E-ISSN 2503 - 1430
ISSN 2541 - 3090

Journal Of Industrial Engineering Management

(JIEM Volume 9. No 1 Tahun 2024)

SCHEDULING MAINTENANCE PROPOSAL FOR TURBINE MACHINES USING THE AGE REPLACEMENT METHOD AT BALAMBANO HYDROELECTRIC POWER PLANT PT. Vale Indonesia Tbk.

Rahmaniah Malik[2], Nurhayati Rauf[2], Takdir Alisyahbana[3], Arfandi Ahmad[4*] Asrul Fole[4]
Institution of Author[1], Institution of Author[2], Institution of Author[34],
[1,2,3,4*] Department of Industrial Engineering, Faculty of Industrial Technology, Muslim University of Indonesia
E-mail: rahmania.malik@umi.ac.id[1], nurhayati.rauf@umi.ac.id[2]
takdir.alisyahbana@umi.ac.id[3], asrulfole@umi.ac.id[4], Arfandi.ahmad@umi.ac.id[5*]

Article history:
Submitted 23 May 2023
Revised 2 February 2024
Accepted 20 April 2024
Available online 30 April 2024

ABSTRACT

PT. Vale Indonesia Tbk. is a company engaged in the mining industry, particularly in nickel processing (Ni). The company operates a power plant at Balambano Hydroelectric Power Plant (2x68.5 MW). The company's usual maintenance practice is limited to corrective maintenance, which involves replacing or repairing components only when they are damaged. The aim of this research is to determine the optimal replacement time for preventive maintenance on turbine machines in order to minimize downtime. The age replacement method is used to calculate the replacement interval for components based on their usage life. The research findings show that the mean time to failure (MTTF) of the wicket gate is 2217.824 hours or 92.41 days, which means that the component may experience failure again after operating for that MTTF duration. Therefore, the recommendation is to replace the component every 85 days of operation and perform inspections every 15 days.

Keywords: **Scheduling, corrective maintenance, Machine maintenance, Age Replacement method**

Published By:
Fakultas Teknologi Industri
Universitas Muslim Indonesia
Address :
Jl. Urip Sumoharjo Km. 5 (Kampus II UMI)
Makassar Sulawesi Selatan.
Email :
Jiem@umi.ac.id
Phone :
+6281341717729
+6281247526640

DOI : http://dx.doi.org/10.33536/jiem.v9i1.1841

1. INTRODUCTION

Maintenance refers to all the necessary activities to keep facilities and machines in good condition, ensuring they continue to function properly (Bokrantz *et al.*, 2020). These activities include checking, lubricating, repairing any damages, and adjusting or replacing components of equipment or facilities (Lozada-Cepeda, Lara-Calle and Buele, 2021; Patel, 2021). The goal of maintenance is to preserve tools, ensure smooth operation of production tools and machinery, and maintain a safe installation (Wang, Guo and Wang, 2022). It also aims to improve the efficiency of production units, extend the lifespan of machines, buildings, and equipment, create ideal working conditions, and uphold the overall condition of facilities (Qin *et al.*, 2022).

Maintenance is categorized into two types: preventive maintenance, which focuses on preventing issues before they occur, and corrective maintenance, which involves addressing problems after they arise (Xiang and Feng, 2021).

PT. Vale Indonesia Tbk. is a company involved in the mining industry, specifically in nickel processing (Ni). The company operates three Hydropower Plants (HPPs), namely Larona HPP (2x65 MW + 1x68.5 MW), Balambano HPP (2x68.5 MW), and Karebbe HPP (2x68.5 MW). One of the main components in HPPs, besides the generator, is the turbine. The turbine is responsible for generating electrical power by utilizing the force of water to rotate its blades (Yadav, Kumar and Jaiswal, 2023). It converts the potential energy of falling water into kinetic energy. Therefore, the turbine is a crucial aspect in the functioning of the generator unit in HPPs.

The production process in HPPs is continuous, so if any machine or equipment experiences damage or failure, it can result in the entire system's shutdown. Sudden machine or equipment failures pose a problem at Balambano HPP, leading to operational downtime and the need to halt production for repairs. This is due to machine failures or malfunctions during production (Kang, Catal and Tekinerdogan, 2020).

