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Preventive Batching Plant Maintenance with Modularity Design Method at PT. RAJA Beton Indonesia

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Abstract:- Producers of liquid concrete are predicted to continue to grow. PT. RAJA Beton Indonesia engaged in readymix business in 2017 - 2019 experienced several times the damage to the production machine during the production process that caused a cost that is not cheap. Appropriate methods are needed to minimize maintenance costs. So the purpose of this research is to find out the preventive maintenance of Batching Plant with modularity design approach in PT. RAJA Beton Indonesia effectively and efficiently to produce a minimum total maintenance cost. Preventive maintenance with modularity design method is done by collecting data with documentation, interviews, and observations. The analysis technique starts from determining the company's initial total cost, and is continued by determining the total cost of this method which in some processes involves minitab 18 software. The results showed that the cost of maintenance using preventive maintenance with modularity design method resulted in a cheaper cost compared to the cost incurred by the company with corrective maintenance.

***Keywords:-** Preventive Maintenance; Correcrive Maintenance; Minitab 18; Modularity Design.*

I. INTRODUCTION

Generally, the companies that are currently doing maintenance activities when the machine is completely stopped, then maintenance activities will be carried out. If the production is processing and the machine stops cause of damaged, it can cause considerable losses for the company.

PT. RAJA Beton Indonesia has problems with the main equipment used for production, the batching plant was damaged during the production process so that it would interfere with the production process, because PT. RAJA Beton Indonesia uses the breakdown maintenance method where maintenance is carried out after damage to a component.

The maintenance system is usually divided in two, preventive maintenance and corrective maintenance [1][2]. Preventive maintenance is maintenance that is carried out before the engine component is damaged, while Corrective Maintenance is maintenance that is carried out after the component experiences damage or breakdown[3].

In running of preventive maintenance system, it is necessary to group machines according to their processes and functions. This machine component grouping can be done using the Modularity design method. [4][5]Modularity Design is a concept that can be used in the process of designing a product and can be adapted in a maintenance system. The goal of Modularity Design is to minimize machine maintenance costs and in replacement or repair work can be done once for several related components so that it can save costs and time [6].

Based on the description, the existing problems can be formulated, namely "How to preventive maintenance of Batching Plant machines with a modularity design approach at PT. RAJA Beton Indonesia effectively and efficiently to produce minimal total maintenance costs? ".

The purpose of this study was to determine the preventive maintenance of Batching Plant machines with a modularity design approach at PT. RAJA Beton Indonesia effectively and efficiently to produce minimal total maintenance costs.

II. LITERATURE REVIEW

A. *Maintenance*

[7][8][9][10]Wannawiset & Tangjitsitcharoen (2018), Ab-Samat et al (2012), Vilarinho et al (2017)Maintenance is an operational activity to maintain facilities, machinery and equipment, carry out repairs, adjust or replace as needed so that a satisfactory production operation condition occurs as expected. Maintenance is an operational process to repair machines or components that require rejuvenation or even replacement so that the function of the machine or component returns normal and the reliability of a machine can be maintained.

B. *Preventive and Corrective Maintenance*

[11][12][13]Guofa Li et al (2018) Preventive Maintenance is maintenance that is done in a fixed period or with special criteria at every stage of the production process. The goal is that products are issued in accordance with the plan, both in cost, quality, and according to time. To avoid

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component damage during the production process, the proper machine maintenance system uses a preventive maintenance system, by using this maintenance system production and operation activities are stable. Corrective Maintenance is maintenance that is done after a component is damaged or breakdown[3].

C. Modularity Design

Modularity design commonly applied by European countries, especially in terms of assembly and manufacturing industry. Modularity design makes manufacturing and assembly much cheaper and simpler. Companies in Indonesia do more corrective maintenance or preventive maintenance activities[14].

III. METHOD

The type of research in this scientific paper is descriptive quantitative. The quantitative research method is a type of research whose specifications are planned, systematic and structured from the start to the making of the research design.

The data used in this article are primary and secondary data. Data obtained from literature studies, field studies in the form of observations and interviews. The data required includes machine downtime data, machine data and its sub-components, downtime, critical sub-component data for batching plant machines, component purchasing costs, labor costs, product prices and employee salaries, and maintenance costs at the company.

