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Proposed Preventive Maintenance of Air Screw Compressor Machine Using Failure Mode and Effect Analysis and Modularity Design Methods at PT XYZ

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A B S T R A C T

Current developments in the industrial world made competition between companies increasingly tight. This required companies to increase the effectiveness and efficiency of their production processes, one of which was by implementing proper machine maintenance so that the machines used could operate well and optimally. PT XYZ is a company engaged in the manufacturing industry which is engaged in making hydrogen peroxide chemical liquid in Indonesia. This company experienced problems with damage to its air screw compressor machine because the maintenance system was carried out when components were damaged, resulting in long downtime. Therefore, this research was carried out with the aim of providing preventive maintenance suggestions using the failure mode and effect analysis (FMEA) method to find critical components of the machine and modularity design to group machine components so as to reduce downtime and minimize maintenance costs. By implementing preventive maintenance with FMEA and modularity design, ten critical sub-components were obtained with a total maintenance cost of IDR 884,839,695, lower than the company's current total maintenance cost of IDR 1,513,836,000. So by applying the proposed method, the company gets an efficiency of 41.55%.

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1. INTRODUCTION

Current developments in the industrial world make competition between companies increasingly tight. This requires companies to increase the effectiveness and efficiency of their production processes, one of which is by implementing proper machine maintenance so that the machines used can operate well and optimally. Maintenance is all actions necessary to maintain goods or equipment to return to a certain condition. This is done by adjusting and checking the function of an object during operation so as to minimize work stops caused by damage (Yulius & Susanto, 2020). PT XYZ is a company engaged in the manufacturing industry which is engaged in making hydrogen peroxide chemical liquid in Indonesia. The company uses a make to stock (MTS) production system and implements a continuous production process (continuous process), namely the company as a hydrogen peroxide producer completes its production and places the production results in inventory which will then be sent to consumers when there is demand. Currently the company uses a type of corrective maintenance on its air screw compressor machine where maintenance is carried out when the machine has failed by identifying the cause of the failure. So, machine maintenance is carried out when the machine can no longer operate normally. This caused huge losses for PT XYZ which implemented a continuous production process because it brought the company's operations to a complete halt. Based on initial interviews between researchers and the maintenance and engineering division manager of PT XYZ, the company had planned to change the type of maintenance to preventive maintenance, but it was canceled because based on the company's calculations, this plan did not really have an impact on downtime and even increased the costs that the company had to incur if preventive maintenance is carried out one by one on each sub component.

Therefore, research was carried out in order to help PT XYZ in determining the most efficient air screw compressor machine maintenance system with proposed preventive maintenance techniques by applying failure mode and effect analysis and modularity design methods. The failure mode and effect analysis method is used to determine the critical subcomponents of the air screw compressor machine, then modularity design itself is used to group the critical subcomponents of the machine based on the relationship between the function and structure of each subcomponent so that it is hoped that it can simplify the maintenance process of the machine subcomponents as well as minimize downtime and reduce costs. The results of this research can be used as input and reference for the company as a basis for PT XYZ's future maintenance system.

2. LITERATURE REVIEW

Maintenance is a variety of activities aimed at maintaining and maintaining factory facilities, machines and equipment. This is necessary to produce a production operation that is in line with existing expectations (Arinta, 2020). Maintenance activities are often carried out to maintain operational continuity of existing facilities and equipment. These maintenance activities include cleaning, inspection, oiling and procurement of spare parts for components contained in industrial facilities and equipment (Pranowo, 2019). Maintenance is carried out focusing on prevention to reduce or even avoid damage by ensuring the reliability and readiness of existing equipment (Sudrajat & Rahmatulloh, 2020). Preventive maintenance is a maintenance method that is carried out within a certain fixed period of time or with specific criteria at each stage of the existing production process (Mentari & Hidayat, 2021). Preventive maintenance is used to avoid component damage during the production process so that production and operational activities become stable and minimize maintenance costs (Handayani & Harada, 2021). The advantage of carrying out this maintenance is that it reduces the possibility of emergency maintenance and reduces idle time, both for machines and labor (Syahrizan, 2023).

