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Optimization of Machine Preventive Maintenance Scheduling Using Steady State Genetic Algorithm

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Abstract. Maintenance management is one of the important factors to support the success of industrial activities. In order for an industry to have a high level of profit. Good maintenance management is needed to minimize costs lost due to the engine failure. Preventive maintenance activities are one of the company's efforts to be able to maintain the life span and engine performance. In conducting preventive maintenance activities, the company wants to maximize machine reliability with minimum costs. The existing maintenance activities implemented by the company are to doing the maintenance every 2 months, but with the implementation of this maintenance policy it still has many obstacles in its implementation. Therefore optimization is needed to overcome this problem, one of the methods proposed to do preventive maintenance scheduling is the steady state genetic algorithm optimization method. On completion, 3 types of fitness functions are used, Fitness function 1 is a fitness function by giving weights to total costs and reliability functions with conditions $w_1 + w_2 = 1$. Fitness function 2 is a fitness function that is used by having a given budget limit. While Fitness function 3 is a fitness function that is used to provide required reliability or reliability that the company wants to achieve. The input from the steady state genetic algorithm has 3 components, the time to failure distribution parameter, the cost and budget, and the iteration input from the genetic algorithm. Based on data that has a 2 parameter Weibull distribution with scale parameter lambda = 0.00184 and shape parameter beta = 1.38194. Found 3 preventive maintenance scheduling proposals for 24 months period. The first result using fitness function 1 produced a total cost of 28.66 million rupiahs with a reliability value of 91.78%. The second proposal using fitness function 2 produced a total cost of 29.75 million rupiahs with a reliability value of 92.47%. The third uses using fitness function 3 resulting in a total cost of 30.79 million rupiahs with a reliability value of 92.52%.

Keywords: Preventive maintenance, Optimization, Reliability, Total cost, Steady State Genetic Algorithm.

1. Introduction

In the manufacturing industry, all production machines must be monitored properly to ensure the machine runs according to a predetermined schedule and there is no sudden damage that can disrupt the production process (Alhilman. J., Atmaji. F., Athari, N., 2017). The machine itself has reliability, namely the opportunity for a component or system to be able to operate according to the function desired for a certain period of time. In general, the longer the use of the engine, the reliability will decrease. This can increase the chance of engine damage and can result in machine reliability that is not in accordance with specifications (Ebeling, 1997). Maintenance is an effort to maintain machine reliability.

Maintenance policies can basically be categorized into several types, one of which is preventive maintenance (PM) (Alhilman. J., Atmaji. F., Athari, N., 2017). PM is a maintenance activity carried out before a component or system is damaged and aims to prevent a

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malfunction (Marquez, 2007). And in this research journal analysed machine failure data from PT UJ, this company is a company engaged in the Indonesian food industry, one of the products produced is UHT milk. The increasing population of Indonesia then indirectly increases the demand for milk to improve the nutritional status of the community in order to improve the welfare of the Indonesian people.

In the production process the machine runs 24 hours a day to meet the production target per day. PT UJ has machine maintenance activities to be applied to the machine, which is to do preventive maintenance every 2 months. But after the implementation of preventive maintenance, the engine continues to experience a decrease in performance, which can be seen from the engine performance during January 2017 - December 2018.

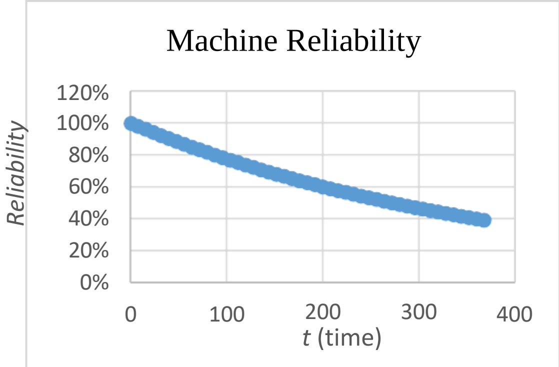

Fig. 1: Reliability of the Machine

It can be seen in the Figure 1 that the longer it decreases over time. In addition, based on data from 2017 to 2018, there is an increase in the maintenance costs of the machine, here is a graph of the maintenance costs.