In data analysis techniques, the first step is to collect data in the form of machines and machine sub-components, data on time of damage and repair of sub-components, price of machine components, and company standard cost data. The second step is to calculate Initial Total Cost (TC) and Proposed Total Cost (TC) by calculating maintenance costs at the company, calculating downtime and labor costs in the form of mechanical and operator costs, after which the company's Initial Total Cost (TC) is found. The next process is the calculation of costs using the Modularity Design method which includes grouping critical components, testing the distribution of damage data, calculating MTTF and MTTR, calculating Cp and Cf, calculating the time interval for damage, and calculating the total cost using the Modularity Design method.

In running of preventive maintenance system, it is necessary to group machines based on their processes and functions. This grouping can be done using the Modularity Design method. Modular design grouping is assisted by a software called Minitab 18. This software can help to group critical machine components or frequent breakdowns in the form of modules in order to facilitate the maintenance process of production machines.

IV. RESULTS AND DISCUSSION

A. Result

1) Engines and Machine Components

TABLE I. BATCHING PLANT MACHINE COMPONENTS

Component	Sub Components
Pump Mixer	Propeller
	Main Shaft
	Outside Bearings
	Inside Bearings
	Gear Box
	Van Belt
	Water Butterfly
	Water Pump
Conveyor	Conveyor Belt
	Roll Conveyor
	Bearing Roll Conveyor
	Van Belt
	Gear Box
	Gear Set
Material Bin	Vibro
	Screen
	ButterflyCement
	Hooper (Aggregate Scales)
	Air Cylynder Pneumatic

2) Breakdown Time and Component Repair Data

TABLE II. BREAKDOWN AND REPAIR TIME INTERVALS

No.	Component	Sub Components	Date	Downtime (Minute)
1	*Conveyor*	*Conveyor Belt*	08 - 01 - 2017	160
2	*Conveyor*	*Roll Conveyor*	23 - 01 - 2017	450
2	*Conveyor*	*Van Belt*	24 - 02 - 2017	184
3	*Pump Mixer*	*Water Pump*	06 - 03 - 2017	430
4	*Conveyor*	*Bearing Roll*	12 - 03 - 2017	160
5	*Material Bin*	*Vibro*	12 - 03 - 2017	175
6	*Pump Mixer*	*Bearings* Outside	11 - 04 - 2017	400

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No.	Component	Sub Components	Date	Downtime (Minute)
7	*Pump Mixer*	Propeller	08 - 05 - 2017	426
8	*Conveyor*	*Van Belt*	29 - 05 - 2017	172
9	*Material Bin*	*Screen*	30 - 05 - 2017	288
10	*Conveyor*	*Van Belt*	01 - 08 - 2017	178
11	*Pump Mixer*	*Van Belt*	25 - 08 - 2017	164
12	*Conveyor*	*Gear Box*	13 - 09 - 2017	380
13	*Pump Mixer*	*Inside Bearings*	29 - 10 - 2017	388
14	*Material Bin*	*Hooper*	17 - 11 - 2017	392
15	*Conveyor*	*Van Belt*	30 - 11 - 2017	173
16	*Conveyor*	*Conveyor Belt*	11 - 12 - 2017	162
17	*Pump Mixer*	*Van Belt*	14 - 01 - 2018	169
18	*Pump Mixer*	*Water Pump*	28 - 01 - 2018	384
19	*Material Bin*	*Cement Butterfly*	02 - 02 - 2018	153
20	*Pump Mixer*	*Water Butterfly*	17 - 02 - 2018	167
21	*Conveyor*	*Van Belt*	18 - 02 - 2018	180
22	*Pump Mixer*	*Main Shaft*	23 - 02 - 2018	410
23	*Conveyor*	*Gear Set*	25 - 02 - 2018	387
24	*Pump Mixer*	*Outside Bearings*	30 - 04 - 2018	370
25	*Conveyor*	*Van Belt*	23 - 05 - 2018	165
26	*Material Bin*	*Air Cylynder Pneumatic*	23 - 05 - 2018	358
27	*Pump Mixer*	*Van Belt*	02 - 7 – 2018	165
28	*Conveyor*	*Van Belt*	29 - 07 - 2018	168
29	*Pump Mixer*	*Gear Box*	18 - 08 - 2018	370
30	*Material Bin*	*Vibro*	24 - 09 - 2018	143
31	*Conveyor*	*Conveyor Belt*	25 - 09 - 2018	177
32	*Material Bin*	*Screen*	13 - 10 - 2018	275
33	*Conveyor*	*Van Belt*	15 - 10 - 2018	166
34	*Conveyor*	*Bearing Roll Conveyor*	16 - 11 - 2018	165
35	*Pump Mixer*	*Inside Bearings*	17 - 11 - 2018	350
36	*Conveyor*	*Roll Conveyor*	27 - 11 - 2018	380
37	*Pump Mixer*	*Water Pump*	19 - 12 - 2018	400
38	*Conveyor*	*Van Belt*	20 - 01 - 2019	160
39	*Pump Mixer*	*Van Belt*	13 - 02 - 2019	180
40	*Conveyor*	*Van Belt*	01 - 04 - 2019	155
41	*Pump Mixer*	*Van Belt*	09 - 05 - 2019	175
42	*Pump Mixer*	*Inside Bearings*	31 - 05 - 2019	310
43	*Conveyor*	*Van Belt*	26 - 06 - 2019	178
44	*Conveyor*	*Roll Conveyor*	01 - 09 - 2019	370
45	*Conveyor*	*Van Belt*	12 - 09 - 2019	165
46	*Conveyor*	*Bearing Roll Conveyor*	30 - 09 - 2019	140
47	*Pump Mixer*	*Water Pump*	21 - 10 - 2019	420
48	*Material Bin*	*Hooper*	27 - 10 - 2019	437

