E-ISSN: 2963-3699
P-ISSN: 2964-0121
Homepage: Homepage: https://return.publikasikupublisher.com

ANALYSIS OF ENGINE MAINTENANCE TECHNIQUES IN DOUBLE-CABIN VEHICLE UNITS USING MODULARITY DESIGN METHOD AT PT WAHYU PUTRA MANDIRI PERKASA

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ABSTRACT

Companies that providing motorised vehicle rental services specialising in coal mining areas have to go the extra mile in carrying out maintenance due to unexpected damage by the maintenance schedule. This research aims to discover problems related to constraints on the maintenance system carried out so that it is less efficient and effective in its implementation. Preventive maintenance with a modularity design method collects data with documentation, interviews, and observations. The analysis technique determines the company's total cost (Initial TC). It continues determining the total cost of the proposal (Proposed TC) which is processed using app. Minitab 2021. The results of this study indicate that maintenance costs using preventive maintenance with the modularity design method are lower and more efficient than maintenance costs using corrective maintenance carried out by the company.

Keywords: *Corrective Maintenance; Double Cabin; Modularity Design; Preventive Maintenance*

INTRODUCTION

The use of motorized vehicles in coal mining areas is very important in carrying out the process of operational activities of mining industry companies (Abuya, 2016). The reason mining industry companies choose to lease motorized vehicles for their operational cars is to avoid depreciation of asset values, free maintenance costs, and availability of replacement units (Trac, 2023).

In the operational activities of mining industry companies, it provide its own challenges in maintaining the vehicles used (Wilhelms et al., 2017). Not a few motorized vehicle units experience heavy damage due to overuse and/or heavy use in the mining environment where the road terrain is muddy when it rains and dusty and gravel (Hadi, 2019; Harada, 2020). Finally, companies providing motorized vehicle rental services specifically for coal mining areas have to work extra in carrying out maintenance due to damage that is not expected according to the maintenance schedule (Ciliberti et al., 2008; Shaheen & Chan, 2016).

Maintenance is any activity such as tests, measurements, replacements, adjustments, and repairs intended to maintain or restore a functional unit in or to a state where it can perform its required function (Gortney, 2016). Poor maintenance can be disruptive, inconvenient, wasteful, and very costly, even exceeding the cost of living (Besterfield et al., 2019; Heizer et al., 2020). With good maintenance, the tools, objects and systems are always in a controlled condition and ready to be used at any time. With this maintenance effort, in addition to ensuring that the goods are ready for use, it will also extend the life of the equipment, goods or system (Taufiqullah, 2022).

In performing the maintenance system required grouping damage to the sub-components of the machine based on the function and process (Tan et al., 2011; Villarini et al., 2017). This grouping can be determined through the Modularity Design method. Modularity Design is a preventive maintenance method that aims to combine several machine components into a maintenance module (Putri et al., 2020; Yanti, 2015). The application of the Modularity Design method by grouping components based on into certain modules in the hope that it can facilitate the replacement of machine components, ten maintenance time, and reduce maintenance costs at the company (Daruhadi et al., 2023; Suwondo & Widjajati, 2020). Modularity allows for a reduction in service costs by grouping components based on similarities and dependencies. Some companies apply modularity design to facilitate the grouping of components/sub-components when performing periodic maintenance which aims to reduce maintenance costs and reduce the occurrence of damage. One example is PT RAJA Beton Indonesia, a batching plant machine that previously carried out maintenance using the breakdown maintenance method to preventive maintenance which greatly reduced previous maintenance costs. PT Wahyu Putra Mandiri Perkasa (PT WPMP) has a double cabin vehicle unit that is chosen by mining companies as an operational vehicle because its function is in accordance with the needs of the company. This study aims to determine the problems related to constraints on the maintenance system carried out so that it is less efficient and effective in its

implementation and determine maintenance scheduling/planning with the modularity design approach method in order to produce efficient maintenance costs for double cabin vehicle units at PT WPMP.

RESEARCH METHOD

The research method used in this research is a descriptive quantitative method with the aim of describing and explaining an event accurately and systematically about the facts in the phenomenon under study (Priadana & Sunarsi, 2021; Yilmaz, 2013). The research was taken in Balikpapan City from May 2021 until April 2022. The population and sample were 13 units of double-cabin cars. Data collecting techniques by interview with the mechanics and secondary data from the company such as list of the vehicles and record notes of maintenance. Data analysis techniques are: the first research method is to calculate maintenance costs by the company; second, grouping sub-components into modules; third, Weibull distribution suitability test; fourth, calculate MTTR and MTTF; fifth, calculate maintenance and damage costs; sixth, calculate total proposed maintenance costs; seventh, comparison between initial maintenance costs and proposed maintenance costs (Díaz-Reza et al., 2019).

RESULT AND DISCUSSION

Company Maintenance Cost / Initial Total Cost

1. Component Maintenance Cost

The company performs maintenance on a scheduled basis, but due to road conditions, weather, and several other factors cause damage to occur more quickly or unexpectedly. Based on information data from the company, component maintenance costs can be seen in table 1 below.