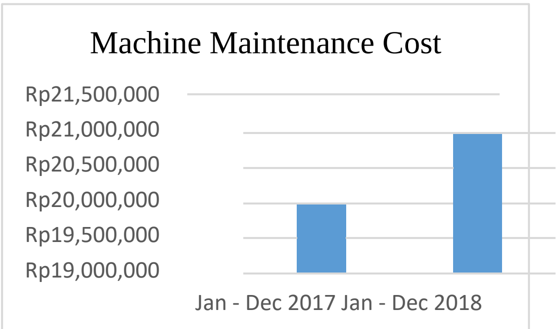

Fig. 2: Maintenance Cost of the Machine

Can be seen in Figure 2, which is the cost of engine maintenance in the period January 2017 - December 2018, an increase every year. This matter is considered to be detrimental to the company if it is not immediately corrected. Therefore, it is necessary to do more effective maintenance for the machine by maximizing the reliability of the engine and minimizing the cost of engine maintenance, so in this research the author uses the Genetic Algorithm (GA) method. GA is a heuristic search approach that can be widely applied to various optimization problems. This flexibility makes this method interesting to apply to various other practical optimization problems (Kramer, 2017).

The reason for choosing this method is because the final result or research output has 2 objective constraints or can be called multi-objective, namely constraint reliability and cost,

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and based on research by Moghaddam in 2010 where his research was conducted on preventive maintenance and replacement scheduling by developing models and algorithms for used in heuristic method optimization (Moghaddam K. S., 2010).

Several studies on the application of genetic algorithms in machine maintenance are by Hyunchul is to optimize maintenance scheduling by combining the methods of genetic algorithms and simulated annealing which are both meta-heuristic optimization methods (Hyunchul, K., Nara, K., & Gen, W., 1994). The research conducted by Moghaddam was to optimize scheduling maintenance using simulated annealing method with three types of maintenance activities, namely nothing, maintenance, and replacement. In this study, a multi-objective function was used, namely minimizing total costs and maximizing reliability and determining fitness with 3 types of fitness functions (Moghaddam, K.S., & Usher, J.S., 2009).

The same thing was done by Molaei, 2014. However, this study was conducted using the method of genetic algorithms and taking into account the effects of engineering insurance on total costs and machine (Molaei, S., Esfahani, M.M.S., & Esfahanipour, A., 2014). is a study conducted by Moghaddam in 2014, where the object of research was Computer Numerical Control (CNC) machines and carried out preventive maintenance scheduling optimization with multi-objective functions using a comparison of algorithm methods (Moghaddam K. , 2015).

Based on this background, this study aims to carry out multi-objective optimization that can minimize total maintenance costs and maximize reliability functions in order to carry out preventive maintenance machines using genetic algorithms. After that it will be compared between the proposed method and the existing method that has been applied by the company.

2. Method

2.1. Cost and Technical Economic Parameters

In this study used technical economic parameters, namely maintenance cost inflation, which changes over time. Then it can be defined the cost of damage or failure cost for the first component in the j-period is as follows (Moghaddam K. S., 2010):

$$F_{ij} = F_i \cdot \lambda_i \left(\left(X'_{i,j} \right)^{\beta_i} - \left(X_{i,j} \right)^{\beta_i} \right) (1 + inf\_failure)^j \quad (1)$$

with $i = 1; j = 1, 2, \ldots T.$

In addition there are maintenance cost, replacement cost, and fixed cost with inflation rate inf_m, inf_r, inf_f in sequence. So the following is a formula for total cost of maintenance using economic parameters (Moghaddam K. S., 2010):

$$M_{i,} = M(1 + inf\_m)^j \quad (2)$$

$$R_{i,} = R_i(1 + inf\_r)^j \quad (3)$$

$$Z_j = (1 + inf\_f)^j \left(1 - \prod_{i=1}^{N} \left(1 - (m_{i,j} + r_{i,j})\right)\right) \quad (4)$$

With $i = 1; j = 1, 2, \ldots T.$ mi,j and $ri,,j$ m is a binary variable to show maintenance (mij) and replacement (rij) on machine i for each j-period.