No.	Component	Sub Components	Date	Downtime (Minute)
49	*Pump Mixer*	*Van Belt*	15 - 11 - 2019	168
50	*Conveyor*	*Conveyor Belt*	17 - 11 - 2019	145
51	Pump Mixer	Propeller	14 - 12 - 2019	488
52	*Conveyor*	*Van Belt*	23 - 12 - 2019	160
TOTAL				**13,835**

Between the time of breakdowns and the length of time to repair a batching plant machine for each critical component based on the time of failure and repair time in Table II, it can be seen with the following calculation examples:

Conveyor Components (Van Belt):
Date (24–02–2017) - Date (29–05– 2017)
= 94 Days
= 94 Days x 24 Hours x 60 Minutes
= 135,360 Minutes

3) Company Standard Cost Data

Based on secondary data obtained from the company, labor costs and product prices can be seen in Table III

TABLE III. PRODUCT AND LABOR COSTS

Information	Total	Unit
Number of Operators	2	Person
Operator Salary	4.200.000	IDR / month / person
Total Mechanics	3	Person
Mechanic Salary	4.200.000	IDR / month / person
Production capacity	300	m^3 / day
Product Selling Price	750.000	IDR / m^3
Production cost	670.000	IDR / m^3

In Table III, data on the number of workers and product prices are obtained from company data. The list of costs above will be used for several calculations in data processing.

4) Maintenance Costs of Company

Maintenance at the company is carried out when there is damage to engine components, what is done is to repair and replace the damaged sub-components. Batching plant machine components during the period 2017 - 2019 suffered 53 times of damage and spent a total cost of IDR 119.050.000 for the purchase of components.

5) Calculation of Downtime Costs and Labor Cost

Downtime costs
= (Product Selling Price-Cost of Production) x Output/hour(1)
= (750.000–670.000) x 18 m^3/hour
= IDR 1.440.000, - per hour

Operator Fee

$$= \frac{salary/month\ (IDR)}{workhours/month\ (Jam)}$$
(2)

$$= \frac{IDR\ 4.200.000/month}{180\ hours/month}$$

= IDR 23.333, - / hour

Total Operator Costs
= Cost of one operator per hour x Number of operators (3)
= IDR 23.333 / hour x 2 people
= IDR 46.666 / hour

$$\frac{Timeofdowntimecomponent}{ConvertionofTimeperHour} xOperatorCostperHour \quad (4)$$

$$\frac{410\ Minutes}{60\ Minutes} xIDR\ 46.666\ perhour = Rp\ 318.884$$

Mechanical Costs
$$= \frac{Salary/month\ (IDR)}{WorkHours/Month\ (Hour)}$$
(5)

$$= \frac{IDR\ 4.200.000/Month}{180\ Hours/Month}$$

= IDR 23.333, - / hour

Total Mechanic Cost
= Cost of one mechanic per hour x Number of mechanics
(6)
= IDR 23.333 / hour x 3 people
= IDR 69.999 / hour