Reliability is the probability that a component, equipment, machine or system will continue to operate properly according to its expected function under certain conditions. In stating whether equipment is functioning or not, the condition is expressed in terms of reliability values. There are two factors commonly used in calculating the level of equipment reliability, namely Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR). MTTF is a value that states the expected service life of a system or tool. Meanwhile, MTTR is the average time for components to be repaired or maintained (Pranowo, 2019). MTTF and MTTR on the Weibull distribution are calculated using the formula (Rosyidi, 2020):

$$MTTF \,\&\, MTTR = \eta\Gamma(1 + \frac{1}{\beta}) \quad (1)$$

Failure Mode and Effect Analysis or FMEA is a systematic method used to identify and prevent problems or obstacles in a system or process (Islam et al., 2020). It involves investigating and assessing all causes and effects of all potential failure modes that may occur in a system, during the earliest phases of development (Novianti & Rochmoeljati, 2023). FMEA can be used to analyze the causes of failure related to equipment reliability (Febriana et al., 2020). The main goal of using the FMEA method is to be able to identify potential failure modes in system units and evaluate the subsequent effects on system performance (Lo & Liou, 2018). The failure referred to in FMEA is anything that causes defects or failures, such as work defects, product defects, or machine failure, so that the resulting output does not meet the specified standards or specifications (Suwandi et al., 2020). The steps for FMEA are to record the failure of a machine and its effects, determine the severity occurrence detection value, calculate the risk priority number value, prioritize the risk of machine failure, and carry out recommendations for appropriate maintenance actions (Manik, 2020). Risk Priority Number (RPN) is a mathematical system that defines a series of effects on the severity of a hazard so that it is able to produce a level of failure (occurrence) as well as expertise in detecting the failure (detection). RPN is obtained by the formula:

$$RPN = S \; x \; O \; x \; D \qquad (2)$$

The RPN value has a range from 1 to 1000. The value 1 indicates the smallest possible risk and the value 1000 indicates the greatest possible risk. The RPN value is used to prioritize units that have a risk of failure from greatest to smallest. There are three recommendations for treatment actions based on the existing RPN values, namely:

Table 1. Recommended maintenance actions

Types of Maintenance	RPN Value Criteria
Corrective Maintenance	RPN<200
Preventive Maintenance	200≤RPN<300
Predictive Maintenance	RPN≥300

Source: (Madyantoro et al., 2022)

Modularity design is a concept used in the design process of a product and can be adapted to a maintenance system. The modularity design method groups machine components into several modules so that it can reduce maintenance costs on the machine (Amanda & Widiasih, 2021). Modularity design is carried out by breaking down a complex problem which will be programmed into several elements which will later be reintegrated into a single unit to meet system needs. Each element is called a module. With modularity design, the system can produce profitable engineering and solutions in factory economics. To determine the cost of replacing components due to preventive maintenance, you can use the following formula:

$$Cp = [(Operator\ Costs + Mechanical\ Costs) \times MTTR] + Component\ prices \qquad (3)$$

Damage repair costs or corrective costs are costs that arise because the production process has to stop suddenly due to machine damage. To determine the cost of repairing damage, you can use the formula:

$$Cf = [(Operator\ Costs + Mechanical\ Costs + Downtime\ Costs) \times MTTR] + Component\ prices \qquad (4)$$

Efficient maintenance time between preventive replacement activities can be determined by choosing the time interval that results in the lowest costs. To find the efficient maintenance time interval using the formula:

$$TM = \eta \times \left| \frac{C_p}{C_f(\beta - 1)} \right|^{\frac{1}{\beta}} \qquad (5)$$

The total maintenance cost using the modularity design method can be found using the Weibull distribution, with the formula:

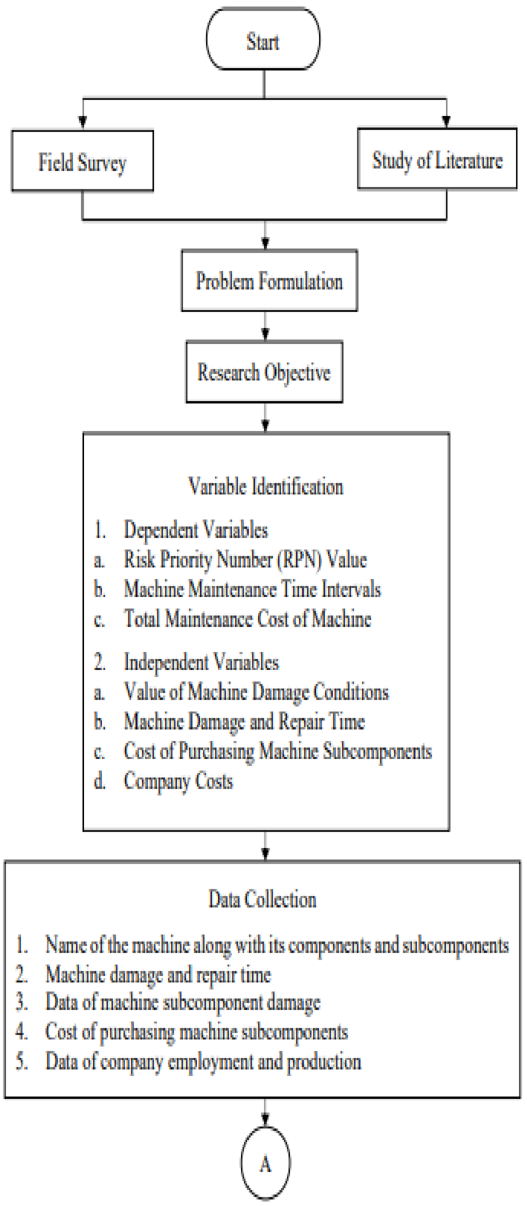
$$TC = \frac{C_f}{\eta^{\beta}} TM^{\beta - 1} + \frac{C_p}{TM} \qquad (6)$$

(Suwondo, 2020)

Research by (Rosyidi, 2020) and (Suwondo, 2020) research, they only used the modularity design method. So it is not known how the indicators determine critical subcomponents of existing machines. This is the reason the failure mode and effect analysis method was added to determine the critical subcomponents of the machine under study.

3. RESEARCH METHOD

This research was carried out at PT XYZ located in Sidoarjo district during May 2023 until the required data was met. In this research, preventive maintenance with Failure Mode and Effect Analysis (FMEA) and modularity design methods are used. The following flow to solve this problem can be seen in Fig. 1.