The company usually performs only corrective maintenance, which involves replacing or repairing components when they are damaged. The turbine machine at Balambano HPP had its last unit replacement in 2011, so the turbine machine is now approximately 12 years old. The components that experienced damage in the turbine machine include the Governor, Turbine Shaft, Wicket Gate, Creep Detector, and Vibro Smart. Specifically, the wicket gate component suffered damage. The cause of the damage was the continuous operation of the machine without regular maintenance (Achouch *et al.*, 2022). There have been multiple breakdowns in the turbine machine. In particular, the wicket gate required the replacement of bushing wicket gate 12 times from April 2021 to December 2022, resulting in breakdowns whenever replacement or repair of damaged components/spare parts was carried out.

Every machine's breakdown cannot be precisely predicted. Therefore, it is necessary to implement machine/equipment maintenance actions to prevent such breakdowns (Yang *et al.*, 2020). One effective strategy to ensure continuous machine operation is to determine the optimal maintenance interval, aiming to minimize downtime and facilitate the production process (Lee *et al.*, 2020; Fole and Kulsaputro, 2023b). Hence, this research employs the preventive maintenance method for scheduling turbine machine maintenance(Inyiama and Oke, 2021).

Preventive maintenance is a scheduled maintenance approach typically carried out periodically (Huang, Chang and Arinez, 2020; Wang *et al.*, 2020). It involves various activities such as inspection, repair, replacement, cleaning, lubrication, adjustment, and alignment (Wang *et al.*, 2020). Preventive maintenance refers to care and maintenance activities performed to prevent unexpected breakdowns and identify conditions that could cause product facilities to malfunction during production. The aim of this research is to determine the optimal preventive replacement time for turbine engines to minimize downtime.

2. METHODS

In implementing the age replacement method in this research, the following steps are undertaken: firstly, identifying the critical machine; secondly, determining the distribution of data between failure times and repair times. Next, in the third step, the mean time to failure (MTTF) and mean time to repair (MTTR) are established. Finally, the turbine machine replacement time at PT. Vale Tbk is calculated.

3. FINDINGS AND DISCUSSION

3.1. Determining Critical Components

The following is the determination of the critical machine with the largest downtime of 425.5 hours or 65.56% of the cumulative downtime percentage for the Turbine machine.

3.2. Determination of the Distribution of Data between Failure Times (Time to Failure)

The data is collected from the start of failure (failure start time) until it is successfully repaired (finish repair time). The Time to Failure (TTF) results for the wicket gate component can be seen in Table 1.

Table 1. Time to Failure for the Wicket Gate Component

Wicket Gate				
No	**Date**	**Start Downtime**	**Downtime is over**	**TTF**
1	08/04/2021	07:00:00	15:00:00	0,0
2	26/04/2021	06:00:00	18:00:00	423
3	27/04/2021	07:00:00	18:00:00	13
4	29/11/2021	07:00:00	19:00:00	5173
5	30/11/2021	07:00:00	19:00:00	12
6	01/12/2021	07:00:00	19:00:00	12
7	05/12/2021	07:00:00	19:00:00	84
8	12/12/2021	07:00:00	20:00:00	156
9	15/12/2021	07:00:00	19:30:00	59
10	16/08/2022	07:00:00	15:00:00	5867,5
11	18/08/2022	07:00:00	15:30:00	40
12	04/12/2022-17/122022	07:00:00	19:30:00	2895,5

Based on the data determination in the above Table 1, it can be observed that the data for the 12 months, ranging from 2021 to 2022, reveal the lowest value of TTF in the first month, which is 0.0. Additionally, the highest TTF value is observed in the 10th month, reaching 5867.5. These findings indicate the outcomes of the company's investigations.