Table 1 Maintenance Cost Data in the Company

Component	Sub-Component	Maintenance Cost (May 2021-April 2022)	
ENGINE	Engine Oil	Rp	2,640,000
	Oil Filter	Rp	1,020,000
	Fuel Filter	Rp	500,000
	Air Filter	Rp	810,000
	Air Radiator	Rp	290,000
	Timing Belt	Rp	450,000
STEERING SYSTEM	Steering Oil	Rp	504,000
	Bearing Roda Depan	Rp	1,050,000
	Tie Rod	Rp	1,000,000
BRAKING SYSTEM	Disc Brake	Rp	2,260,000
	Brake Pad	Rp	300,000
	Brake Shoe	Rp	1,400,000
	Drum Brake	Rp	1,200,000
	Master Brake	Rp	1,500,000
	Minyak Rem	Rp	160,000
POWER TRAIN	Oli Transmisi	Rp	240,000
	Oli Gardan	Rp	370,000
BATTERY & ELECTRICAL SYSTEM	Air ACCU	Rp	165,000
	ACCU	Rp	1,050,000
	Head Lamp	Rp	360,000
	Fog Lamp	Rp	150,000
	Reverse Lamp	Rp	1,800,000
	Back Alarm	Rp	300,000
	Lampu Rotari	Rp	4,800,000
	Brake Lamp	Rp	100,000
	Lampu Sein	Rp	40,000
WHEEL, SUSPENSION	Ban Kendaraan	Rp	1,350,000
	Shock Absorber	Rp	475,000
	Spring / Per	Rp	750,000

TOTAL		**Rp**	**27,034,000**

The data is obtained from the company and is the real data of the company's maintenance costs for the period May 2021 to April 2022**.**

2. Calculation of Downtime Costs and Labor Costs

Based on the data collected, the calculation of labor costs and downtime costs can be seen in the table 2.

Table 2 Disadvantages of Each Component

Component	Sub-Component	Tanggal	Kerugian Akibat *Downtime*		Biaya Mekanik	
Engine	Oil Filter	03/05/2021	Rp	31,944	Rp	21,485
Engine	Fuel Filter	03/05/2021	Rp	31,944	Rp	14,323
Engine	Engine Oil	07/05/2021	Rp	31,944	Rp	21,485
Steering System	Tie Rod	19/05/2021	Rp	31,944	Rp	42,969
Steering System	Bearing Roda Depan	31/05/2021	Rp	31,944	Rp	85,938
Battery & Electrical System	Air ACCU	31/05/2021	Rp	31,944	Rp	14,323
Engine	Engine Oil	04/06/2021	Rp	31,944	Rp	21,485
Battery & Electrical System	ACCU	04/06/2021	Rp	31,944	Rp	21,485
Steering System	Steering Oil	16/06/2021	Rp	31,944	Rp	42,969
Battery & Electrical System	Air ACCU	18/06/2021	Rp	31,944	Rp	14,323
Wheel, Suspension	Spring	18/06/2021	Rp	31,944	Rp	85,938
Engine	Air Filter	30/06/2021	Rp	31,944	Rp	14,323
Engine	Oil Filter	01/07/2021	Rp	31,944	Rp	21,485
Battery & Electrical System	Air ACCU	01/07/2021	Rp	31,944	Rp	14,323
Engine	Engine Oil	06/07/2021	Rp	31,944	Rp	21,485
Steering System	Tie Rod	13/07/2021	Rp	31,944	Rp	42,969
Braking System	Brake Shoe	06/08/2021	Rp	31,944	Rp	85,938
Braking System	Drum Brake	06/08/2021	Rp	31,944	Rp	85,938
Braking System	Disc Brake	09/08/2021	Rp	31,944	Rp	85,938
Braking System	Minyak Rem	09/08/2021	Rp	31,944	Rp	42,969
Power Train	Oli Transmisi	09/08/2021	Rp	31,944	Rp	14,323
Power Train	Oli Gardan	09/08/2021	Rp	31,944	Rp	14,323
Engine	Engine Oil	09/08/2021	Rp	31,944	Rp	21,485
Engine	Fuel Filter	09/08/2021	Rp	31,944	Rp	14,323
Engine	Air Filter	09/08/2021	Rp	31,944	Rp	14,323
Steering System	Steering Oil	14/08/2021	Rp	31,944	Rp	42,969
Battery & Electrical System	Air ACCU	14/08/2021	Rp	31,944	Rp	14,323
Steering System	Steering Oil	03/09/2021	Rp	31,944	Rp	42,969
Battery & Electrical System	Reverse Lamp	11/09/2021	Rp	31,944	Rp	14,323
Battery & Electrical System	Fog Lamp	15/09/2021	Rp	31,944	Rp	14,323
Engine	Oil Filter	16/09/2021	Rp	31,944	Rp	21,485
Engine	Engine Oil	16/09/2021	Rp	31,944	Rp	21,485
Battery & Electrical System	Air ACCU	16/09/2021	Rp	31,944	Rp	14,323
Battery & Electrical System	Head Lamp	25/09/2021	Rp	31,944	Rp	14,323
Battery & Electrical System	Lampu Rotari	25/09/2021	Rp	31,944	Rp	21,485
Engine	Engine Oil	13/10/2021	Rp	31,944	Rp	21,485
Engine	Air Filter	13/10/2021	Rp	31,944	Rp	14,323
Braking System	Brake Pad	16/10/2021	Rp	31,944	Rp	85,938
Braking System	Brake Shoe	16/10/2021	Rp	31,944	Rp	85,938
Wheel, Suspension	Shock Absorber	16/10/2021	Rp	31,944	Rp	85,938
Steering System	Steering Oil	17/10/2021	Rp	31,944	Rp	42,969
Battery & Electrical System	Air ACCU	17/10/2021	Rp	31,944	Rp	14,323
Steering System	Tie Rod	02/11/2021	Rp	31,944	Rp	42,969
Engine	Fuel Filter	09/11/2021	Rp	31,944	Rp	14,323
Engine	Engine Oil	13/11/2021	Rp	31,944	Rp	21,485
Engine	Oil Filter	13/11/2021	Rp	31,944	Rp	21,485

