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Preventive Maintenance Analysis Using Monte Carlo Simulation and Failure Mode and Effect Analysis (FMEA)

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Abstract. *Filter - 2321 is one of the critical components in the production department III A phosphoric acid plant of PT Petrokimia Gresik. Critical components mean that if the filter-2321 is damaged, the production process will stop (Shutdown). Filter-2321 is the highest damaged component that affects the production process is stopped, therefore this study was conducted in order to analyze the causes of failure and improve the value of reliability by using monte carlo and FMEA simulation methods. The first step is to calculate the actual reliability value to determine the effectiveness of the maintenance system that has been implemented by the company. Furthermore, monte carlo simulation reliability simulation and determine the preventive maintenance interval, thus increasing the reliability of the filter-2321. FMEA is used to analyze the cause of the damage and determine the RPN (risk priority number) in failure mode. the results of this study is the value of the actual reliability of the filter-2321 of 30.8264% with MTBF of 1050.99 hours, this value is still too far from the value of the reliability of SII (Indonesian industrial standard) of 70%. The result of RPN (Risk Priority Number) assessment obtained from failure mode and effect analysis is, that the highest value is found in the damaged torque module of 135 and failure mode bearing fix damaged of 135. The suggestion to increase the reliability value is to perform preventive maintenance at intervals of 438.60 hours to increase the reliability value, taking into account the results of the analysis of the causes of the damage that occurred using FMEA.*

Keywords: *maintenance; failure; reliability; monte carlo; FMEA.*

I. INTRODUCTION

Machine maintenance and care have an important role in the production process in the manufacturing industry. The role of maintenance is very important for a company, without maintenance the company will experience losses, namely the quality and quantity of production decreases, and the machine is damaged and cannot function (Febianti et al., 2020). Maintenance is an action taken to prevent or repair a machine to function normally so that the production plan can be carried out. Maintenance is carried out to maintain the system and all components to be able to work properly (Rahayu, 2014). Good engine maintenance can repair and maintain engine reliability (Febianti et al., 2020). The function of maintenance is to ensure and control the reliability of a machine or system (Kelly, 1997).

Maintenance carried out on components or equipment is divided into two parts, namely planned maintenance and unplanned maintenance (Lutfiananda, 2021). Planned maintenance is maintenance that has been planned before the machine or equipment experiences problems, in its activities preventive maintenance is a form of planned maintenance. Planned maintenance is carried out to anticipate equipment damage in the future, this treatment tends to be passive and only solves problems regularly, but sometimes also reactively (Marsetio et al., 2017). Preventive maintenance is maintenance carried out at predetermined intervals, to reduce the possibility of machines or equipment not meeting the desired conditions. Preventive maintenance is an act of maintenance before the occurrence of damage, and the high-reliability value reflects the good maintenance system carried out by the company (Pamungkas et al., 2019).

Reliability is a measure of the success of the maintenance system, so the value of reliability is

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very dependent on the maintenance system implemented by the company (Pamungkas et al., 2018). Reliability can be described as the probability that a tool or component performs a task under certain conditions and within a certain time (Chen et al., 2022). To determine the reliability value of the machine or equipment, the Monte Carlo simulation is used. The use of the Monte Carlo simulation method for maintenance management and reliability of machines or components is also carried out by (Andrilia et al., 2014; Anggraini Wresni & Aditia Arfan, 2016; Anindita et al., 2013; Chen et al., 2022; Hugo et al., 2018; Listiana Putri et al., 2013; Maharani Angel Ein Suryono, 2017; Nugroho et al., 2019; Pamungkas et al., 2020; Rahmat & Jovanovic, 2015; Salgado Duarte et al., 2020).

A monte carlo simulation is a useful tool for modeling significant data uncertainty and has many applications including reliability, availability and logistic forecasting, risk analysis, strength load interference analysis, random process simulation including fixable systems, geometric dimensions and tolerances, and a wide range of applications. business (O'Connor Patrick D.T. & Kleyner Andre, 2011). According to Feldman et al., Monte Carlo simulation is a type of simulation that is applied using random numbers to trigger a statistical result (Anindita et al., 2013). The Monte Carlo simulation is used to predict the MTBF (Mean Time Between Failure) value by generating the TBF (Time Between Failure) value so that component maintenance intervals can be determined based on their reliability values. Mean Time to Failure (MTTF) is a parameter for systems or components that cannot be repaired, while Mean Time Between Failure (MTBF) is a parameter for components that can be repaired (Lutfiananda, 2021).

After the reliability value of the machine or tool is known, further, identification is carried out using a fishbone diagram and Failure Mode and Effect Analysis (FMEA) to find the root cause of the failure of the equipment, the identification is reviewed using a fishbone diagram from four aspects, namely human, method, material, and machine. Fishbone diagrams that are shaped like fish bones are tools that are often used to analyze the cause and effect of a complex problem (Coccia, 2017). Then the Monte Carlo simulation is used to determine the results of the preventive maintenance time on the desired reliability. According to Pamungkas et al., (2019), the minimum reliability value by the Reliability Standard Power Plant recommendation is 80%, while according to Sutopo & Nugroho, (2008) the minimum reliability value according to SII (Standar Industri Indonesia) is 70%, this is can be used as a minimum reference of the reliability value of a machine. Meanwhile, Failure Mode and Effect Analysis (FMEA) is a method used to identify the cause of a failure and evaluate the consequences and risks that occur in a product or process (Suwandono, 2016). When the cause of a failure is identified, improvements can be made by looking at the priority scale. The calculation of the FMEA priority is based on the RPN (Risk Priority Number), the RPN value is obtained from the multiplication of each impact value (severity), occurrence, and detection (Findiani et al., 2019). The results of the calculation of the RPN will be a reference for recommendations for improvement, the higher the value of the RPN, the higher the priority.