2.2. Multi-Objective Function

The multi-objective optimization model is an optimization that has two objective functions that must be optimized simultaneously, namely minimizing the total cost function and maximizing the reliability function. The forms of the two objective functions are as follows (Moghaddam K. , 2015):

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$$Min\ Total\ Cost = \sum_{i=1}^{N}\sum_{j=1}^{T}\left(\begin{array}{c}\left[\begin{array}{l}F_i \cdot \lambda_i\left(\left(X'_{i,j}\right)^{\beta_i} - \left(X_{i,j}\right)^{\beta_i}\right)(1+\inf\_.faillure)^j \\ +M_i(1+inf\_.m)^j \cdot m_{i,j} + R_i(1+inf\_.r)^j \cdot r_{i,j}\end{array}\right] \\ +\sum_{j=1}^{T}\left[Z(1+inf\_.f)^j\left(1-\prod_{i=1}^{N}\left(1-(m_{i,j}+r_{i,j})\right)\right)\right]\end{array}\right)(1+int)^{-j} \quad (5)$$

$$Max\ Reliability = \prod_{i=1}^{N}\prod_{j=1}^{T} e^{-\left[\lambda_i\left(\left(X'_{i,j}\right)^{\beta_i} - \left(X_{i,j}\right)^{\beta_1}\right)\right]} \quad (6)$$

with:

$X_{i,1} = 0; i = 1$

$X_{i,j} = (1-m_{i,j-1})(1-r_{i,j-1})X'_{i,j-1} + m_{i,j-1}(\alpha_i . X'_{i,j-1});$ $\quad i = 1, j = 2, \ldots, T$

$X'_{i,j} = X_{i,j} + \frac{T}{J}$; $\quad i = 1, j = 2, \ldots, T$

$m_{i,j} + r_{i,j} \leq 1$; $\quad i = 1, j = 2, \ldots, T$

$m_{i,j} + r_{i,j} = 0\ atau\ 1$; $\quad i = 1, j = 2, \ldots, T$

$X_{i,j}, X'_{i,j} \geq 0$; $\quad i = 1, j = 2, \ldots, T$

2.3. Genetic Algorithm

Genetic Algorithm (GA) is a problem solving method based on the principle of natural selection and genetics. GA was first developed by John Holland in 1960 and introduced in his book entitled Adaptation in Natural and Artificial in 1975. In his book John Holland said that each case of adaptive problems (natural or artificial) can be formulated with genetic terminology. GA is able to solve various complex problems, therefore the GA method has been widely applied for problem solving and modeling in various fields (Suyanto, 2005).

The genetic algorithm method has several stages in its implementation. The following is an explanation of the steps in the genetic algorithm method (Suyanto, 2005):

1. Form encoding of the solutions
   The encoding of the solution at the beginning of the iteration is to form a matrix with dimensions N × T that contains a value of 0, this is meant by the beginning of the iteration there are no preventive maintenance actions performed on the machine.
2. The Role of Chromosomes
   At this stage explain that the thing that acts as a chromosome is the action on maintenance, namely maintenance and replacement.
3. Matrix Size
   Chromosomes are in the form of matrices with N × T. N indicating the number of components of the object under study, while T is the period of research.
4. Value of Chromosomes
   The value on the N × T matrix or chromosome will contain values based on the actions taken on the scheduling, value 0 (without action), 1 (maintenance / maintenance action), or 2 (replacement action).
5. Specifies the Fitness Function
   This stage is the defining phase of the fitness function which is used to calculate the fitness value as a measuring value in optimization. Here are 3 types of fitness used.
   $$FItness\ 1 = w_1\left(\frac{Total\ Cost}{Costmax}\right) + w_2(-Reliability) \quad (7)$$
   $$Fitness\ 2 = (-Reliability) + \left(\frac{1}{Costmax}\right) x\ |Total\ Cost - Given\ budget| \quad (8)$$
   $$Fitness\ 3 = \left(\frac{Total\ Cost}{Costmax}\right) + |Reliability - Required\ Reliability| \quad (9)$$
6. Crossover Procedure
   The crossover procedure creates a new solution, namely the offspring is the chosen solution pair from the "parent". There are several types of crossover, which will be used in this study is One- Point Inverse Crossover, with the following steps:
   a. Generate two random numbers between 1 until $N \times T$.
   b. Create descendants from selected "parents" whose elements are outside the position of the random number copied from the first "parent" but in the reverse order and the element copied from the second "parent". If the "parent" chosen is identical, then the crossover will produce a different offspring that is not the same as the "parent".