Steering System	Steering Oil	13/11/2021	Rp	31,944	Rp	42,969
Battery & Electrical System	Back Alarm	15/11/2021	Rp	31,944	Rp	14,323
Steering System	Bearing Roda Depan	19/11/2021	Rp	31,944	Rp	85,938
Battery & Electrical System	Air ACCU	19/11/2021	Rp	31,944	Rp	14,323
Battery & Electrical System	Lampu Sein	19/11/2021	Rp	31,944	Rp	14,323
Wheel, Suspension	Spring	03/12/2021	Rp	31,944	Rp	85,938
Braking System	Master Brake	03/12/2021	Rp	31,944	Rp	42,969
Engine	Engine Oil	06/12/2021	Rp	31,944	Rp	21,485
Battery & Electrical System	Air ACCU	11/12/2021	Rp	31,944	Rp	14,323
Steering System	Tie Rod	25/12/2021	Rp	31,944	Rp	42,696
Engine	Timing Belt	25/12/2021	Rp	31,944	Rp	85,938
Steering System	Steering Oil	27/12/2021	Rp	31,944	Rp	42,969
Engine	Air Filter	27/12/2021	Rp	31,944	Rp	14,323
Battery & Electrical System	Brake Lamp	04/01/2022	Rp	31,944	Rp	14,323
Engine	Engine Oil	07/01/2022	Rp	31,944	Rp	21,485
Battery & Electrical System	Air ACCU	14/01/2022	Rp	31,944	Rp	14,323
Braking System	Disc Brake	18/01/2022	Rp	31,944	Rp	85,938
Braking System	Brake Shoe	18/01/2022	Rp	31,944	Rp	85,938
Braking System	Drum Brake	18/01/2022	Rp	31,944	Rp	85,938
Battery & Electrical System	Head Lamp	18/01/2022	Rp	31,944	Rp	14,323
Engine	Oil Filter	20/01/2022	Rp	31,944	Rp	21,485
Engine	Engine Oil	02/02/2022	Rp	31,944	Rp	21,485
Engine	Air Filter	04/02/2022	Rp	31,944	Rp	14,323
Steering System	Bearing Roda Depan	11/02/2022	Rp	31,944	Rp	85,938
Steering System	Steering Oil	25/02/2022	Rp	31,944	Rp	42,969
Battery & Electrical System	Air ACCU	25/02/2022	Rp	31,944	Rp	14,323
Engine	Engine Oil	01/03/2022	Rp	31,944	Rp	21,485
Engine	Oil Filter	01/03/2022	Rp	31,944	Rp	21,485
Engine	Fuel Filter	01/03/2022	Rp	31,944	Rp	14,323
Braking System	Minyak Rem	01/03/2022	Rp	31,944	Rp	42,969
Power Train	Oli Transmisi	01/03/2022	Rp	31,944	Rp	14,323
Power Train	Oli Gardan	01/03/2022	Rp	31,944	Rp	14,323
Engine	Air Radiator	02/03/2022	Rp	31,944	Rp	14,323
Battery & Electrical System	Back Alarm	02/03/2022	Rp	31,944	Rp	14,323
Battery & Electrical System	Lampu Rotari	05/03/2022	Rp	31,944	Rp	21,485
Battery & Electrical System	Reverse Lamp	08/03/2022	Rp	31,944	Rp	14,323
Steering System	Steering Oil	10/03/2022	Rp	31,944	Rp	42,969
Battery & Electrical System	Air ACCU	14/03/2022	Rp	31,944	Rp	14,323
Wheel, Suspension	Ban Kendaraan	14/03/2022	Rp	31,944	Rp	42,969
Battery & Electrical System	Brake Lamp	18/03/2022	Rp	31,944	Rp	14,323
Battery & Electrical System	Lampu Sein	18/03/2022	Rp	31,944	Rp	14,323
Battery & Electrical System	Fog Lamp	27/03/2022	Rp	31,944	Rp	14,323
Battery & Electrical System	Head Lamp	14/04/2022	Rp	31,944	Rp	14,323
Battery & Electrical System	Reverse Lamp	14/04/2022	Rp	31,944	Rp	14,323
Battery & Electrical System	Lampu Rotari	16/04/2022	Rp	31,944	Rp	21,485
Steering System	Steering Oil	20/04/2022	Rp	31,944	Rp	42,969
Braking System	Master Brake	25/04/2022	Rp	31,944	Rp	42,969
Braking System	Brake Pad	28/04/2022	Rp	31,944	Rp	85,938
Braking System	Brake Shoe	28/04/2022	Rp	31,944	Rp	85,938
TOTAL			**Rp**	**3,034,680**	**Rp**	**3,243,897**