In the Phosphoric Acid Production Unit I, Production Department IIIA, PT Petrokimia Gresik whose main production is phosphoric acid with a capacity of 171,540 tons/year. In the production stage, there are five stages of the process, namely grinding unit, hemihydrate reaction & filtration, dihydrate reaction & filtration, fluorine recovery, and concentration unit. In Grinding Unit phosphatrock into raw materials will be smoothed to meet the needs of the reaction with a maximum water content of 1%, then hemihydrate reaction & filtration unit aims to react between phosphate rock with sulfuric acid to form hemihydrate crystals and then separated in the filter hemihydrate. Dihydrate reaction & filtration unit aims to convert hemyhidrate into dihydrate, then separated in the dyhidrate filter. Flourine Recovery, this unit aims to convert flourine gas derived from Digester, filtration and hydration tank reactions into H2SIF6. Concentration unit aims to concentrate phosphoric acid solution of 45% P2O5 to 54% P2O5.

Filter - 2321 is a component contained in the hemihydrate reaction & filtration process, filter-2321 functions to separate pfhosphoric acid from gypsum hemihydrate, from the results of this filtration, it produces first filter (acid product with a concentration of 45% P2O5), second filter (32.1% P2O5), mix slurry (as cell pan filter washing liquid), wash water (as pan back wash water) and exhaust gas (containing flourin 50 mgr/m3). According to historical data of damage that occurred at the beginning of 2020 until August 2021 filter-2321 is a tool or machine that has the highest frequency of damage. This causes a decrease in the production of phosphoric acid from the previous year, fiilter - 2321 is a critical component which means that if the filter-2321 stops operating or has problems it will result in the termination of the production process at the phosphoric acid production unit I.

The maintenance department III has carried out preventive maintenance on the phosphoric acid production unit I, which is in the form of shutdown cleaning which is carried out at intervals of seven days. Mechanical cleaning cake on components and line in order to avoid deadlocks during the production process and inspect visually and repair components that have problems, the plant will be stopped for approximately ten hours in the process of shutdown cleaning. For preventive activities carried out on filter-2321, namely check bolts on tilt arm, check lock ring on each tilt arm roll, check car frame connection, check vacuum hose, check splash guard condition, check greaser line, check oil pump temperature and check water on vacuum pump. Although preventive maintenance and corrective maintenance have been carried out on each component in the phosphoric acid production unit I, but in its implementation does not look at the reliability factor of each machine or equipment. To minimize the chance of damage to the filter-2321 reliability analysis is needed to determine the maintenance interval that may be done at the time of shutdown cleaning is carried out, and find the root cause of the damage that occurs.

Therefore, the objectives to be achieved in this study are (1) to determine the reliability value of filter-2321 as a parameter of the success of the maintenance system, (2) to identify the root cause of damage that occurs in filter-2321 and (3) determine the proposed preventive maintenance filter. -2321.

II. RESEARCH METHOD

This study uses monte carlo simulation method and failure mode and effect analysis (FMEA). According to Ge & Asgarpoor (2011) Approach through monte carlo simulation method is a powerful tool to handle more conditions related to reliability and uncertainty compared to analytical methods. Failure mode and effect analysis (FMEA) is done because this method is a strong reliability engineering methodology, this method evaluates components and identifies failure modes and effects on system function. According to Yeh & Sun (2011)the failure mode and effect analysis (FMEA) method is more suitable for studying the failure behavior of system components, and the assessment of failure mode and effect analysis (FMEA) indicators is based on standard scales or empirical ratings. Besides stated methods of failure mode and effect analysis (FMEA) and fault tree analysis (FTA) are more detailed and objective than the cause consequence (CCA) method (Tazi et al., 2017). However, the fault tree analysis (FTA) method is based on deductive logic that presupposes failures and the probability of their occurrence is already known.

The research activity begins with preliminary research that has been carried out and obtains the problem formulation and research objectives. The next stage is a literature study to support the determination of research objectives. The data collection needed is adjusted to the research objectives to be achieved. Data collection is done by looking for historical data on the damage that occurred to the machine, direct observation, and interviews with related parties.

The data that has been collected is then processed and data analysis is carried out. Associated with solving the problem of determining reliability on the machine, identifying the root cause of the damage that occurred, and determining the proposed preventive maintenance filter-2321 based on the reliability value using the Monte Carlo simulation method and failure mode and effect analysis. The following are the stages of this research:

Determination of Actual Reliability Value

Determination of reliability value by using historical data of damage that occurred to the machine. The steps, namely (Billinton & Wang, 1999):

1. Determination of time between failure (TBF). Time Between Failure (TBF) is the time interval or interval between failures, which is calculated as the time difference between one damage and the next damage. The data needed is the damage data that occurs in filter-2321.
2. Determine the type of distribution and the time between failure parameters. Based on the TBF data that has been determined, then testing the probability distribution of the TBF data with the index of fit test and the goodness of fit test to determine the parameters of the selected TBF distribution. The test was carried out using the Anderson Darling (AD) method and the Pearson correlation coefficient with the help of Minitab 18 software. The Anderson Darling (AD) test results were chosen with the smallest value because the approach used was weighted squared distance and the Pearson correlation coefficient was chosen with the largest value because of the approach used. is the least square estimate, at this stage the mean time between failure (MTBF) value will also be obtained based on the selected distribution type.
3. Calculation of machine reliability value. This reliability calculation is carried out based on the type and parameters of the selected distribution.