So that the manual calculation of mechanical costs on the Main Shaft sub components are:

$$\frac{TimeofDowntimeComponent}{ConvertionofTimeperHour} xMechanicCostperHour$$
(7)
$$\frac{410\ Minutes}{60\ Minutes} xIDR\ 69.999\ perhour = IDR\ 478.327$$

The results of the calculation of the company's total maintenance costs (Initial TC) are as follows:

Initial TC = Total Maintenance Costs + Downtime Loss + Unemployment Operator Loss + Mechanical Costs
= IDR 119.050.000 + IDR 38.160.000 + IDR 10.760.406 + IDR 16.140.608
= **IDR 184.111.014**

6) Calculation of Downtime Costs and Labor Cost

Sub-components are grouped into modules according to their structure. For clearer information, see Table IV.

TABLE IV. SUB-COMPONENT MODULE FOR BATCHING PLANT MACHINE

Module	Sub Component (Component)
Module 1	Outside Bearings (Pump Mixer)
	Inside Bearings (Pump Mixer)
	Bearing Roll Conveyor (Conveyor)
	Roll Conveyor (Conveyor)
Module 2	Gear Box (Pump Mixer)
	Gear Box (Conveyor)
	Gear Set (Conveyor)
Module 3	Van Belt (Pump Mixer)
	Van Belt (Conveyor)
Module 4	Water Butterfly(Pump Mixer)
	Cement Butterfly (Bin Material)
	Conveyor Belt (Conveyor)
	Water Pump (Pump Mixer)
	Propeller (Pump Mixer)
	Main Shaft (Pump Mixer)
Module 5	Vibro (Bin Material)
	Screen (Bin Material)
	Hooper (Bin Material)
	Air Cylinder Pneumatic (Bin Material)

7) Minitab 18 Distribution Test

Furthermore, the distribution test was carried out using Minitab 18 software. The following is a table of distribution test results for each module.

TABLE V. DISTRIBUTION TEST RESULTS BASED ON DOWNTIME DATA

No.	Component	Type Distribution	Parameter	
			β (shape)	***η (scale)***
1	Module 1	*Weibull*	3,747	352,429
2	Module 2	*Weibull*	65,590	382,337
3	Module 3	*Weibull*	23,815	173,442
4	Module 4	*Weibul*	2,542	341,952
5	Module 5	*Weibull*	3,367	330,375

Table V is the result of data processing carried out by Minitab 18 software. The parameter value is obtained by looking at the estimate value in the distribution test. The shape parameter (β) describes the shape of the distribution in the Weibull distribution. While the scale parameter (η) describes the data distribution in the Weibull distribution.

TABLE VI. DISTRIBUTION TEST RESULTS BASED ON DOWNTIME DATA

No.	Component	Type Distribution	Parameter	
			β (shape)	***η (scale)***
1	Module 1	*Weibull*	2,410	476,814
2	Module 2	*Weibull*	12,859	963,207
3	Module 3	*Weibull*	2,754	178,893
4	Module 4	*Weibull*	2,072	690,544
5	Module 5	*Weibull*	7,415	910,640

The parameter value is obtained by looking at the estimate value in the distribution test. The shape parameter (β) describes the shape of the distribution in the Weibull distribution. While the scale parameter (η) describes the data distribution in the Weibull distribution.

8) MTTR and MTTF calculations

After knowing the distribution and parameters of each distribution in Table V and Table VI, then calculate the Mean Time To Repair (MTTR) and Mean Time To Failure (MTTF) with the formula.

$$\text{MTTR / MTTF} = .\eta\Gamma\left(1 + \frac{1}{\beta}\right) \quad (8)$$

TABLE VII. MTTF AND MTTR CALCULATIONS

MODULE	MTTR	MTTF
1	318,067 minutes	422.819,583 minutes
2	378,070 minutes	924.418,654 minutes
3	169,703 minutes	159.246,971 minutes
4	303,602 minutes	611.649,348 minutes
5	296,502 minutes	855.937,855 minutes

9) Treatment Time Intervals (TM)