Source: Data Processing

In table 2, that the loss due to downtime experienced by the company during the period May 2021-April 2022 was IDR 3,034,680, - and mechanical costs of IDR 3,243,897.

So that the results of the calculation of the total cost of company maintenance (Initial TC) are as follows:

Initial TC = Total Maintenance Cost + Downtime Losses + Mechanical Costs

= Rp 27.034.000 + Rp 3.034.680 + Rp 3.243.897
= Rp 33.312.577,-

Maintenance Cost Calculation with Modularity Design Method

To calculate maintenance costs using the modularity design method or the proposed TC.

1. Grouping Critical Components According to Modularity Design

The following is a grouping of critical components into several modules according to the layout/position of machine repair. For more details can be seen in Table 3.

Table 3 Data Grouping by Module

Module	Sub-components (components)
Module 1	Engine Oil (Engine)
	Oil Filter (Engine)
	Fuel Filter (Engine)
	Air Filter (Engine)
	Air Radiator (Engine)
	Timing Belt (Engine)
	Oli Transmisi (Power Train)
	Oli Gardan (Power Train)
Module 2	Steering Oil (Steering System)
	Bearing Roda Depan (Steering System)
	Tie Rod (Steering System)
	Ban Kendaraan (Wheel, Suspension)
	Shock Absorber (Wheel, Suspension)
	Spring / Per (Wheel, Suspension)
Module 3	Air ACCU (Battery & Electrical System)
	ACCU (Battery & Electrical System)
	Head Lamp (Battery & Electrical System)
	Fog Lamp (Battery & Electrical System)
	Reverse Lamp (Battery & Electrical System)
	Back Alarm (Battery & Electrical System)
	Lampu Rotari (Battery & Electrical System)
	Brake Lamp (Battery & Electrical System)
	Lampu Sein (Battery & Electrical System)
Module 4	Disc Brake (Braking System)
	Brake Pad (Braking System)
	Brake Shoe (Braking System)
	Drum Brake (Braking System)
	Master Brake (Braking System)
	Minyak Rem (Braking System)

Source: Data Processing

2. Test for Distribution Conformity of Damage Data

The following is the data that has been grouped for each module which is displayed in table 4.

Table 4 Grouping Data by Module

Module	Sub-Component	Downtime (Minute)	Time Between Breakdowns (Minute)
Module 1	Oil Filter	15	-
		15	84,960
		15	109,440
		15	83,520
		15	97,920
		15	57,600

	Engine Oil	15	-
		15	40,320
		15	46,080
		15	48,960
		15	54,720
		15	38,880
		15	44,640
		15	34,560
		15	46,080
		15	37,440
		15	38,880
	Fuel Filter	10	-
		10	141,120
		10	132,480
		10	161,280
	Air Filter	10	-
		10	57,600
		10	93,600
		10	108,000
		10	56,160
	Air Radiator	10	-
	Timing Belt	60	-
	Oli Transmisi	10	-
		10	293,760
	Oli Gardan	10	-
		10	293,760
Module 2	Steering Oil	30	-
		30	84,960
		30	28,800
		30	63,360
		30	38,880
		30	63,360
		30	86,400
		30	18,720
		30	59,040
	Bearing Roda Depan	60	-
		60	247,680
		60	120,960
	Tie Rod	30	-
		30	79,200
		30	161,280
		30	77,760
	Spring	60	-
		60	241,920
	Shock Absorber	60	-
	Vehicle Tires	30	-
Module 3	Air ACCU	10	-
		10	25,920
		10	18,720
		10	63,360
		10	47,520
		10	44,640
		10	47,520
		10	31,680
		10	48,960

		10	60,480
		10	24,480
	ACCU	15	-
	Head Lamp	10	-
		10	165,600
		10	123,840
	Fog Lamp	10	-
		10	277,920
	Reverse Lamp	10	-
		10	256,320
		10	53,280
	Back Alarm	10	-
		10	154,080
	Rotary Light	15	-
		15	231,840
		15	60,480
	Brake Lamp	10	-
		10	105,120
	Turn Signal	10	-
		10	171,360
Module 4	Disc Brake	60	-
		60	233,280
	Brake Pad	60	-
		60	279,360
	Brake Shoe	60	-
		60	102,240
		60	135,360
		60	144,000
	Drum Brake	60	-
		60	237,600
	Master Brake	30	-
		30	205,920
	Brake Fluid	30	-
		30	293,760

Furthermore, the distribution test was carried out using app. Minitab 2021. The following are the results of distribution testing on individual modules.