Table 2. Exponential Distribution Time to Failure

Wicket Gate							
i	**ti (hours)**	**xi = ti**	**F(ti)**	**yi**	**xi * yi**	**xi^2**	**yi^2**
1	12	12,00	0,0614	0,0634	0,7604	144,00	0,00402
2	12	12,00	0,1491	0,16	1,94	144,00	0,026
3	13	13,00	0,2368	0,27	3,51	169,00	0,073
4	40	40,00	0,3246	0,39	15,70	1600,00	0,154
5	59	59,00	0,4123	0,53	31,36	3481,00	0,282
6	84	84,00	0,5000	0,69	58,22	7056,00	0,480
7	156	156,00	0,5877	0,89	138,22	24336,00	0,785
8	423	423,00	0,6754	1,13	475,99	178929,00	1,266
9	2895,5	2895,50	0,7632	1,44	4170,57	8383920,25	2,075
10	5173	5173,00	0,8509	1,90	9844,14	26759929,00	3,621
11	5867,5	5867,50	0,9386	2,79	16372,02	34427556,25	7,786
Total	14735	14735	5,5	10,257	31112,434	69787264,5	16,55312
Index of Fit				**0,9289**			

Based on the results of determining TTF in the exponential distribution in the above Table 2, it is found that the index of fit is 0.9289.

Table 3. Lognormal Distribution Time to Failure

Wicket Gate							
i	**ti (hours)**	**xi = ln ti**	**F(ti)**	**zi**	**xi * zi**	**xi^2**	**zi^2**
1	12	2,48	0,0614	-1,46	-3,63	6,17	2,132
2	12	2,48	0,1491	-0,96	-2,39	6,17	0,922
3	13	2,56	0,2368	-0,68	-1,74	6,58	0,462
4	40	3,69	0,3246	-0,35	-1,29	13,61	0,123
5	59	4,08	0,4123	-0,18	-0,73	16,63	0,032
6	84	4,43	0,5000	0,19	0,84	19,63	0,036
7	156	5,05	0,5877	0,38	1,92	25,50	0,144
8	423	6,05	0,6754	0,54	3,27	36,57	0,292
9	2895,5	7,97	0,7632	0,88	7,01	63,54	0,774
10	5173	8,55	0,8509	1,16	9,92	73,12	1,346
11	5867,5	8,68	0,9386	1,66	14,40	75,29	2,756
Total	14735	56,028	5,5	1,18	27,581	342,818	9,0182
Index of Fit				**0,9545**			

Based on the results of determining TTF in the longnormal distribution in the above Table 3, it is found that the index of fit is 0.9545.

Table 4. Weibull Distribution Time to Failure

Wicket Gate							
i	**ti (hours)**	**xi = ln ti**	**F(ti)**	**yi**	**xi * yi**	**xi^2**	**yi^2**
1	12	2,484	0,0614	-2,759	-6,86	6,1748	7,611
2	12	2,48	0,1491	-1,82	-4,53	6,17	3,325
3	13	2,56	0,2368	-1,31	-3,36	6,58	1,712
4	40	3,69	0,3246	-0,94	-3,45	13,61	0,875
5	59	4,08	0,4123	-0,63	-2,58	16,63	0,399
6	84	4,43	0,5000	-0,37	-1,62	19,63	0,134
7	156	5,05	0,5877	-0,12	-0,61	25,50	0,015
8	423	6,05	0,6754	0,12	0,71	36,57	0,014
9	2895,5	7,97	0,7632	0,36	2,91	63,54	0,133
10	5173	8,55	0,8509	0,64	5,50	73,12	0,414
11	5867,5	8,68	0,9386	1,03	8,90	75,29	1,053
Total	14735	56,028	5,5	-5,792	-4,976	342,818	15,684
Index of Fit				**0,9106**			

Based on the results of determining TTF in the weibull distribution in the above Table 4, it is found that the index of fit is 0.9106.

3.3. Determination of the Distribution of Data between Repair Times (Time to Repair /TTR)

Next, once the critical component is identified, determining the distance between failures for the Wicket Gate component can be seen in the calculation results presented in the following Table 5.

Table 5. Time to Repair for the Wicket Gate Component

No	Date	Initial Damage Schedule	Final Damage Schedule	TTR (hours)
1	08/04/2021	07:00:00	15:00:00	8
2	26/04/2021	06:00:00	18:00:00	12
3	27/04/2021	07:00:00	18:00:00	11
4	29/11/2021	07:00:00	19:00:00	12
5	30/11/2021	07:00:00	19:00:00	12
6	01/12/2021	07:00:00	19:00:00	12
7	05/12/2021	07:00:00	19:00:00	12
8	12/12/2021	07:00:00	20:00:00	13
9	15/12/2021	07:00:00	19:30:00	12,5
10	16/08/2022	07:00:00	15:00:00	8
11	18/08/2022	07:00:00	15:30:00	8,5
12	04/12/2022 -17/122022	07:00:00	19:30:00	331,5

Based on the data determination in the above Table 5, it can be observed that the data for the 12 months, ranging from 2021 to 2022, show the lowest TTR value in months 1 and 10, which is 8 hours. Additionally, the highest TTR value is observed in the 12th month, reaching 331.5 hours. These findings indicate the outcomes of the company's investigations.