Monte Carlo Simulation

The process used to evaluate the distribution system reliability indices using time sequential simulation consists of the following steps:

Step 1: Generate a random number for each element in the system and convert it into TTF corresponding to the probability distribution Of element parameter.

Step 2: Determine the with minimum TTF.

Step 3: Generate a random number and convert this number into the repair time (RT) of the element with minimum TTF according to the probability distribution of the repair time.

Step 4: Generate another random number and convert this number into switching time (ST) according to the probability distribution of the switching time if this action is possible.

Step 5: 'Utilize the procedure described earlier under "Determination of Load Point Failures" and record the outage duration for each failed load point.

Step 6: Generate a new random number for the failed element and convert it into a new TTF, and return to Step 2 if the simulation time is less than one year. If the simulation time is greater than one year, go to Step 9.

Step 7: Calculate the number and duration of failures for each load point for each year.

Step 8: Calculate the average value of the load point failure rate and failure duration for the sample years.

Step 9: Calculate the system indices and record these indices for each year.

Step 10: Calculate the average values of these system indices.

Step 11: Return to Step 2 if the simulation time is less than the specified total simulation years, otherwise output the results.

In this study Montecarlo simulation is done with the following steps:

Step 1: generate random numbers using the help of microsoft excel software by considering the type of data distribution Actua Time Between Failure (TBF). Microsoft Excel has a built - in distribution function uniform =RAND (), when the formula =RAND () is entered into a cell, it generates a number, which is equally likely to assume any value between 0 and 1 (O'Connor Patrick D.T. & Kleyner Andre, 2011).

Step 2: after obtaining random numbers that are uniformly distributed, then the data transformation is carried out according to the actual Time Between Failure (TBF) distribution.

Step 3: perform data validation using SPSS 20 software. Validation was performed using the Mann-Whitney test. The Mann-Whitney test is performed to test the similarity of two mutually independent populations (Yanti, 2007).

Step 4: then generate the data and perform replication to be able to analyze the results of the simulation run.

Step 5: calculate the Mean Time Between Failure (MTBF) value and the reliability value of the data that has been generated.

After the simulation results obtained, then the next will be analyzed related to the cause of damage to the filter - 2321 using the method of failure mode and effect analysis. The results of failure mode and effect analysis will be used as a reference for preventive maintenance that must be done to improve the value of reliability.

Analyzing the Cause of Failure

Analysis of the causes of damage begins with making an Ishikawa diagram or also known as a fishbone diagram which is viewed from four aspects, namely humans, machines, methods, and materials. The results of the fishbone diagram are then used to make a failure mode and effect analysis (FMEA). When failures are identified, improvements can be made by looking at the priority scale. The FMEA priority scale is based on the risk priority number (RPN) obtained from the multiplication of severity, occurrence, and detection. The higher the risk priority number, the higher the priority.

III. Result and Discussion

Determination of Actual Reliability Value

The first step in determining the reliability value is determining the time between failures. The time between failures (TBF) is the time between failures. The data needed is damage data that occurs on filter-2321, the following is damage data and Time Between Failure (TBF) that occurs on filter-2321 in the period January 2020 to August 2021.

Table 1. Failure data and Time Between Failure

No	Failure Date	TBF (*Hours*)
1	02/01/2020	0
2	22/01/2020	480
3	03/02/2020	288
4	28/02/2020	600
5	09/03/2020	240
6	15/06/2020	2352
7	14/07/2020	696
8	02/09/2020	1200
9	15/10/2020	1032
10	18/02/2021	3024
11	28/05/2021	2376
12	30/05/2021	48
13	24/06/2021	600
14	13/08/2021	1200
15	16/08/2021	72
16	20/08/2021	96
17	25/08/2021	120
	Total	14424

After obtaining the damage data in the form of time between failures, then testing the probability distribution of the TBF data with the index of fit test and the goodness of fit test to determine the parameters of the selected TBF distribution. The test was carried out using the Anderson Darling (AD) method and the Pearson correlation coefficient with the help of Minitab 18 software. The Anderson Darling (AD) test results were chosen with the smallest value because the approach used was the weighted squared distance and the Pearson correlation coefficient was chosen with the largest value because the approach used was the largest. used is the least square estimate. After testing, the results are obtained in Table 2

Table 2. Distribution test results

Distribution	Anderson-Darling (adj)	*Correlation Coefficient*
Weibull	0.991	0.982
Lognormal	1.002	0.982
Exponential	0.981	*
Normal	1.791	0.915
3-P Weibull	0.913	0.993