The calculation for this maintenance time interval includes replacement costs due to maintenance (Cp), the cost of replacing sub-components due to damage (Cf), scale value, and shape value at time between treatments. The formula that can be used to calculate the maintenance time interval is as follows:

$$\text{TM} = \boldsymbol{\eta}\text{x} \left|\frac{C_p}{C_f(\beta - 1)}\right|^{\frac{1}{\beta}} \quad (9)$$

TABLE VIII. TREATMENT TIME INVTERVAL

Module	Parameter β (shape)	*Parameter* η *(scale)*	Cp	Cf	TM (Minutes)
1	2,410	476,814	IDR 32.391.803	IDR 116.361.491	243.212.923
2	12,859	963,207	IDR 10.323.225	IDR 37.544.265	718.767.989
3	2,754	178,893	IDR 16.111.696	IDR 93.496.246	77.036.326
4	2,072	690,544	IDR 48.804.561	IDR 143.528.385	396.752.305
5	7,415	910,640	IDR 25.521.398	IDR 75.333.734	612.477.666

10) Total Maintenance Costs Using Modularity Design Method

Total maintenance costs are calculated according to the unit of time used. Because the data above uses minutes, it is based on distributed weibull data then the total maintenance costs are:

$$TC = \frac{C_f}{\eta^{\beta}} TM^{\beta-1} + \frac{C_p}{TM} \quad (10)$$

TABLE IX. RECAPITULATION OF TC CALCULATIONS

Module	TC (IDR / minute)
Module 1	IDR 228 / minute
Module 2	IDR 16 / minute
Module 3	IDR 328 / minute
Module 4	IDR 238 / minute
Module 5	IDR 48 / minute

TABLE X. CALCULATION OF THE TOTAL COST OF USINGMODULARITY

Module	Total Cost (IDR / 3 Years)
Module 1	IDR 33.481.738
Module 2	IDR 9.039.810
Module 3	IDR 33.997.023
Module 4	IDR 47.933.210
Module 5	IDR 23.356.480
Total	**IDR 147.808.261**

The total Batching Plant maintenance cost calculated using the modularity design method is IDR 147.808.261 per 3 years.

11) Selection of Minimum Cost Treatment Methods

TABLE XI. COMPARISON OF THE COMPANY'S TOTAL MAINTENANCE COSTS AND MODULARITY DESIGN

Total Company Maintenance Costs	Total Cost with Modularity Design
IDR 184.111.014, - / 3 years	IDR 147.808.261, - / 3 years

From Table XI, it can be seen that the total cost of maintaining the company is IDR 184.111.014 per 3 years. Meanwhile, the modularity design method resulted in a total maintenance cost of IDR 147.808.261 per 3 years. Furthermore, it can be calculated the efficiency between the company's maintenance costs with the proposed method. The efficiency calculation is as follows:

$$\text{Efficiency} = \frac{\text{TC Company - TC Modularity Design}}{\text{TC Copany}} \times 100\% \quad (11)$$

$$= \frac{\text{IDR 184.111.014} - \text{IDR 147.808.261}}{\text{Rp 184.111.014}} \times 100\%$$

= **19.72%**

B. Discussion

Based on the results of the above data processing, it can be seen that PT. RAJA Beton Indonesia is still using the corrective maintenance method for all components. Corrective maintenance is a maintenance activity that is carried out after a breakdown or abnormality occurs in a facility or equipment so that it cannot function properly[15][16][17]. PT. RAJABeton Indonesia carries out repairs or maintenance when the engine components are damaged or stop operating during production activities which result in losses to the company. This can be happens because the company does not have the spare parts needed when these components need to be replaced which results in a longer repair time. According to [18][19]It is explained that if the repair and the repetitive set-up time can be detrimental to the company because long breakdown times and repeated set-ups will affect the costs incurred by the company, namely costs such as the salary of machine operators who are not doing their jobs during the breakdown period and costs for the mechanic to repair the machine during the required period of time.

The method currently used by the company is still quite costly and needs other alternative methods in order to minimize costs incurred for maintenance activities. Alternative methods used in this research are preventive maintenance. Preventive maintenance is an activity that aims to prevent damage that can be predicted in advance and if you can take advantage of good preventive maintenance procedures, the benefits of this method are that the loss of production time can be minimized, large repair costs can be reduced[20][21][22]Eeryilmaz (2020). The Modularity Design method can be said to be more efficient than other methods because of ease to understand which means it is easier to understand because in the process it divides modules that are easier to understand in detail, more efficient maintenance, decreased failure of machine components, and decreased maintenance time. Based on the results of processing and analysis of Preventive Maintenance data that have been carried out using the Modularity Design method on a readymix concrete production machine at PT. RAJA Beton

Indonesia there are several stages carried out, namely the first grouping of sub-components based on their structure and function, determining the grouping of these sub-components based on interconnected sub-components. The purpose of grouping the sub components in this module is to determine the critical components and reduce the component's downtime. The contents of the table in this module are the downtime and the time interval between damage to each sub-component.