Table 5 Distribution Test Results Based on Downtime Data

Component	Type of Distribution	Parameter	
		β (shape)	***η (scale)***
Module 1	*Weibull*	1,83502	16,0865
Module 2	*Weibull*	3,02398	43,7987
Module 3	*Weibull*	5,43491	11,4742
Module 4	*Weibull*	5,24138	56,3823

Source: Data Processing with Minitab App 2021

The table above is the result of data processing carried out with App Minitab 2021. Parameter values are obtained by looking at the estimate value in the distribution test. The shape parameter (β) describes the shape of the Weibull distribution. While the scale parameter (η) describes the distribution of data on the Weibull distribution and is also displayed in table 6.

Table 6 Distribution Test Results Based on Time Between Damages

Komponen	Jenis Distribusi	Parameter	
		β (shape)	***η (scale)***
Modul 1	*Weibull*	1,48275	102.745
Modul 2	*Weibull*	1,51913	109.535
Modul 3	*Weibull*	1,33427	110.284
Modul 4	*Weibull*	3,60585	227.301

Source: Data Processing with Minitab App 2021

3. MTTR and MTTF Calculations

After obtaining the distribution and parameters of each distribution, then the calculation of Mean Time To Repair (MTTR) and Mean Time To Failure (MTTF) can be done using the formula MTTR/MTTF = $\eta\Gamma(1+\frac{1}{\beta})$ (Ebeling 2019).

Table 7 MTTR dan MTTF Calculation Result

MODUL	MTTR	MTTF
1	14,2930 menit	92.885,9 menit
2	39,1251 menit	98.734,3 menit
3	10,5858 menit	101.345 menit
4	51,9093 menit	204.840 nit

Source: Data Processing

4. Calculation of Component Replacement Cost Due to Maintenance (Cp) and Component Replacement Cost Due to Damage (Cf)

Calculation of component costs due to maintenance includes mechanical costs and the price of each component. The following Cp calculations for each module can be seen in Table 8:

Table 8 Component Replacement Cost Due to Maintenance (Cp)

Module	Sub- Component (Component)	MTTR (Minute)	Cp	Total of Damages	Total Cp
Module 1	Engine Oil (Engine)	14.293	Rp 246,824	11	Rp 2,715,064
	Oil Filter (Engine)	14.293	Rp 176,824	6	Rp 1,060,944
	Fuel Filter (Engine)	14.293	Rp 131,824	4	Rp 527,296
	Air Filter (Engine)	14.293	Rp 168,824	5	Rp 844,120
	Air Radiator (Engine)	14.293	Rp 296,824	1	Rp 296,824
	Timing Belt (Engine)	14.293	Rp 456,824	1	Rp 456,824
	Oli Transmisi (Power Train)	14.293	Rp 126,824	2	Rp 253,648
	Oli Gardan (Power Train)	14.293	Rp 191,824	2	Rp 383,648
	TOTAL				**Rp 6,538,368**
Module 2	Steering Oil (Steering System)	39.1251	Rp 62,108	9	Rp 558,972
	Bearing Roda Depan (Steering System)	39.1251	Rp 356,108	3	Rp 1,068,324
	Tie Rod (Steering System)	39.1251	Rp 256,108	4	Rp 1,024,432
	Ban Kendaraan (Wheel, Suspension)	39.1251	Rp 1,356,108	1	Rp 1,356,108
	Shock Absorber (Wheel, Suspension)	39.1251	Rp 481,108	1	Rp 481,108
	Spring / Per (Wheel, Suspension)	39.1251	Rp 381,108	2	Rp 762,216
	TOTAL				**Rp 5,251,160**
Module 3	Air ACCU (Battery & Electrical System)	10.5858	Rp 20,054	11	Rp 220,594
	ACCU (Battery & Electrical System)	10.5858	Rp 1,055,054	1	Rp 1,055,054
	Head Lamp (Battery & Electrical System)	10.5858	Rp 125,054	3	Rp 375,162
	Fog Lamp (Battery & Electrical System)	10.5858	Rp 80,054	2	Rp 160,108
	Reverse Lamp (Battery & Electrical System)	10.5858	Rp 605,054	3	Rp 1,815,162
	Back Alarm (Battery & Electrical System)	10.5858	Rp 155,054	2	Rp 310,108
	Lampu Rotari (Battery & Electrical System)	10.5858	Rp 1,605,054	3	Rp 4,815,162
	Brake Lamp (Battery & Electrical System)	10.5858	Rp 55,054	2	Rp 110,108

	Lampu Sein (Battery & Electrical System)	10.5858	Rp	25,054	2	Rp	50,108
	TOTAL					**Rp**	**8,911,566**
Module 4	Disc Brake (Braking System)	51.9093	Rp	1,154,783	2	Rp	2,309,566
	Brake Pad (Braking System)	51.9093	Rp	174,783	2	Rp	349,566
	Brake Shoe (Braking System)	51.9093	Rp	374,783	4	Rp	1,499,132
	Drum Brake (Braking System)	51.9093	Rp	624,783	2	Rp	1,249,566
	Master Brake (Braking System)	51.9093	Rp	774,783	2	Rp	1,549,566
	Minyak Rem (Braking System)	51.9093	Rp	104,783	2	Rp	209,566
	TOTAL					**Rp**	**7,166,962**

Source: Data Processing (2022)

The calculation of component costs due to maintenance includes mechanical costs, costs of losses due to downtime and the price of each component where all of these costs are losses caused by component damage. The following Cf calculations for each module can be seen in table 9.