Table 6. Exponential Distribution Time to Repair

Wicket Gate							
i	**ti (hours)**	**xi = ti**	**F(ti)**	**yi**	**xi * yi**	**xi^2**	**yi^2**
1	8	8,00	0,0565	-2,8455	-22,7637	64,00	8,096
2	8	8,00	0,1371	-1,9142	-15,31	64,00	3,664
3	8,5	8,50	0,2177	-1,4042	-11,94	72,25	1,972
4	11	11,00	0,2984	-1,0374	-11,41	121,00	1,076
5	12	12,00	0,3790	-0,7413	-8,90	144,00	0,550
6	12	12,00	0,4597	-0,4852	-5,82	144,00	0,235
7	12	12,00	0,5403	-0,2520	-3,02	144,00	0,064
8	12	12,00	0,6210	-0,0303	-0,36	144,00	0,001
9	12	12,00	0,7016	0,1901	2,28	144,00	0,036
10	12,5	12,50	0,7823	0,4216	5,27	156,25	0,178
11	13	13,00	0,8629	0,6867	8,93	169,00	0,472
12	331,5	331,50	0,9435	1,0558	350,01	109892,25	1,115
Total	452,5	452,5	6	-6,3559	286,956	111258,75	17,458
Index of Fit				**0,4571**			

Based on the results of determining TTR in the exponential distribution in the above Table 6, it is found that the index of fit is 0,4571.

Table 7. Longnormal Distribution Time to Repair

Wicket Gate							
i	**ti (hours)**	**xi = ln ti**	**F(ti)**	**zi**	**xi * zi**	**xi^2**	**zi^2**
1	8	2,08	0,056	-1,59	-3,31	4,32	2,528
2	8	2,08	0,137	-1,09	-2,27	4,32	1,188
3	8,5	2,14	0,218	-0,78	-1,67	4,58	0,608
4	11	2,40	0,298	-0,53	-1,27	5,75	0,281
5	12	2,48	0,379	-0,31	-0,77	6,17	0,096
6	12	2,48	0,460	-0,10	-0,25	6,17	0,010
7	12	2,48	0,540	0,29	0,72	6,17	0,084
8	12	2,48	0,621	0,49	1,22	6,17	0,240
9	12	2,48	0,702	0,67	1,66	6,17	0,449
10	12,5	2,53	0,782	0,82	2,07	6,38	0,672
11	13	2,56	0,863	1,10	2,82	6,58	1,210
12	331,5	5,80	0,944	1,61	9,34	33,68	2,592
Total	452,5	32,015	6	0,58	8,307	96,492	9,959
Index of Fit				**0,6446**			

Based on the results of determining TTR in the longnormal distribution in the above Table 7, it is found that the index of fit is 0,6446.

Table 8. Weibull Distribution Time to Repair

Wicket Gate							
i	**ti (hours)**	**xi = ln ti**	**F(ti)**	**yi**	**xi * yi**	**xi^2**	**yi^2**
1	8	2,08	0,06	-2,85	-5,92	4,32	8,10
2	8	2,08	0,14	-1,91	-3,98	4,32	3,664
3	8,5	2,14	0,22	-1,40	-3,01	4,58	1,972
4	11	2,40	0,30	-1,04	-2,49	5,75	1,076
5	12	2,48	0,38	-0,74	-1,84	6,17	0,550
6	12	2,48	0,46	-0,49	-1,21	6,17	0,235
7	12	2,48	0,54	-0,25	-0,63	6,17	0,064
8	12	2,48	0,62	-0,03	-0,08	6,17	0,001
9	12	2,48	0,70	0,19	0,47	6,17	0,036
10	12,5	2,53	0,78	0,42	1,06	6,38	0,178
11	13	2,56	0,86	0,69	1,76	6,58	0,472
12	331,5	5,80	0,94	1,06	6,13	33,68	1,115
Total	452,5	32,0157	6	-6,355	-9,713	96,4921	17,458
Index of Fit				**0,5799**			

Based on the results of determining TTR in the weibull distribution in the above Table 8, it is found that the index of fit is 0,5799.