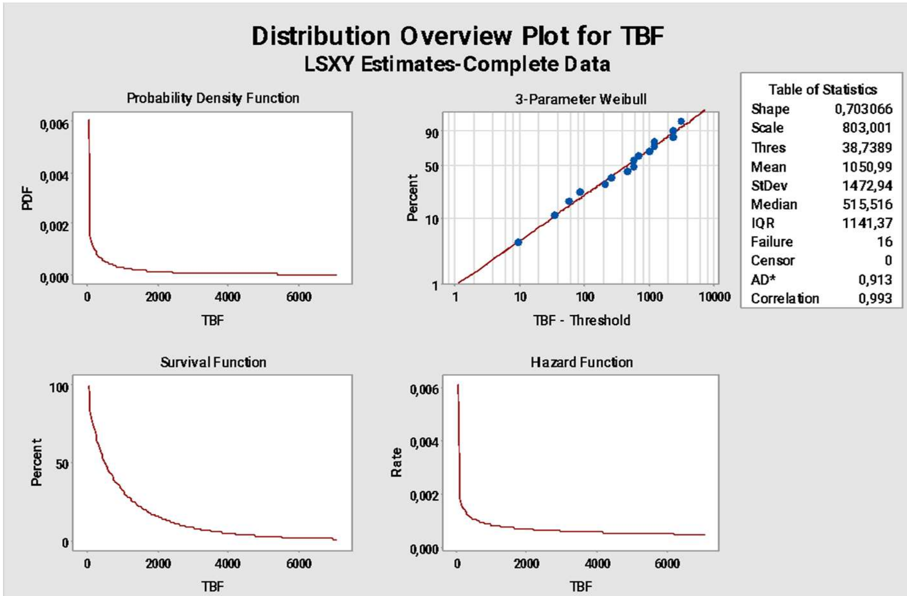

Figure 1. Distribution overview

Table 3. Recapitulation of parameters and MTBF

Equipment	Distribution	Parameter			MTBF (hours)
		θ	β	γ	
Filter-2321	*3-P Weibull*	803.001	0.703066	38.7389	1050.99

Based on the distribution test results, the results can be seen in Table 2. The data shows the distribution of the damage data with a 3-P Weibull distribution, this is obtained with the smallest Anderson Darling value and the largest Pearson Correlation Coefficient, namely 0.913 and 0.993.

After the type of distribution is known, the next step is to determine the parameters of the 3-P Weibull distribution. Parameter calculation results can be seen in Figure 1.

From the distribution overview above can be concluded the parameters of the selected distribution of Data Time Between Failure (TBF) filter-2321. The recapitulation of parameter data and MTBF can be seen in Table 3.

After knowing the Mean Time Between Failure (MTBF) value, it is possible to calculate the reliability value according to the selected distribution type. The following is the reliability formula for the 3-P Weibull distribution (Ebeling, 1997).

$$R(t) = e^{-(\frac{t-\gamma}{\theta})^{\beta}} \quad (1)$$

The calculation of the actual reliability of the filter-2321 is as follows:

R(t)= $e^{-(\frac{t-\gamma}{\theta})^{\beta}}$

R(t)= exp[-($\frac{1050{,}99 \quad {,}7389}{803{,}001}$)$^{0{,}703066}$]

R(t)= 0,308264

R(t)= 30,8264%

Based on the calculation results above, it is known that the actual reliability value of the filter-2321 is 30.8264% with an MTBF of 1050.99 hours.

Simulasi Monte Carlo

After knowing the actual reliability value, then at this stage is to generate data according to the distribution of the actual TBF data, which is the 3-P Weibull distribution. It can be seen in table 4 that TBF is the actual data from the time between failure and TBF' is the generated data.

Table 4. Actual data and generation time between failure (TBF)

TBF	TBF'
480	926
288	497
600	638
240	1107
2352	1638
696	425
1200	430
1032	222
3024	2017
2376	3357
48	2354
600	217
1200	1501
72	1091
96	177
120	1188

Table 5. Mann-Whitney test results

	DATA
Mann-Whitney U	104.000
Wilcoxon W	240.000
Z	-.905
Asymp. Sig. (2-tailed)	.366
Exact Sig. [2*(1-tailed Sig.)]	.381[b]

After the data is generated, then the two data are then validated to find out whether there are similarities between the two data. The test is carried out using the Mann-Whitney test with the help of SPSS 20 software. The test hypotheses are as follows:

H_0 : TBF=TBF'

H_1 : TBF≠TBF'

By criteria:

1) H_0 is accepted if the value of Asymp.Sig (2-tailed) is 0.05.
2) H_1 accepted Asymp.Sig (2-tailed) 0.05.

The results of the test can be seen in table 5, with the results of the. Sig (2-tailed) value of 0.366 which means H0 is accepted and H1 is rejected. H0 is accepted, which means that the two data populations have significant similarities.

After the validity test is carried out, the next step is to determine the number of replications or simulations to be carried out. This calculation

Table 6. Determination of the number of replications

N	Ttable	Tcount	Result
2	12.706205	654.98366	8322.3565
3	4.3026527	534.79192	2301.0239
4	3.1824463	463.14339	1473.929
5	2.7764451	414.24804	1150.1369
6	2.5705818	378.15499	972.07836
7	2.4469118	350.10349	856.67239
8	2.3646243	327.49183	774.39513
9	2.3060041	308.76226	712.00705
10	2.2621572	292.9176	662.62564
11	2.2281388	279.28597	622.28792
12	2.2009852	267.39596	588.53454
13	2.1788128	256.90573	559.7495
14	2.1603687	247.56056	534.82206
15	2.1447867	239.16622	512.96052
16	2.1314495	231.5717	493.58338
17	2.1199053	224.65754	476.25271
18	2.1098156	218.32789	460.63157
19	2.100922	212.50476	446.45594
20	2.093024	207.12402	433.51556
....	....	....	....
75	1.9925435	106.95838	213.11923
76	1.9921021	106.25238	211.66559
77	1.9916726	105.56018	210.24131
78	1.9912544	104.88132	208.8454
79	1.990847	104.2154	207.47693
80	1.9904502	103.56201	206.13502

uses a reference to the difference in the average sample data (absolute error). The value of the absolute error of the sample is 209.9, it can be seen in Table 6 that the replication that must be done is 78 times.