After that, testing the distribution of each module with assistance Minitab software 18 to find out the Weibull distribution of each module. This Weibull distribution is used to solve the problem of the length of time (age) of a production machine component that can last until the production machine component does not function properly (damaged or dead). The weibull distribution is widely used because it has a scale that affects the middle value of the data pattern and shape parameters that are useful for determining the level of damage from the formed data patterns [23].

The results of the distribution test data for each module are needed to determine the MTTR and MTTF values. Mean Time To Repair (MTTR) is the time required to repair each damaged sub-component until the sub-component returns to its proper function. Meanwhile, Mean Time To Failure (MTTF) is the time a sub-component functions optimally and properly until the sub-component does not function or is damaged. Each module is calculated its MTTR and MTTF to find out how long the repair time and reliability time of the engine sub-components in the module are.

Next up is Cp, that is Cost Preventive namely costs arise because there is component maintenance that has been scheduled and not in the production process. Then Cf, cost corrective is the cost that arises due to a machine component that breaks suddenly until the production process has to stop, this results in losses due to production failure. The calculation of Cp and Cf will be used to calculate the optimal maintenance time interval. Determination of TM or maintenance time interval which means the time interval of a machine component from optimal conditions until the component needs to be maintained, is done by calculating the costs incurred for maintenance (Cp), the cost for repairs (Cf), therefore the large costs involved issued for maintenance and repair is determined before calculating the TM value.

In this study, (TC) is proposed by the method modularity design has the lowest cost than the company's initial (TC) method. [14]Jong Joo (2007) Modularity design makes the manufacturing and assembly processes cheaper and simpler. Modularity allows for a reduction of service costs by grouping components by similarity and dependenc[24][25]Yicong & Jianrong (2015), Petersen et al (2016).[26]Modularity design has several advantages, namely the design of the new components is easier, reduces the time and cost of training for mechanical labor, ease of maintenance, reduced maintenance time, low capability requirements to move the modular unit, and easier removal of failed units.

According to research results[4] and [14]shows that the best proposal is to apply preventive maintenance with modularity design methods because the company can save and reduce costs from the initial state compared to companies doing corrective maintenance activities. So is research[6] with the result that machine maintenance costs with preventive modularity maintenance can issue lower maintenance costs compared to breakdown maintenance costs. [14][27][28][29]also shows the results that doing preventive maintenance with a modularity design can minimize previous maintenance costs.

V. CONCLUSION

The results of the data processing and analysis carried out concluded that the company carried out machine maintenance operations using corrective maintenance with a total cost of IDR 184.111.014 per 3 years. Meanwhile, the proposed preventive maintenance method, the modularity design method, resulted in a cheaper cost, which is IDR 147.808.261 per 3 years compared to the total maintenance cost at the company with a savings IDR 36.302.753 per 3 years and an efficiency value of 19.72%. So that this proposed maintenance method with modularity design can be accepted.

REFERENCES

[1]. F. T. D. Atmaji dan A. A. N. N. U. Putra, “Kebijakan Persediaan Suku Cadang di PT ABC Menggunakan Metode RCS (Reliability Centered Spares),” *J. Manaj. Ind. Dan Logistik*, vol. 2, no. 1, hal. 90–102, 2018.

[2]. A. L. B. Costa dan Â. R. Balduino, “The Importance of Preventive and Corrective Maintenance in Works,” *Int. J. Adv. Eng. Res. Sci.*, vol. 5, no. 5, hal. 72–76, 2018, doi: 10.22161/ijaers.5.5.10.

[3]. M. Holgado, M. Macchi, dan L. Fumagalli, “Value-in-use of e-Maintenance in Service Provision: Survey Analysis and Future Research Agenda,” *IFAC-PapersOnLine*, vol. 49, no. 28, hal. 138–143, 2016, doi: 10.1016/j.ifacol.2016.11.024.