Table 9 Cost of replacing parts due to damage (Cf)

Module	Sub-Component (Component)	MTTR (Minute)	Cf		Total of Damages	Total Cf/ Sub-Component	
Module 1	Engine Oil (Engine)	14.293	Rp	254,434	11	Rp	2,798,774
	Oil Filter (Engine)	14.293	Rp	184,434	6	Rp	1,106,604
	Fuel Filter (Engine)	14.293	Rp	139,434	4	Rp	557,736
	Air Filter (Engine)	14.293	Rp	176,434	5	Rp	882,170
	Air Radiator (Engine)	14.293	Rp	304,434	1	Rp	304,434
	Timing Belt (Engine)	14.293	Rp	464,434	1	Rp	464,434
	Oli Transmisi (Power Train)	14.293	Rp	134,434	2	Rp	268,868
	Oli Gardan (Power Train)	14.293	Rp	199,434	2	Rp	398,868
	TOTAL					**Rp**	**6,781,888**
Module 2	Steering Oil (Steering System)	39.1251	Rp	68,920	9	Rp	620,280
	Bearing Roda Depan (Steering System)	39.1251	Rp	362,920	3	Rp	1,088,760
	Tie Rod (Steering System)	39.1251	Rp	262,920	4	Rp	1,051,680
	Ban Kendaraan (Wheel, Suspension)	39.1251	Rp	1,362,920	1	Rp	1,362,920
	Shock Absorber (Wheel, Suspension)	39.1251	Rp	487,920	1	Rp	487,920
	Spring / Per (Wheel, Suspension)	39.1251	Rp	387,920	2	Rp	775,840
	TOTAL					**Rp**	**5,387,400**
Module 3	Air ACCU (Battery & Electrical System)	10.5858	Rp	25,690	11	Rp	282,590
	ACCU (Battery & Electrical System)	10.5858	Rp	1,060,690	1	Rp	1,060,690
	Head Lamp (Battery & Electrical System)	10.5858	Rp	130,690	3	Rp	392,070
	Fog Lamp (Battery & Electrical System)	10.5858	Rp	85,690	2	Rp	171,380
	Reverse Lamp (Battery & Electrical System)	10.5858	Rp	610,690	3	Rp	1,832,070
	Back Alarm (Battery & Electrical System)	10.5858	Rp	160,690	2	Rp	321,380
	Lampu Rotari (Battery & Electrical System)	10.5858	Rp	1,610,690	3	Rp	4,832,070
	Brake Lamp (Battery & Electrical System)	10.5858	Rp	60,690	2	Rp	121,380
	Lampu Sein (Battery & Electrical System)	10.5858	Rp	30,690	2	Rp	61,380
	TOTAL					**Rp**	**9,075,010**
Module 4	Disc Brake (Braking System)	51.9093	Rp	1,182,420	2	Rp	2,364,840
	Brake Pad (Braking System)	51.9093	Rp	202,420	2	Rp	404,840
	Brake Shoe (Braking System)	51.9093	Rp	402,420	4	Rp	1,609,680
	Drum Brake (Braking System)	51.9093	Rp	652,420	2	Rp	1,304,840
	Master Brake (Braking System)	51.9093	Rp	802,420	2	Rp	1,604,840
	Minyak Rem (Braking System)	51.9093	Rp	132,420	2	Rp	264,840
	TOTAL					**Rp**	**7,553,880**

Source: Data Processing

5. Calculating maintenance time intervals

Calculations for this maintenance time interval include replacement costs due to maintenance (Cp), component replacement costs due to damage (Cf), scale values, and shape values at the time between treatments. The value of TM in each module can be seen in table 10 below.

Table 10 Maintenance Interval Time (TM)

Modules	Parameters β *(shape)*	Parameters η *(scale)*	Cp		Cf		TM (Minutes)
1	1,48275	102.745	Rp	6.538.368	Rp	6.781.874	163.815,670
2	1,51913	109.535	Rp	5.251.160	Rp	5.387.396	165.827,344
3	1,33427	110.284	Rp	8.911.566	Rp	9.075.007	247.328,033
4	3,60585	227.301	Rp	7.166.962	Rp	7.553.876	171.757,060

Source: Data Processing

6. Calculation of Total Maintenance Costs Using the Modularity Design Method

The total maintenance cost is calculated according to the unit of time used. Because the data above uses units of minutes, then based on Weibull-distributed data, the total maintenance cost is shown in Table 11.

Table 11 Recapitulation of TC Calculation per Module

Modules	TC (Rp/min)	
1	Rp	123/minute
2	Rp	93/ minute
3	Rp	144/ minute
4	Rp	58/ minute

Source: Data Processing

The total maintenance costs per year are shown in Table 12 below.