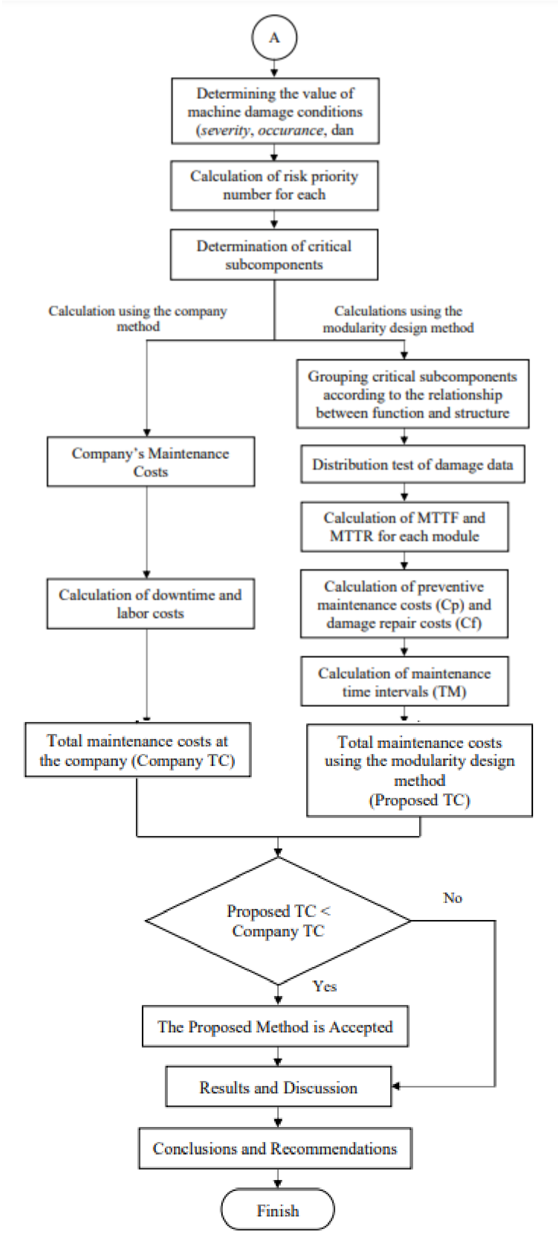


Figura 1. Research flowchart

4. RESULT AND DISCUSSION

4.1 Determination of Critical Sub Components of Air Screw Compressor Machines

Air screw compressor machine subcomponents that have a risk priority number value of 200 to 299 then the subcomponent is in the critical category and is proposed for preventative maintenance.

Table 2. Risk priority number-RPN value for each subcomponent

Subcomponent	RPN
Drive Motor	80
V-Belt	240
Screw Body	80
Air Filter	210
Air Tank and Silencer	210
Oil Pump	210
Oil Separator	280
Oil Tank	240
Oil Cooler	210
Control Cabinet	250
Electric Panel	250
Communication Module	240

Source: Processed data

4.2Calculation of Maintenance Costs using the Company Method

Maintenance costs using the company method are obtained by adding up subcomponent maintenance costs with downtime costs and labor costs. Based on information data from the company, subcomponent maintenance costs can be seen in the following table:

Table 3. Company subcomponent maintenance cost

Subcomponent	Maintenance Cost (April 2022 - March 2023) (IDR)
V-Belt	482,000
Air Filter	4,562,500
Air Tank and Silencer	34,600,000
Oil Pump	23,8000,000
Oil Separator	4,542,000
Oil Tank	5,002,000
Oil Cooler	17,670,000
Control Cabinet	19,750,000
Electric Panel	8,500,000
Communication Module	11,200,000
Total	**103,108,500**

Source: PT XYZ data

Based on Table 3, it is found that the total of company subcomponent maintenance cost is IDR 103,108,500.

The following are downtime and labor costs due to damage to each subcomponent:

Table 4. Downtime and labor costs

Subcomponent	Losses Due to Downtime (IDR)	Losses Due to Unemployed Operators (IDR)	Mechanical Costs (IDR)
V-Belt	106,968,750	2,445,000	3,973,125
Air Filter	43,968,750	1,005,000	1,633,125
Air Tank and Silencer	253,312,500	5,790,000	9,408,750
Oil Pump	45,937,500	1,050,000	1,706,250
Oil Separator	126,000,000	2,880,000	4,680,000
Oil Tank	254,625,000	5,820,000	9,457,500
Oil Cooler	28,875,000	660,000	1,072,500
Control Cabinet	186,375,000	4,260,000	6,922,500
Electric Panel	154,875,000	3,540,000	5,752,500
Communication Module	129,937,500	2,970,000	4,826,250
Total	**1,330,875,000**	**30,420,000**	**49,432,500**

Source: Processed Data

Thus, the total maintenance costs for the company (Company TC) are as follows:

Company TC = IDR 103,108,500 + IDR 1,330,875,000 + IDR 30,420,000 + IDR 49,432,500

= IDR 1,513,836,600

4.3Calculation of Maintenance Costs using the Modularity Design Method

Starting with grouping the critical subcomponents of the air screw compressor machine according to modularity design according to the relationship between the function and structure of each subcomponent.