[4]. A. Witonohadi, T. G. Amran, dan N. Herawati, “Usulan Perawatan Mesin Secara Preventif Dengan Pendekatan Modularisasi Desain Pada PT. Bai,” *J. Tek. Ind.*, vol. 3, no. 1, hal. 1–9, 2013, doi: 10.25105/jti.v3i1.1581.

[5]. W. Anggono, Julianingsih, dan Linawati, “Preventive Maintenance System Dengan Modularity Design Sebagai Solusi Penurunan Biaya Maintenance (Studi Kasus di Perusahaan Tepung Ikan),” *J. Tek. Ind.*, vol. 7, no. 1, hal. 61–75, 2005, doi: 10.9744/jti.7.1.pp.61-75.

[6]. P. Tarigan, E. Ginting, dan I. Siregar, “Perawatan Mesin Secara Preventive Maintenance Dengan Modularity Design Pada PT. Rxz,” *e-Jurnal Tek. Ind. USU*, vol. 3, no. 3, hal. 35–39, 2013.

[7]. R. A. M. Puteri dan M. I. Alrosyid, “Perencanaan Perawatan Air Compressor Unit Untuk Komponen Air Quick Couplings Dengan Metode Reliability Centered Maintenance Di PT Astra International Tbk – TSO Cabang Salemba,” *J. PASTI*, vol. 9, no. 2, hal. 129–137, 2015.

[8]. D. S. Dhamayanti, J. Alhilman, dan N. Athari, “Usulan Preventive Maintenance Pada Mesin Komori LS440

Dengan Menggunakan Metode Reliability Centered Maintenance (R IICM) Dan Risk Based Maintenance (RBM) Di Pt ABC," *J. Rekayasa Sist. Ind.*, vol. 3, no. 02, hal. 31–37, 2016, doi: 10.25124/jrsi.v3i02.29.

[9]. W. Ayuningrum dan T. Aspiranti, "Analisis Pemeliharaan Mesin dengan Metode Preventive dan Breakdown Maintenance dalam Rangka Meminimumkan Biaya Pemeliharaan Mesin pada PT. World Yamatex Spinning Mills Bandung," *Prosisding Manaj.*, vol. 4, no. 1, hal. 365–370, 2018.

[10]. F. Trojan dan R. F. M. Marçal, "Proposal of Maintenance-types Classification to Clarify Maintenance Concepts in Production and Operations Management," *J. Bus. Econ.*, vol. 8, no. 7, hal. 560–572, 2017, doi: 10.15341/jbe(2155-7950)/07.08.2017/005.

[11]. S. Prawirosentono, *Manajemen Produksi*. Jakarta: Bumi Aksara, 2010.

[12]. M. Z. Z. Muhtadi, "Manajemen Pemeliharaan Untuk Optimalisasi Laba Perusahaan," *J. Pendidik. Akunt. Indones.*, vol. VIII, no. 1, hal. 35–43, 2009, doi: 10.21831/jpai.v8i1.943.

[13]. F. Qian dan K. Dong, "Optimizing Preventive Maintenance of Used Equipment for Lease Using Enumeration Algorithm," vol. 11, hal. 86–93, 2017, doi: 10.2174/1874110X0171101008.

[14]. H. Hariyanto, S. Rahayuningsih, dan H. B. Santoso, "Analisa Preventive Maintenance System Dengan Modularity Design Pada PT. Surya Pamenang," *JATI UNIK J. Ilm. Tek. dan Manaj. Ind.*, vol. 1, no. 1, hal. 24–29, 2017, doi: 10.30737/jatiunik.v1i1.66.

[15]. S. D. Pandi, H. Santosa, dan J. Mulyono, "Perancangan Preventive Maintenance Pada Mesin Corroguting dan Mesin Flexo di PT Surindo Teguh Gemilang," *J. Ilm. Widya Tek.*, vol. 13, no. 1, hal. 33–38, 2014.

[16]. K. Kulsum, E. Febianti, dan I. S. H, "Usulan Waktu Preventive Maintenance Untuk Menururnkan Downtime Mesin Paper Mill 1 Dengan Reliability Block Diagram (Studi Kasus: PT Indah Kiat Pulp and Paper)," *Semin. Nas. Sains dan Teknol. Fak. Tek. Univ. Muhammadiyah*, hal. 1–8, 2018.