3.4. Goodness of Fit Test for Wicket Gate

The Goodness of Fit test is used to evaluate the extent to which a set of observed data fits a specific probability distribution. The test results for TTF and TTR on the wicket gate were obtained using Minitab software version 21 to facilitate the visualization of the formed distribution pattern in the form of a diagram in the image below.

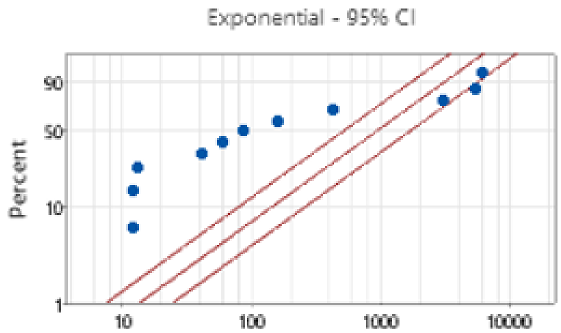

Figure 1. Probability plot for time between failures in exponential distribution

Based on the above Figure 1, it can be observed that in the Goodness of Fit test for the exponential distribution, there are several data points that do not fall on the desired data pattern line. The test results with a 95% confidence interval indicate an Anderson-Darling (AD) statistic of 8.016 and a P-Value less than 0.003.

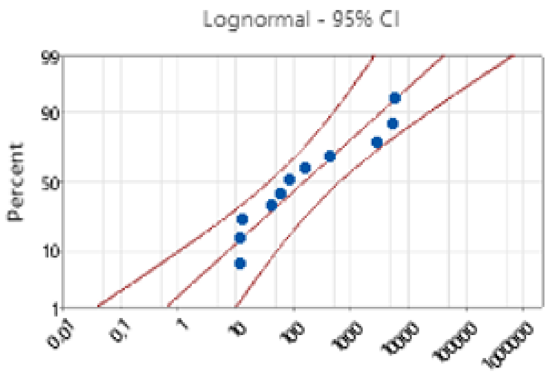

Figure 2. Probability plot for time between failures in longnormal distribution

Based on the above Figure 2, it can be observed that in the Goodness of Fit test for the lognormal distribution, all data points are on the desired data pattern line. The test results with a 95% confidence interval indicate an Anderson-Darling (AD) statistic of 0.488 and a P-Value less than 0.176.

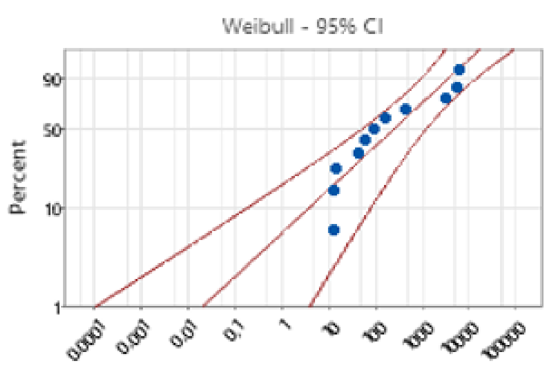

Figure 3. Probability plot for time between failures in weibull distribution

Based on the above Figure 2, it can be observed that in the Goodness of Fit test for the lognormal distribution, all data points are on the desired data pattern line. The test results with a 95% confidence interval indicate an Anderson-Darling (AD) statistic of 0.675 and a P-Value less than 0.067.

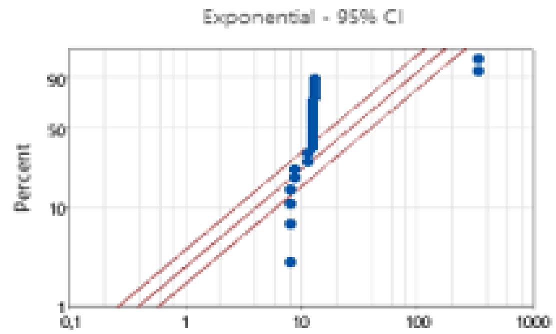

Figure 4. Probability plot for time between repairs in exponential distribution.