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7. Mutation Procedure
   Mutation procedures are applied to the solution of "offspring". With the following steps:
   a. Generate two random numbers between 1 until $N \times T$.
   b. Then mark the "gene" which changes to 1 or 2 if it equals 0, or changes to 0 if it is equal to 1 or 2.

3. Results and Discussion

Steady State Genetic Algorithm which is implemented in the maintenance of Homogenizer A. This machine is used in processing UHT milk. Failure data used is damage data from January 2017 to December 2018.

After a distribution test, it was found that the failure time data had Weibull distribution with parameters η = 535,907 and β = 1,36854. The value of costs obtained from the company that uses the machine is maintenance cost Rp 751.575, replacement cost Rp 70.000.000, fixed cost RP 370.907, and failure cost Rp 157.677.205. Inflation rate 3,20% and interest rate 2%.

The component of the genetic algorithm iteration input used is required reliability 90%, number of components 1 number of periods 24, number of generations 1, population size 100, genetic cycle 15.000, number of iterations 100, and probability of mutation 0.4.

Based on the results of Homogenizer A machine failure data analysis, preventive maintenance scheduling optimization using genetic algorithm optimization method with 3 fitness functions and using MATLAB R2018b software. The consideration of choosing a treatment scheduling proposal is a proposal that has more than 90% reliability and the maximum interval of each treatment is 2 months based on company policy. And the following is the result of analysis of each fitness.

3.1. Fitness Value Analysis with Fitness Function 1

Fitness function 1 is a function using weights to total costs and reliability. The following is a summary of the results of 11 fitness function 1 scenarios using MATLAB 2018b software.

Table 1: Fitness Function 1 with 11 Scenarios

Fitness Function 1			
Weight		Genetic Algorithm	
w1	*w2*	Total Costs (Rupiah)	Reliability
0	1	1.294.500.599	0.95206
0.1	0.9	244.377.093	0.93586
0.2	0.8	102.125.461	0.92796
0.3	0.7	101.381.078	0.92533
0.4	0.6	100.794.913	0.92586
0.5	0.5	28.664.706	0.91784
0.6	0.4	29.414.924	0.92017
0.7	0.3	26.856.767	0.90886
0.8	0.2	26.871.825	0.91563
0.9	0.1	24.870.546	0.90731
1	0	24.656.833	0.90856

Based on the results of data processing there are several scenarios that cannot be accepted / rejected due to not meeting the requirements of the company to be considered. Therefore the following are data from scenarios that can be accepted for consideration.

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Table 2: Fitness Function 1 to Consider

Fitness Function 1				
Scenarios	Weight		Genetic Algorithm	
	w1	*w2*	Total Costs (Rupiah)	Reliability
1	0	1	1.294.500.599	0.95206
2	0.1	0.9	244.377.093	0.93586
3	0.2	0.8	102.125.461	0.92796
4	0.3	0.7	101.381.078	0.92533
5	0.4	0.6	100.794.913	0.92586
6	0.5	0.5	28.664.706	0.91784
7	0.6	0.4	29.414.924	0.92017

Based on the table above it can be seen that the scenario chosen is scenario 6 fitness function 1 by giving weight to the total cost of 0.5 and the weight of reliability 0.5, because it has the smallest total cost compared to other proposals namely with a total cost of Rp. 28,664,706 and reliability values more than 90% which is equal to 91.78%. And the following is the result of optimizing scenario maintenance scheduling 6 fitness function 1.

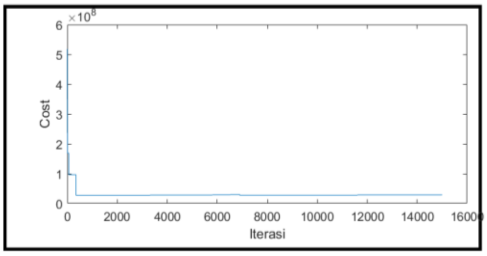

Fig. 3: Convergence in Total Costs Aspects to Iteration Fitness 1

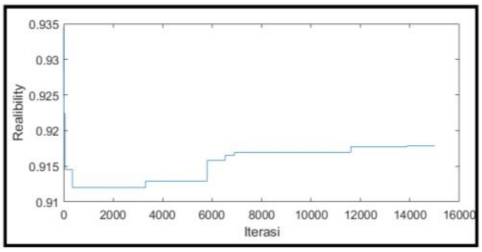

Fig. 4: Convergence in Reliability Aspects to Iteration Fitness 1

Table 3: Preventive Maintenance Schedule Fitness function 1

Preventive maintenance Schedule												
Period	1	2	3	4	5	6	7	8	9	10	11	12
Action	-	M	M	M	M	-	-	M	-	M	-	M
Period	13	14	15	16	17	18	19	20	21	22	23	24
Action	M	-	-	M	M	M	M	M	-	-	M	-
Note : ' - ' = Do nothing, M = Maintenance, R = Replacement												