Table 5. Critical subcomponent modules

Module	Subcomponent	Function
Module 1	Oil Pump	Pumps and distributes oil to all parts of the engine
	Oil Separator	Filter and separate oil from water
	Oil Tank	Holds oil
	Oil Cooler	Cooling oil

Module 2	Control Cabinet	Controlling machine operations
	Electric Panel	Controlling machine electricity
Module 3	Communication Module	Controlling engine pressure
Module 4	Air Filter	Filters incoming air
	Air Tank and Silencer	Holds compressed air and reduces noise
	V-Belt	Transferring motion energy

Source: Processed data

Based on table 5, it can be seen that the critical subcomponents of the air screw compressor machine are divided into four modules based on the relationship between the function and structure of the critical subcomponents. Followed by testing the distribution of damage data using Minitab 19 software (Table 6).

Table 6. Critical subcomponent modules

Module	Distribution Type	Parameter	
		Based on Downtime	Based on Time Lapse Between Damages
Module 1	Weibull	Shape (β) = 1.44194 Scale (η) = 769.51	Shape (β) =1.0793 Scale (η) = 31839.9
Module 2	Weibull	Shape (β) = 3.34219 Scale (η) = 1999.45	Shape (β) = 0.839476 Scale (η) = 52525.6
Module 3	Weibull	Shape (β) = 1.14791 Scale (η) = 794.231	Shape (β) = 1.43341 Scale (η) = 58287.6
Module 4	Weibull	Shape (β) = 5.78105 Scale (η) = 665.951	Shape (β) = 1.8524 Scale (η) = 166016

Source: Processed data

Next is the calculation of Mean Time To Repair (MTTR) and Mean Time To Failure (MTTF) for each module:

Table 7. MTTR and MTTF each module

Module	MTTR	MTTF
Module 1	697.78	30961.12
Module 2	1794.45	57560.18
Module 3	755.98	52962.44
Module 4	617.14	147452.09

Source: Processed data

Next, preventive maintenance costs (Cp) and damage repair costs (Cf) are calculated.

Table 8. Cp and Cf each module

Module	Cp (IDR)	Cf (IDR)
Module 1	21,552,692	143,664,192
Module 2	33,856,293	269,377,857
Module 3	13,531,396	79,679,646
Module 4	1,740,493	28,740,368

Source: Processed data

So that efficient maintenance time intervals (TM) for each module can be calculated

Table 9. TM Each Module

Module	TM (Minutes)
Module 1	57,479
Module 2	39,246
Module 3	30,319
Module 4	39,826

Source: Processed data

Based on table 9, it was found that the efficient maintenance time interval for module 1 was every 57,479 minutes, module 2 was every 39,246 minutes, module 3 was every 30,319 minutes, and module 4 was every 39,826 minutes. Finally, the total maintenance costs are calculated according to the unit of time used. Because table 9 uses units of minutes, the total maintenance costs are calculated per minute.

Table 10. TC per minute each module

Module	TC (IDR/Minutes)
Module 1	5,104
Module 2	6,237
Module 3	1,476
Module 4	95

Source: Processed data

Because the company's total maintenance costs are in units of time per year, the total maintenance costs will be calculated using the proposed method (modularity design) per year as well so that they can be compared.

Table 11. TC per year for each module using modularity design

Module	TC (IDR/Year)
Module 1	182,491,994
Module 2	661,490,969
Module 3	37,369,188
Module 4	3,487,544
Total	**884,839,695**

Source: Processed data

Based on table 11, the total maintenance cost for the air screw compressor machine calculated using the modularity design method is IDR 884,839,695 per year. From the results of these calculations, it was found that the total maintenance costs using the proposed method were lower than the company's current total maintenance costs, so the company would benefit if it carried out air screw compressor machine maintenance using the proposed method.

5. CONCLUSION

Based on the results of calculating the maintenance costs for the air screw compressor machine in PT XYZ, the total maintenance costs were IDR 1,513,836,000 per year. Meanwhile, the proposed method, namely preventive maintenance with modularity design, results in total maintenance costs of IDR 884,839,695 per year. So if using the proposed method, the company gets an efficiency of 41.55%, which means the proposed maintenance method is acceptable. Suggestions for further research are to combine it with other related maintenance methods to produce better results.

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