Then the next step is to generate data and perform simulations 78 times, as well as test parameters and find the MTBF value so that the reliability value is obtained. The following is the simulation data that can be seen in Table 7.

From the simulation results above, the best reliability value from the simulation results is 0.48

Table 7. Simulation

Data	MTBF (hours)	Parameter			R	Data	MTBF (hours)	Parameter			R
		β	θ	γ				β	θ	γ	
1	885.22	0.65	488.92	215.88	0.29	40	1808.95	1.12	1927.67	-41.05	0.38
2	1193.54	1.15	1236.35	16.72	0.39	41	850.24	0.80	677.69	79.14	0.33
3	1304.06	0.90	1139.94	106.68	0.35	42	1509.76	1.65	1628.29	53.76	0.44
4	983.57	0.94	787.58	173.90	0.36	43	1305.17	0.94	1270.28	0.09	0.36
5	1022.02	1.18	1009.95	67.23	0.39	44	1667.21	0.93	1605.67	2.38	0.36
6	1066.08	1.27	1055.48	86.31	0.40	45	879.69	0.71	672.40	41.53	0.31
7	1413.70	0.80	1239.84	11.76	0.33	46	1262.88	1.11	1291.25	19.30	0.38
8	950.72	1.14	968.38	124.79	0.43	47	1903.98	0.54	1064.11	61.22	0.26
9	1682.93	0.97	1663.21	0.97	0.36	48	843.39	2.50	1418.41	-415.07	0.48
10	1548.02	1.02	1514.06	43.92	0.37	49	1303.45	0.95	1193.46	82.50	0.36
11	1888.21	0.91	1807.67	-0.86	0.35	50	1574.26	0.62	1054.74	33.89	0.28
12	1001.04	0.71	778.09	30.59	0.31	51	1019.85	1.12	1051.78	10.69	0.38
13	1928.39	0.89	1712.62	114.83	0.35	52	919.02	0.87	683.80	185.32	0.35
14	2548.42	0.67	1893.61	50.35	0.30	53	1587.44	1.25	1472.57	217.43	0.40
15	959.75	1.06	916.04	63.89	0.38	54	1646.33	0.95	1474.71	137.69	0.36
16	1249.14	0.64	855.92	51.01	0.29	55	2101.21	1.18	2234.16	-9.01	0.39
17	1286.18	1.38	1510.58	-94.48	0.41	56	947.25	1.18	961.95	32.08	0.39
18	1582.90	0.68	1084.88	169.19	0.30	57	1041.50	0.99	960.58	76.05	0.37
19	949.25	1.08	746.25	225.26	0.38	58	1404.09	1.11	1432.78	27.39	0.38
20	1341.94	0.78	1095.90	79.12	0.33	59	1330.23	1.57	1645.27	-147.67	0.43
21	1904.11	0.75	1580.60	31.91	0.32	60	1015.39	0.78	813.95	72.28	0.33
22	1057.14	0.60	669.23	40.38	0.28	61	1281.03	0.93	1183.93	57.09	0.36
23	1787.61	1.14	1794.26	76.32	0.39	62	1378.06	0.95	1224.01	127.52	0.36
24	1087.96	0.98	1060.56	18.50	0.36	63	908.01	0.78	740.34	52.67	0.33
25	973.21	1.57	1104.19	-18.28	0.43	64	1065.49	1.07	1066.93	25.11	0.38
26	993.81	0.75	778.33	64.43	0.32	65	1932.42	0.70	1230.39	371.94	0.31
27	1079.86	0.79	925.02	22.24	0.33	66	1358.48	0.67	952.30	106.25	0.30
28	1101.57	0.93	1055.36	12.02	0.36	67	946.68	1.35	1099.55	-62.06	0.41
29	852.31	1.06	843.11	28.19	0.38	68	1391.61	0.93	1066.15	290.45	0.36
30	1771.14	0.78	1327.84	245.72	0.33	69	1385.32	0.79	1139.45	81.80	0.33
31	1490.97	1.02	1547.05	-46.22	0.37	70	1513.15	1.10	1604.18	-36.74	0.38
32	1044.22	1.19	924.52	172.61	0.39	71	1408.78	1.52	1557.41	4.59	0.43
33	1093.62	1.02	824.32	256.86	0.36	72	1085.10	1.01	995.84	95.26	0.37
34	2417.63	0.49	1122.99	106.26	0.24	73	1035.63	1.71	1281.27	-107.14	0.44
35	1337.17	1.11	1433.45	-43.86	0.38	74	963.27	1.82	1319.62	-209.53	0.45
36	908.93	1.42	1068.06	-62.53	0.42	75	1579.58	0.99	1538.04	33.74	0.37
37	1375.51	1.70	1221.61	218.50	0.40	76	1933.25	0.68	1310.00	215.26	0.30
38	1249.09	1.35	1564.13	-184.37	0.41	77	1529.05	0.77	1253.02	66.72	0.32
39	1109.27	0.86	975.02	53.74	0.34	78	1146.63	0.77	952.30	37.87	0.32

or 48% with an MTBF (Mean Time Between Failure) of 843.39 hours which is obtained from the results of the 48 replications. This result is still below the reliability standard of SII (Indonesian Industrial Standard), which is 70% (Sutopo & Nugroho, 2008). From the results of this simulation, it still has a very significant difference from the reliability standard of SII (Indonesian Industry Standard), which is 22%. results of reliability analysis using Minitab 18 software can be seen in Figure 2.