[17]. T. Niyamosoth dan S. Pathumnakul, "Joint Determination of Preventive Maintenance and Buffer Stock for a Production Unit Under Lease," *J. Ind. Eng. Manag.*, vol. 11, no. 3, hal. 497–512, 2018, doi: 10.3926/jiem.2578.

[18]. A. Silalahi, R. Sukwadi, dan T. P. Hidayat, "Usulan Preventive Maintenance Dengan Menggunakan Metode Modularity Design Pada Mesin Surface Mounting Technology (Studi Kasus : PT. X)," *Pros. Semin. Nas. Teknoin Bid. Tek. Ind.*, hal. C173–C180, 2008.

[19]. M. Savsar, "Analysis and Scheduling of Maintenance Operations for a Chain of Gas Stations," *J. Ind. Eng.*, vol. 2013, hal. 1–7, 2013, doi: 10.1155/2013/278546.

[20]. Y. Praharsi, I. K. Sriwana, dan D. M. Sari, "Perancangan Penjadwalan Preventive Maintenance Pada PT. Artha Prima Sukses Makmur," *J. Ilm. Tek. Ind.*, vol. 14, no. 1, hal. 60–65, 2015, [Daring]. Tersedia pada: http://journals.ums.ac.id/index.php/jiti/article/viewFile/624/364.

[21]. H. Liu dan J. Wu, "Research on Preventive Maintenance Strategy of Elevator Equipment," *Open J. Soc. Sci.*, vol. 06, no. 01, hal. 165–174, 2018, doi: 10.4236/jss.2018.61012.

[22]. V. Hernández-Chover, L. Castellet-Viciano, dan F. Hernández-Sancho, "Preventive Maintenance Versus Cost of Repairs in Asset Management: An Efficiency Analysis in Wastewater Treatment Plants," *Process Saf. Environ. Prot.*, vol. 141, hal. 215–221, 2020, doi: 10.1016/j.psep.2020.04.035.

[23]. T. Taufik dan S. Septyani, "Penentuan Interval Waktu Perawatan Komponen Kritis pada Mesin Turbin Di PT Pln (Persero) Sektor Pembangkit Ombilin," *J. Optimasi Sist. Ind.*, vol. 14, no. 2, hal. 238–258, 2015, doi: 10.25077/josi.v14.n2.p238-258.2015.

[24]. D. Ernawati, E. Pudji, Y. Ngatilah, dan R. Handoyo, "Modularity Design Approach for Preventive Machine Maintenance," *J. Phys. Conf. Ser.*, vol. 953, no. 1, hal. 1–5, 2018, doi: 10.1088/1742-6596/953/1/012232.

[25]. N. T. Putri, Taufik, dan F. S. Buana, "Preventive Maintenance Scheduling by Modularity Design Applied to Limestone Crusher Machine," *Procedia Manuf.*, vol. 43, hal. 682–687, 2020, doi: 10.1016/j.promfg.2020.02.123.

[26]. T. Subagja, "Analisis Perawatan Mesin Rolling Secara Berkala dengan Pendekatan Modularisasi Desain," *Semin. Nas. Teknol.*, hal. 172–177, 2018.

[27]. A. Z. Z. Suwondo dan E. P. Widjajati, "Penerapan Metode Modularity Design Pada Perwatan Mesin Mixer Secara Preventive di PT XYZ," *Juminten Jurnak Manaj. Ind. dan Teknol.*, vol. 1, no. 5, hal. 37–48, 2020, doi: 10.33005/juminten.v1i5.165.

[28]. C. H. Wu, Y. C. Yao, S. Dauzère-Pérès, dan C. J. Yu, "Dynamic Dispatching and Preventive Maintenance for Parallel Machines with Dispatching-Dependent Deterioration," *Comput. Oper. Res.*, vol. 113, hal. 104779, 2020, doi: 10.1016/j.cor.2019.104779.

[29]. J. Xiao, J. Song, D. Liang, L. Zhai, dan X. Nong, "Decision Method on Optimal Time of Preventive Maintenance for Metro Shield Tunnels in Soft Soils," *Int. J. Transp. Sci. Technol.*, vol. 9, no. 4, hal. 344–354, 2020, doi: 10.1016/j.ijtst.2020.03.006.