In Figure 4, it can be seen that in the Goodness of Fit test for the exponential distribution, all data points in TTR align along a straight line, although there are a few points that deviate from the expected distribution pattern. The test results, with a 95% confidence interval, show an Anderson-Darling (AD) statistic of 10.370 and a P-Value less than 0.003.

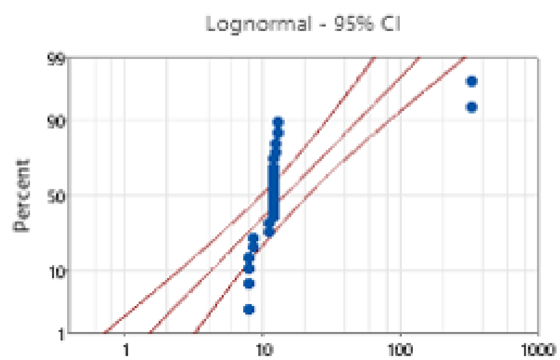

Figure 5. Probability plot for time between repairs in longnormal distribution.

In Figure 5, it can be seen that in the Goodness of Fit test for the longnoemal distribution, all data points in TTR align along a straight line, although there are a few points that deviate from the expected distribution pattern. The test results, with a 95% confidence interval, show an Anderson-Darling (AD) statistic of 5.494 and a P-Value less than 0.005.

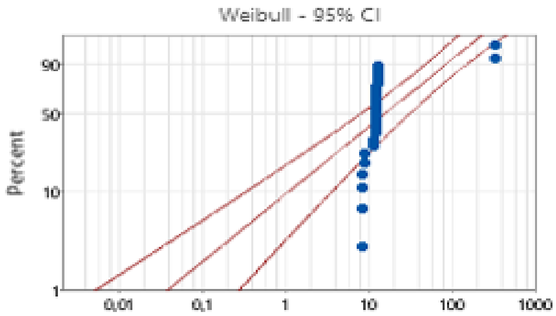

Figure 5. Probability plot for time between repairs in weibull distribution.

In Figure 5, it can be seen that in the Goodness of Fit test for the longnoemal distribution, all data points in TTR align along a straight line, although there are a few points that deviate from the expected distribution pattern. The test results, with a 95% confidence interval, show an Anderson-Darling (AD) statistic of 5.992 and a P-Value less than 0.0010.

3.4. Calculating the Preventive Replacement Time for the Wicket Gate component

Table 9. Interval of Preventive Replacement Time for the Wicket Gate Component.

Tp (hours)	R(tp)	F(tp)	M(tp)	Tp*R(tp)	Tf*F(tp)	tp+Tp	D(tp)
1100	0,71864	0,28136	7882,43	5,7491	6,43227	1108	0,004033
1150	0,72323	0,27677	8013,13	5,78581	6,32736	1158	0,003956
1200	0,80925	0,27235	8143,19	5,82117	6,2263	1208	0,003882
1250	0,73191	0,26809	8272,62	5,85526	6,12889	1258	0,003811
1300	0,73602	0,26398	8401,43	5,88815	6,03492	1308	0,003742
1350	0,73999	0,26001	8529,64	5,91989	5,94421	1358	0,003675
1400	0,80617	0,25618	8657,28	5,95056	5,85657	1408	0,003610
1450	0,74753	0,25247	8784,35	5,98021	5,77185	1458	0,003547
1500	0,75111	0,24889	8910,89	6,00889	5,68989	1508	0,003486
1550	0,75458	0,24542	9036,9	6,03665	5,61055	1558	0,003427
1600	0,757942	0,24206	9162,4	6,06354	5,5337	1608	0,003369
1650	0,812337	0,2388	9287,42	6,08961	5,45921	1658	0,003314
1700	0,764368	0,23564	9411,96	6,11489	5,38697	1708	0,003259
1750	0,767432	0,23257	9536,05	6,13942	5,31687	1758	0,003207
1800	0,770467	0,2296	9659,7	6,16324	5,24881	1808	0,003156
1850	0,773326	0,2267	9782,93	6,18637	5,1827	1858	0,003106
1900	0,804636	0,19536	11352,3	6,43709	4,46625	1908	0,002902
1950	0,822966	0,17703	12527,7	6,58373	4,04719	1958	0,002773
2000	0,826193	0,17381	12760,3	6,60954	3,97342	2008	0,002727
2050	0,840595	0,15941	13913,1	6,72476	3,64418	2058	0,002624
2100	0,786608	0,21339	10393,2	6,29286	4,87838	2108	0,002879
2150	0,789063	0,21094	10514,2	6,31251	4,82225	2158	0,002837
2200	0,791456	0,20854	10634,8	6,33165	4,76755	2208	0,002796
2250	0,793789	0,20621	10755,1	6,35031	4,71421	2258	0,002756