From the simulation results using Minitab software, the reliability value reaches 75.4605% when the filter operating hours reach 438.60 hours. This can be a reference for the implementation of preventive maintenance to increase the reliability of the filter-2321, but it is also necessary to analyze the causes of failure or damage to prevent damage or breakdown maintenance. The results of the damage analysis that will be carried out using the failure mode and effect analysis method will be used to guide preventive maintenance activities. Even though preventive maintenance activities for the phosphoric acid plant are carried out every seven-day intervals, the plant will be shut down for ten hours. Considering that the phosphoric acid plant equipment is very large and complex, it is not

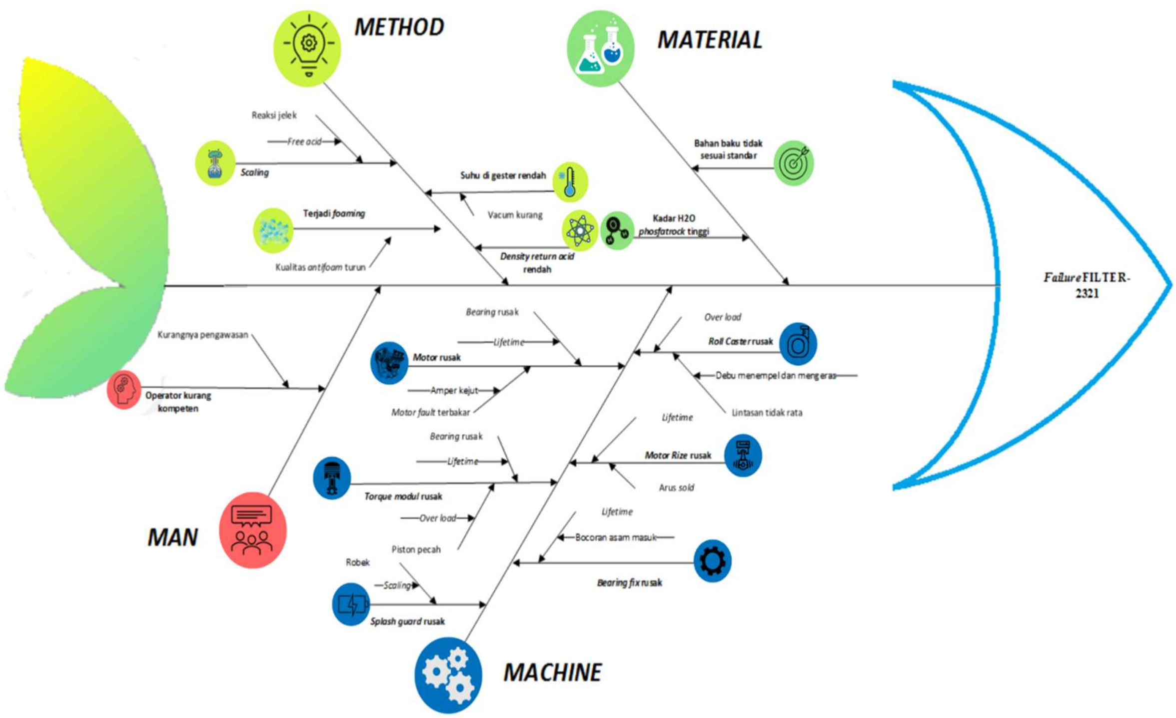

Figure 3. Fishbone diagram filter-2321

Table 8. Failure Mode and Effect Analysis filter-2321

ID	**Potential Failure Mode**	**Potential Effect of Failure**	**SEV**	**Potential Cause**	**OCC**	**DET**
F1	Roll Caster is broken	Shutdown factory if >15 damaged	8	Overload Uneven track	8	1
F2	The bearing fix is broken	Shutdown	9	Lifetime	3	5
F3	The torque module is broken	Shutdown	9	Broken bearing Piston broke	3	5
F4	Splash guard broken	Shutdown	9	Ripped	6	1
F5	Raw materials are not up to standard	Scaling more	6	full cloth filter	4	1
F6	High levels of H2O in phosphate rock	Scaling occurs	4	More use of H2SO4	2	5
F7	The temperature in gester is too low	Scaling	7	less vacuum	3	1
F8	Low-density return acid	, can not be filtered	5	Scaling / dilute,	3	1
F9	Foaming occurs	Foaming filtration results	6	Antifoam is of poor quality	6	2
F10	Incompetent operator	Upset operating parameters	6	Lack of experience	1	1

efficient to carry out one-by-one inspections of factory tools or equipment.

Analyzing the Cause of Damage

The first step is to make a fishbone diagram, this diagram is used to find the cause and effect of a problem, often also referred to as a fishbone diagram because of its shape that resembles a fishbone. The following is a fishbone diagram that is used to analyze the causes of the failure of filter-2321.

After analyzing the failure on filter-2321 using a fishbone diagram, then the initial problem and root cause will be analyzed further to determine the level of risk using Failure Mode and Effect Analysis (FMEA).

Failure Mode and Effect Analysis (FMEA) according to is a method used to identify the cause of a failure and evaluate the consequences and risks that occur in a product or process. FMEA itself aims to determine the impact (severity), the level of possibility (occurrence), and the level of ease of detecting failures (detection) on failures that occur in products or processes.

