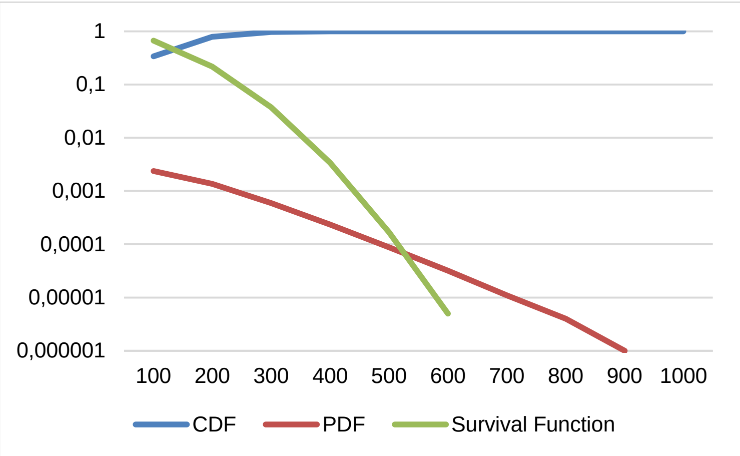

Fig. 5 Failure function plotting graph.

Based on the data processing above, the Mean Time Between Failure (MTBF) value is 24.5 hours. After plotting the failure function and it can be seen that the intensity function graph continues to increase at t starting from 0 to 1000. So, it indicates that the possibility of damage will occur with the chance of the percentage of engine damage every t>800 above 50% and at t>200 hours the graph will continue to increase due to continuous use. Intensity function indicates that damage will increase significantly over time, if there is no good product maintenance. In the cumulative distribution function results, it is found that at time (t) 200 hours, the probability of damage is already 78% and at t> 600 hours the machine will have a probability of damage of more than 90% and close to 100% damage, this graph will continue to increase every time until the chance of 100% damage. It is inversely proportional to the probability distribution function and survival function which is decreasing because the longer the time used, the performance of the machine will decrease and even run out so that it needs repair or replacement. This is also supported by data from the survival function, namely the possibility of the machine still operating normally at 200 hours is 21% which means very low and at time t> 600 hours the possibility of the machine operating normally is 0% or the machine cannot operate. This is different from the intensity function which tends to increase based on Figure 3, indicating that over time the machine will experience damage. So, at the time between 100 to 200 hours there must be preventive maintenance.

In machine maintenance, the cost aspect needs to be considered so that the company does not experience over cost. The consideration of the total cost used for maintenance can be done by comparing the maintenance policy of the repairable system in policy 4 and 5. Based on data processing of the minimum cost per policy, the following is Table 5 containing comparison data from policy 4 and 5.

Table 5 Comparison of total minimum cost of policy 4 and 5

Variable	Policy 4	Policy 5
T*	922.83	
K*		41
J*	Rp 11,447,000	Rp 15,500,000

This study presents several limitations that should be acknowledged. First, the analysis is based on only 10 recorded failure events from a single production line, which may limit the robustness of the reliability and cost estimations due to the small sample size. Second, the model assumes perfect minimal repair during corrective actions, whereas in real industrial settings, the quality of repairs may vary and influence the future failure behaviour of the equipment. Third, the results are derived from short-term simulation and have not yet been validated over longer operational horizons. Therefore, further studies using larger and more representative historical data are necessary to confirm the proposed preventive maintenance schedule and ensure its practical applicability in real-world operations. According to the table above, the results obtained are by considering the policy that has the minimum total cost. Thus, policy 4 is more recommended because it results in a smaller total maintenance cost than policy 5, which is Rp 11,447,000. So, policy 4 can be used, namely by replacing the machine regularly for 923 hours or 39 days to minimize the use of excess costs. Policy 4 yields a lower total maintenance cost in the Vacotin Water Heater context primarily because the machine exhibits an aging behaviour, as indicated by the Weibull shape parameter $\beta = 1.89867$ ($\beta > 1$), signifies that the failure rate increases over time, meaning the longer the machine operates, the more likely it is to fail. In such conditions, Policy 4 which performs preventive replacement at fixed intervals effectively prevents failures from escalating as the hazard rate steepens. By replacing the component at 923 hours intervals (before the risk sharply increases), Policy 4 minimizes unplanned downtime and high corrective costs, unlike Policy 5 which allows multiple minor repairs before replacement, leading to higher cumulative costs due to frequent failures as the machine ages.

4. Conclusion

Based on the research that has been done, it can be concluded that the Mean Time Between Failure (MTBF) is 24.5 hours. Early preventive repairs have the potential to indicate damage that is not predicted by the company. Intensity function indicates the chance that engine damage occurs at t ranging from 0 to 1000, namely every t>800 above 50% so that it tends to increase and indicates that over time the engine will be damaged. The Cumulative Distribution Function shows that at 200 hours the probability of damage is already 78%. Supported by the survival function, the possibility of the machine still operating normally is 21%, which means it is very low. So, it indicates that between 100 to 200 hours there must be preventive maintenance, and damage will increase significantly over time if there is no good maintenance.

Future research is recommended to address the limitations of this study by incorporating a larger dataset across multiple production lines to improve the statistical robustness of the reliability models. It is also suggested to evaluate additional maintenance policies, such as condition-based maintenance or hybrid strategies, to compare their cost-effectiveness under different operating conditions. Furthermore, future studies could explore non-ideal repair models that account for imperfect repairs or partial restorations, which may better reflect actual industrial maintenance practices. Finally, implementing and validating the proposed maintenance schedule in real-time industrial settings over an extended period will be essential to assess its long-term effectiveness and adaptability.

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