Based on the calculations in Table 9, we can determine that the smallest value of D(tp) is found in the 2050-hour or 85-day interval, with a downtime value of 0.002624. Consequently, the preventive replacement time for the Wicket Gate component in the Turbine Machine is scheduled for the 85th day.

3.5. Discussion on the application of the age replacement method

In determining critical machines, the Turbine machine stands out with the highest downtime, reaching 425.5 hours or 65.56% of the cumulative downtime percentage in the company's machines. This finding highlights the importance of monitoring and managing the Turbine machine's performance to minimize significant production downtime. Implementing appropriate preventive actions and maintenance on this machine can enhance operational efficiency and mitigate the negative impact of high downtime.

In determining the time of failure and repair for the wicket get component, three distribution patterns were evaluated: exponential, lognormal, and Weibull. The test results showed that the lognormal distribution had the highest goodness-of-fit value for both failure data (95.45%) and repair data (64.46%). The lognormal distribution is suitable for representing the time patterns in modeling and preventive component replacement planning. Its usage is crucial for improving the efficiency and performance of the wicket get system. These findings also provide insights for repair planning, inventory management, and maintenance scheduling. This method helps optimize maintenance strategies to reduce the impact of failures and downtime in the wicket get component.

In the Goodness of Fit test with a 95% confidence level for the failure and repair data patterns, the obtained AD statistic was 0.488 with a P-Value <0.176. For the repair data plot, the AD statistic was 5.494 with a P-Value <0.005. From these results, it can be concluded that the observed data fits well with the tested data patterns. This means that the chosen distribution aligns with the observed data, and the selected model can effectively represent the patterns of failure and repair time for the wicket get component.

Based on the calculations for Preventive Replacement Time on the Wicket Gate Component, the interval for preventive replacement of the Wicket Gate component in the Turbine machine is every 85 days. This conclusion is drawn from the analysis, which indicates that this interval has the lowest risk of failure, potentially enhancing overall system efficiency and performance. Timely replacements will help reduce downtime and ensure optimal availability of the Wicket Gate component.

4.CONCLUSION AND SUGGESTION

Based on the findings at PLTA Balambano PT. Vale Indonesia Tbk, the wicket gate component has a Mean Time to Failure (MTTF) of 2217.824 hours or around 92.41 days. To prevent breakdowns and minimize downtime, it is recommended to replace the component preventively every 85 days and conduct inspections every 15 days. Future research should consider environmental factors, compare different maintenance methods (predictive or condition-based), explore advanced monitoring technologies, analyze cost and benefits, and conduct comparative studies with similar hydropower plants. These steps will enhance understanding and identify best practices for improving wicket gate component reliability and performance.

ACKNOLEDGEMENT

The authors would like to express their sincere gratitude to PT. Vale Indonesia Tbk for their support and the opportunity to conduct research at PLTA Balambano. They also extend their thanks to the Industrial Engineering program for providing this research opportunity. The authors would like to acknowledge their supervising faculty for their guidance and dedication. Finally, they recognize the invaluable assistance from their colleagues in completing this study, which provided valuable insights into the MTTF of the wicket gate component and formed the basis for improved maintenance recommendations.

References

Achouch, M. *et al.* (2022) 'On Predictive Maintenance in Industry 4.0: Overview, Models, and Challenges', *Applied Sciences (Switzerland)*. MDPI, pp. 1–22. Available at: https://doi.org/10.3390/app12168081.