After determining the severity, occurrence, and detection, the RPN (Risk Priority Number) can be calculated from each cause of failure or failure that occurs using the severity x occurrence x detection formula. The results of failure analysis on filter-2321 using FMEA (Failure Mode and Effect Analysis) can be seen in Table 8.

After knowing each impact value (severity), the probability of occurrence (occurrence), and the level of ease of detecting failure (detection), then the risk priority number (RPN) value is calculated by multiplying the severity, occurrence, and detection. The following is the result of calculating the value of the Risk Priority Number (RPN).

Table 9. Risk Priority Number (RPN)

ID	Severity	Occurrence	Detection	RPN
F1	8	8	1	64
F2	9	3	5	135
F3	9	3	5	135
F4	9	6	1	54
F5	6	4	1	24
F6	4	2	5	40
F7	7	3	1	21
F8	5	3	1	15
F9	6	6	2	72
F10	6	1	1	6

From the ranking results, the highest risk priority number is found in the faulty torque module failure mode followed by damaged bearing fixes. For that to reduce the occurrence of failure and increase the value of the reliability of the filter-2321, at the time of preventive maintenance on the filter-2321 to do is check the state of the module torque and bearing fix on the filter-2321.

IV. CONCLUSION

Preventive maintenance can increase the reliability value of a machine and a large reliability value indicates a good maintenance system. In this study, the actual reliability value of filter-2321 was 30.8264% with an MTBF of 1050.99 hours. After doing the simulation for the reliability of the simulation, reliability results were obtained by 48% with an MTBF of 843.39 hours, this is still far from the standard value of SII (Indonesian Industrial Standard), which is 70%. So based on the reliability simulation results, an analysis using the Minitab 18 software was carried out, and the reliability value was at 75.4605% when the filter operating hours reached 438.60 hours. The suggestion to increase the reliability value is to perform preventive maintenance at intervals of 438.60 hours to increase the reliability value above the SII standard (Standar Industri Indonesia), taking into account the results of the analysis of the causes of the damage that occurred using FMEA (Failure Mode and Effect Analysis).

The results of the RPN (Risk Priority Number) assessment obtained from the failure mode and effect analysis are, that the highest value is found in the damaged torque module of 135 caused by damaged bearings and broken pistons. Torque module damage can affect filter-2321 not operating which results in shutdown. As for the recommendations for this failure mode, every preventive maintenance implementation is always prioritized to be checked, especially on bearings and pistons, and always maintain stock of spare parts. Furthermore, the same RPN value of 135 is obtained in failure mode bearing fix is damaged, this failure mode is caused by lifetime, this failure mode can also cause a shutdown. The lifetime of the bearing fix has decreased due to the corrosive environment and raw materials from the phosphoric acid plant. The recommendation from this failure mode is that for every preventive maintenance implementation, it is always prioritized on the bearing fix and the stock of these spare parts is always maintained.

REFERENCES

Andrilia, D., Tama, I. P., & Rahman, A. (2014). Strategi Perawatan Pada Mesin Las Mig Di Industri Karoseri Kendaraan Niaga Dengan Simulasi Monte Carlo (Studi kasus: PT. Adi Putro Wirasejati Malang). *Jurnal Rekayasa Dan Manajemen Sistem Industri*, *2*(1), 163–174.

Anggraini, W., & Aditia, A. (2016). Simulasi Montecarlo pada Penjadwalan Preventive Maintenance Komponen Kritis Mesin Breaker dan Mesin Hammermill. *Seminar Nasional Teknologi Informasi, Komunikasi Dan Industri 8*, *November*, 253–262.

Anindita, R. W., Arina, F., & Ferdinant, P. F. (2013). Identifikasi Pola Kerusakan Komponen Kritis pada Mesin EAF dengan Simulasi Monte Carlo. *Jurnal Teknik Industri*, *1*(4), 316–321.

Chen, Y., Chen, Z., Liao, Y., Zhu, M., Hong, Z., & Jiang, Z. (2022). A study on the reliability of smart meters based on the Monte-Carlo method and fault trees. *Distributed Generation and Alternative Energy Journal*, *37*(2), 199–214. https://doi.org/10.13052/dgaej2156-3306.3726

Coccia, M. (2017). The fishbone diagram to identify, systematize and analyze the sources of general purpose technologies. *Journal of Social and Administrative Sciences*, *4(4)*(January), 291–303.

Delfian Lutfiananda. (2021). *Peningkatan Availability Pabrik Asam Sulfat I PT Petrokimia Gresik Dengan Failure Mode & Effect Analysis.Thesis.* Fakultas Desain Kreatif dan Bisnis Digital Institut Teknologi Sepuluh November.

Febianti, E., Ferdinant, P. F., Wahyuni, N., & Riyani, D. N. (2020). Usulan Penjadwalan Perawatan Mesin Menggunakan Metode Reliability Block Diagram. *Performa: Media Ilmiah Teknik Industri*, *19*(1). https://doi.org/10.20961/performa.19.1.40983

Findiani, R., Novareza, O., & Choiron, M. A. (2019). *Seminar dan Konferensi Nasional IDEC Analisa Kegagalan Kantong Plastik rHDPE dengan Menggunakan Metode Failure Mode and Effect Analysis (FMEA)*.