Table 12 Calculation of Total Cost per 1 Year Using Modularity Design

Modules	Total Cost (Rupiah/ 1 Year)	
1	Rp	6.500.500
2	Rp	5.359.658
3	Rp	8.858.943
4	Rp	6.948.986
Total	**Rp**	**27.668.087**

Choosing a Maintenance Method with Minimum Cost

Based on the calculation results, the next treatment comparison can be calculated in table 13 as follows:

Table 13 Comparison of Total Maintenance Cost of The Company and Modularity Design

Company's Total Maintenance Cost	Total Cost with Modularity of Design
Rp 33.312.577,-/1 tahun	**Rp 27.577.211,-**/1 tahun

Source: Data Processing

From table 13 above, it can be seen that the total maintenance cost of the company is IDR 33,312,577 per 1 year. Meanwhile, the modularity design method resulted in a total maintenance cost of Rp 27,577,211 per 1 year. The efficiency between maintenance costs in the company and the proposed method can be calculated. The calculation is as follows:

$$\text{Efficiency} = \frac{TC\ Perusahaan - TC\ Usulan}{TC\ Perusahaan} \times 100\%$$

$$= \frac{Rp\ 33.312.577 - Rp\ 27.577.211}{Rp\ 33.312.577} \times 100\%$$
$$= \mathbf{17{,}22\%}$$

Discussion

Based on the data processing above, it can be seen that in operational maintenance activities, vehicle units more often use corrective maintenance methods for most components. Corrective Maintenance is maintenance that is carried out repeatedly or maintenance carried out to repair a part (including adjustments and repairs) that has stopped to meet an acceptable condition (Karabağ et al., 2020; Suzen & Feriadi, 2019).

The method used by the company currently still incurs considerable costs and requires other alternative methods in order to minimize the costs incurred for maintenance activities. The alternative method used in this study has been applied by the company, it's just very rare, namely preventive maintenance. Preventive maintenance is maintenance that is carried out in a planned manner to prevent potential damage from occurring which aims to minimize losses in production time and large repair costs (Ansori & Mustajib, 2013). Modularity Design can be said to be more efficient than other methods, because it specifically divides more complicated components into more understandable parts, making maintenance more efficient and reducing the time needed to complete it.

In this study, the proposed (TC) with the modularity design method has the lowest cost than the initial (TC) with the method carried out by the company with an efficiency of 17.22% for the period May 2021-April 2022. According to Subagja (Subagja, 2018) modularity design has several advantages, namely easier design of new components, reduced maintenance labor training costs and time, ease of maintenance, decreased maintenance time, low capability requirements for moving modular units, and easier removal of failed units.

The results of this study indicate that the application of preventive maintenance through the modularity design method can minimize total maintenance costs rather than corrective maintenance carried out by the previous company. Preventive maintenance is an action that needs to be taken by the company so that the vehicle engine is maintained, reliability is maintained and stable, and can reduce maintenance costs (Afiva et al., 2019). The contribution of cost efficiency by implementing preventive maintenance is that the economic life of engine components will be more durable for the next 3 to 5 years.

CONCLUSION

Based on the results of the analysis conducted, the company more often conducts machine maintenance activities using corrective maintenance which causes high-cost losses due to component replacement after damage occurs. Whereas by implementing preventive maintenance through the modularity design method, prevention before damage occurs and faster maintenance is carried out can extend component life. So by implementing preventive maintenance, the costs incurred are lower than corrective maintenance.

REFERENCES

Abuya, W. O. (2016). Mining conflicts and Corporate Social Responsibility: Titanium mining in Kwale, Kenya. *The Extractive Industries and Society*, *3*(2), 485–493. https://doi.org/10.1016/j.exis.2015.12.008 Google Scholar

Afiva, W. H., Atmaji, F. T. D., & Alhilman, J. (2019). Penerapan Metode Reliability Centered Maintenance (RCM) pada Perencanaan Interval Preventive Maintenance dan Estimasi Biaya Pemeliharaan Menggunakan Analisis FMECA (Studi Kasus : PT. XYZ). *Jurnal PASTI (Penelitian Dan Aplikasi Sistem Dan Teknik Industri)*, *13*(3), 298–310. https://doi.org/2598-4853 Google Scholar

Ansori, N., & Mustajib, M. I. (2013). *Sistem Perawatan Terpadu*. Graha Ilmu. Google Scholar

Besterfield, D. H., Michna, C. B., Besterfield, G. H., Scare, M. B., Udhwareshe, H., & Udhwareshe, R. (2019). *Total Quality Management* (Fifth Edision). Pearson India Educational Pvt. Ldt. Google Scholar

Ciliberti, F., Pontrandolfo, P., & Scozzi, B. (2008). Logistics social responsibility: Standard adoption and practices in Italian companies. *International Journal of Production Economics*, *113*(1), 88–106. https://doi.org/10.1016/j.ijpe.2007.02.049 Google Scholar