Bokrantz, J. *et al.* (2020) 'Smart Maintenance: a research agenda for industrial maintenance management', *International Journal of Production Economics*, 224(107547), pp. 1–14. Available at: https://doi.org/10.1016/j.ijpe.2019.107547.

Fole, A. and Kulsaputro, J. (2023a) 'Implementasi Lean Manufacturing Untuk Mengurangi Waste Pada Proses Produksi Sirup Markisa', *JIEI: Journal ofIndustrial Engineering Innovation*, 1(1), pp. 23–29. Available at: https://doi.org/10.58227/jiei.v1i1.59.

Fole, A. and Kulsaputro, J. (2023b) 'Implementation of Lean Manufacturing to Reduce Waste in The Passion Fruit Syrup Production Process', *JIEI: Journal ofIndustrial Engineering Innovation*, 1(1), pp. 23–29. Available at: https://doi.org/10.58227/jiei.v1i1.59.

Huang, J., Chang, Q. and Arinez, J. (2020) 'Deep reinforcement learning based preventive maintenance policy for serial production lines', *Expert Systems with Applications*, 160(113701), pp. 1–34. Available at: https://doi.org/10.1016/j.eswa.2020.113701.

Inyiama, G.K. and Oke, S.A. (2021) 'Maintenance downtime evaluation in a process bottling plant', *International Journal of Quality and Reliability Management*, 38(1), pp. 229–248. Available at: https://doi.org/10.1108/IJQRM-12-2018-0340.

Kang, Z., Catal, C. and Tekinerdogan, B. (2020) 'Machine learning applications in production lines: A systematic literature review', *Computers and Industrial Engineering*. Elsevier Ltd, pp. 1–11. Available at: https://doi.org/10.1016/j.cie.2020.106773.

Lee, J. *et al.* (2020) 'Intelligent Maintenance Systems and Predictive Manufacturing', *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, 142(11), p. 110805. Available at: https://doi.org/10.1115/1.4047856.

Lozada-Cepeda, J.A., Lara-Calle, R. and Buele, J. (2021) 'Maintenance Plan Based on TPM for Turbine Recovery Machinery', in *Journal of Physics: Conference Series*. IOP Publishing Ltd, p. 012034. Available at: https://doi.org/10.1088/1742-6596/1878/1/012034.

Patel, J.K. (2021) 'The Importance of Equipment Maintenance Forecasting', *International Journal of Mechanical Engineering*, 8(5), pp. 7–11. Available at: https://doi.org/10.14445/23488360/ijme-v8i5p102.

Qin, W. *et al.* (2022) 'Sustainable service oriented equipment maintenance management of steel enterprises using a two-stage optimization approach', *Robotics and Computer-Integrated Manufacturing*, 75(102311), pp. 1–13. Available at: https://doi.org/10.1016/j.rcim.2021.102311.

Wang, N. *et al.* (2020) 'An active preventive maintenance approach of complex equipment based on a novel product-service system operation mode', *Journal of Cleaner Production*, 277(123365), pp. 1–17. Available at: https://doi.org/10.1016/j.jclepro.2020.123365.

Wang, Z., Guo, Y. and Wang, H. (2022) 'Review on Monitoring and Operation-Maintenance Technology of Far-Reaching Sea Smart Wind Farms', *Journal of Marine Science and Engineering*. MDPI, pp. 1–19. Available at: https://doi.org/10.3390/jmse10060820.

Xiang, Z.T. and Feng, C.J. (2021) 'Implementing total productive maintenance in a manufacturing small or medium-sized enterprise', *Journal of Industrial Engineering and Management*, 14(2), pp. 152–175. Available at: https://doi.org/10.3926/jiem.3286.

Yadav, P.K., Kumar, A. and Jaiswal, S. (2023) 'A critical review of technologies for harnessing the power from flowing water using a hydrokinetic turbine to fulfill the energy need', *Energy Reports*. Elsevier Ltd, pp. 2102–2117. Available at: https://doi.org/10.1016/j.egyr.2023.01.033.

Yang, Y. *et al.* (2020) 'Robust scheduling based on extreme learning machine for bi-objective flexible job-shop problems with machine breakdowns', *Expert Systems with Applications*, 158(113545), pp. 1–12. Available at: https://doi.org/10.1016/j.eswa.2020.113545.