Ge, H., & Asgarpoor, S. (2011). Parallel Monte Carlo simulation for reliability and cost evaluation of equipment and systems. *Electric Power Systems Research*, *81*(2), 347–356. https://doi.org/10.1016/j.epsr.2010.09.012

Hall, P. L., & Strutt, J. E. (2003). Probabilistic physics-of-failure models for component reliabilities using Monte Carlo simulation and Weibull analysis: A parametric study. *Reliability Engineering and System Safety*, *80*(3), 233–242. https://doi.org/10.1016/S0951-8320(03)00032-2

Kelly, A. (1997). *Maintenance Organization and Systems*. 280. https://books.google.com/books/about/Maintenance_Organization_and_Systems.html?hl=id&id=8wKqmxi2x-0C

Listiana Putri, E., Bahauddin, A., Ferdinant, P. F., Teknik, J., Universitas, I., & Tirtayasa, A. (2013). Usulan Jadwal Perawatan pada Mesin Electric Arc Furnace 5 dengan Simulasi Monte Carlo. In *Jurnal Teknik Industri* (Vol. 1, Issue 4).

Maharani Angel Ein Suryono. (2017). *Penentuan Interval Maintenance Mesin Pada Lini Produksi Pelumas Proses Filling Lithos PT. Pertamina Lubricants Production Unit Gresik Dengan Metode Simulasi Monte Carlo*. *Skripsi*. Program Studi Sarjana Teknik Industri, Fakultas Teknik, Universitas Sebelas Maret Surakarta.

Marsetio, Supartono, Octavian, A., Ahmadi, Ritonga, R., & Rudiyanto. (2017). Optimization of Time Delay-based Preventive Maintenance using Markov Decision Process. *International Journal of Signal Processing, Image Processing, and Pattern Recognition*, *10*(8), 125–134. https://doi.org/10.14257/ijsip.2017.10.8.11

Nugroho, H. A., Alhilman, J., & Budiasih, E. (2019). Usulan Retirement Age Dan Jumlah Maintenance Crew Optimal Pada Mesin Huron Di Pt.xyz Menggunakan Metode Dynamic Life Cycle Cost (dlcc) Dengan Simulasi Monte Carlo. *EProceedings of Engineering*, *6*(2). https://openlibrarypublications.telkomuniversity.ac.id/index.php/engineering/article/view/10976

O'Connor Patrick D.T., & Kleyner Andre. (2011). *Practical Reliability Engineering* (Fifth). A Jhon Wiley & Sons, Ltd. https://doi.org/10.1002/9781119961260

Pamungkas, I., Irawan, H. T., Arhami, A., & Dirhamsyah, M.(2019). Usulan Waktu Perawatan Dan Perbaikan Berdasarkan Keandalan Pada Bagian Boiler Di

Pembangkit Listrik Tenaga Uap. *Jurnal Optimalisasi*, *5*, 82–95. http://180.250.41.45/joptimalisasi/article/view/1255

Pamungkas, I., Irawan, H. T., Arhami, A., & Dirhamsyah, M. (2020). Simulasi Monte Carlo Untuk Menentukan Keandalan Pada Bagian Boiler Di Pembangkit Listrik Berbasis Batubara. *Jurnal Optimalisasi*, *4*(2), 83–96. https://doi.org/10.35308/JOPT.V4I2.1505

Rahayu, A. (2014). Evaluasi Efektivitas Mesin Kiln Dengan Penerapan Total Productive Maintenance Pada Pabrik Ii/Iii Pt Semen Padang. *Jurnal Optimasi Sistem Industri*, *13*(1), 454–485.

Rahmat, M. K., & Jovanovic, S. (2015). Reliability and availability estimation of DC Uninterruptible Power Supply systems using Monte-Carlo simulation. *Proceeding - 2015 IEEE International Conference on Industrial Informatics, INDIN 2015*, 76–81. https://doi.org/10.1109/INDIN.2015.7281713

Rocco, C. M., & Moreno, J. A. (2003). System reliability evaluation using Monte Carlo & support vector machine. *Proceedings of the Annual Reliability and Maintainability Symposium*, *76*, 482–484.

Salgado Duarte, Y., Szpytko, J., & del Castillo Serpa, A. M. (2020). Monte Carlo simulation model to coordinate the preventive maintenance scheduling of generating units in isolated distributed Power Systems. *Electric Power Systems Research*, *182*. https://doi.org/10.1016/j.epsr.2020.106237

Sutopo, W., & Nugroho, A. (2008). Usulan Jadwal Perawatan Preventif Mesin HGF di Stasiun Puteran Pabrik Gula. *Performa: Media Ilmiah Teknik Industri*, *7*(1), 19–30. https://jurnal.uns.ac.id/performa/article/view/13766

Suwandono, H. (2016). Analisa Kerusakan Pada Forklift Elektrik NICHIYU FB20-75C Dengan Metode FMEA. *Jurnal Teknik Mesin*, *5*(1), 1. https://doi.org/10.22441/jtm.v5i1.703

Wahyuni, H. C., Putra, B. I., Handayani, P., & Maulidah, W. U. (2021). Risk Assessment and Mitigation Strategy in The Halal Food Supply Chain in The Covid-19 Pandemic. *Jurnal Ilmiah Teknik Industri*, *20*(1), 1–8. https://doi.org/10.23917/jiti.v20i1.12973

Yanti, T. S. (2007). Uji Rank Mann-Whitney Dua Tahap. *Statistika*, *7*(1), 55–60. https://ejournal.unisba.ac.id/index.php/statistika/article/view/954

Yeh, T. M., & Sun, J. J. (2011). Preventive maintenance model with FMEA and Monte Carlo simulation for the key equipment in semiconductor foundries. *Scientific Research and Essays*, *6*(26), 5534–5547. https://doi.org/10.5897/SRE11.884