Daruhadi, G., Yuliati, E., Elgasari, F. M., Indradewa, R., & Negoro, D. A. (2023). Strategic Formulation Analysis of Business Development of PT Mega Power Surya (A Subsidiary of PT Mega Power Teknindo). *Return: Study of Management, Economic and Bussines*, *2*(05), 526–542. https://doi.org/https://doi.org/10.57096/return.v2i05.108 Google Scholar

Díaz-Reza, J. R., Gracia-Alcaraz, & Loya, V. M. (2019). *Impact Analysis of Total Productive Maintenance-Critical Success Factors and Benefits*. Springer Nature. Google Scholar

Ebeling, C. E. (2019). *An Introduction To Reliability And Maintenance Engineering* (3rd ed.). Waveland Press, Incorporated. Google Scholar

Gortney, W. E. (2016). *Department of Defense Dictionary of Military and Associated Terms*. United States Department of Defense. Google Scholar

Hadi, S. (2019). *Perawatan dan Perbaikan Mesin Industri*. Andi Offset. Google Scholar

Harada, M. K. (2020). *Perawatan Mesin Batching Plant Secara Preventive dengan Metode Modularity Design pada PT Restu Anak Jaya Abadi Beton Indonesia – Plant Osowilangun*. UPN "Veteran" Jawa Timur. Google Scholar

Heizer, J., Render, B., & Munson, C. (2020). *Operations Management: Sustainability and Supply Chain Management*. Pearson Education London. Google Scholar

Karabağ, O., Eruguz, A. S., & Basten, R. (2020). Integrated optimization of maintenance interventions and spare part selection for a partially observable multi-component system. *Reliability Engineering & System Safety*, *200*, 106955. https://doi.org/10.1016/j.ress.2020.106955 Google Scholar

Priadana, S., & Sunarsi, D. (2021). *Metode Penelitian Kuantitatif* (1st ed.). Pascal Books. Google Scholar

Putri, N. T., Taufik, & Buana, F. S. (2020). Preventive Maintenance Scheduling by Modularity Design Applied to Limestone Crusher Machine. *Procedia Manufacturing*, *43*, 682–687. https://doi.org/10.1016/j.promfg.2020.02.123 Google Scholar

Shaheen, S., & Chan, N. (2016). Mobility and the Sharing Economy: Potential to Facilitate the First- and Last-Mile Public Transit Connections. *Built Environment*, *42*(4), 573–588. https://doi.org/10.2148/benv.42.4.573 Google Scholar

Subagja, T. (2018). Analisis Perawatan Mesin Rolling Secara Berkala dengan Pendekatan Modularisasi Desain. *Seminar Nasional Teknologi*, 172–177. Google Scholar

Suwondo, A. Z. Z., & Widjajati, E. P. (2020). Perawatan Mesin Mixer Secara Preventive dengan Metode Modularity Design di PT XYZ. *Juminten: Jurnal Manajemen Industri Dan Teknologi*, *1*(52), 37–48. Google Scholar

Suzen, Z. S., & Feriadi, I. (2019). Pembuatan Program Aplikasi Laporan Perawatan Korektif Laboratorium Pemesinan Polman Babel. *Manutech : Jurnal Teknologi Manufaktur*, *10*(01), 53–57. https://doi.org/10.33504/manutech.v10i01.59 Google Scholar

Tan, Z., Li, J., Wu, Z., Zheng, J., & He, W. (2011). An evaluation of maintenance strategy using risk based inspection. *Safety Science*, *49*(6), 852–860. https://doi.org/10.1016/j.ssci.2011.01.015 Google Scholar

Taufiqullah, T. (2022). *Pengertian Perawatan dan Perbaikan*. TN Mesin. https://www.tneutron.net/mesin/pengertian-perawatan-dan-perbaikan/ Google Scholar

Trac. (2023, January 27). *Alasan Kenapa Perusahaan Tambang Sebaiknya Rental Mobil Untuk Kendaraan Operasional*. Trac Member of Astra. https://www.trac.astra.co.id/blog/berita/alasan-kenapa-perusahaan-tambang-sebaiknya-rental-mobil-untuk-kendaraan-operasional/466 Google Scholar

Villarini, M., Cesarotti, V., Alfonsi, L., & Introna, V. (2017). Optimization of photovoltaic maintenance plan by means of a FMEA approach based on real data. *Energy Conversion and Management*, *152*, 1–12. https://doi.org/10.1016/j.enconman.2017.08.090 Google Scholar

Wilhelms, M.-P., Merfeld, K., & Henkel, S. (2017). Yours, mine, and ours: A user-centric analysis of opportunities and challenges in peer-to-peer asset sharing. *Business Horizons*, *60*(6), 771–781. https://doi.org/10.1016/j.bushor.2017.07.004 Google Scholar

Yanti, V. T. (2015). *Penerapan Preventive Maintenance dengan Menggunakan Metode modularity Design pada Mesin Goss di PT.ABC* [Tugas Akhir]. Institut Teknologi Sepuluh Nopember. Google Scholar

Yilmaz, K. (2013). Comparison of Quantitative and Qualitative Research Traditions: epistemological, theoretical, and methodological differences. *European Journal of Education*, *48*(2), 311–325. https://doi.org/10.1111/ejed.12014 Google Scholar