Based on the table above, a proposal for treatment scheduling is given by carrying out

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maintenance in the 2nd month, 3rd month, 4th month, 5th month, 8th month, 10th month, 12th month, month 13, 16th month, 17th month, 18th month, 19th month, 20th month, 23rd month.

3.2 Fitness Value Analysis with Fitness Function 2

Fitness function 2 is a function by giving a given budget. The following is a summary of the results of 5 scenarios for processing genetic algorithms with fitness function 2 using MATLAB 2018b software.

Table 4: Fitness Function 2 with 5 Scenarios

Fitness Function 2		
Given Budget	Genetic Algorithm	
	Total Costs (Rupiah)	Reliability
20.000.000	26.447.188	0.91774
25.000.000	24.304.699	0.91064
30.000.000	29.757.758	0.92476
35.000.000	27.817.138	0.92291
40.000.000	29.790.814	0.92449

Based on the results of data processing there are several scenarios that cannot be accepted / rejected due to not meeting the requirements of the company to be considered. Therefore the following are data from scenarios that can be accepted for consideration.

Table 5: Fitness Function 2 to Consider

Fitness Function 2			
cenarios	Given Budget	Genetic Algorithm	
		Total Costs (Rupiah)	Reliability
3	30.000.000	29.757.758	0.92476
5	40.000.000	29.790.814	0.92449

Based on the table above it can be seen that the scenario chosen is scenario 3 fitness function 2 by giving a given budget of Rp 30,000,000, because it has the smallest total cost compared to other proposals namely with a total cost of Rp 29,757,758 and a reliability value of more than 90% that is equal to 92.47%. And the following is the result of optimization of scenario maintenance scheduling 3 fitness function 2.

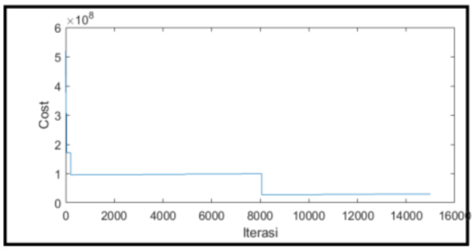

Fig. 5: Convergence in Total Costs Aspects to Iteration
Fitness 2

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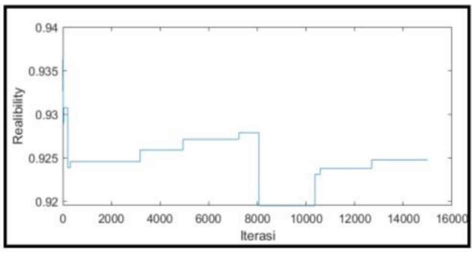

Fig. 6: Convergence in Reliability Aspects to Iteration Fitness 2

Table 6: Preventive Maintenance Schedule Fitness Function 2

Preventive maintenance Schedule												
Period	1	2	3	4	5	6	7	8	9	10	11	12
Action	-	M	-	M	M	M	-	M	-	M	M	-
Period	13	14	15	16	17	18	19	20	21	22	23	24
Action	M	M	M	M	-	M	M	-	M	-	M	M
Note : ' - ' = Do nothing, M = Maintenance, R = Replacement												

Based on the table above, the proposed treatment scheduling is given by carrying out maintenance in the 2nd month, 4th month, 5th month, 6th month, 8th month, 10th month, 11th month, month 13, 14th month, 15th month, 16th month, 18th month, 19th month, 21st month, 24th month.

3.3 Fitness Value Analysis with Fitness Function 3

Fitness function 3 is a function by determining the required reliability. The following is a summary of the results of 11 scenarios for processing genetic algorithms with fitness function 3 using MATLAB 2018b software.

Table 7: Fitness Function 3 with 11 Scenarios

Fitness Function 3		
Required Reliability	**Genetic Algorithm**	
	Total Costs (Rupiah)	**Reliability**
0%	22.563.645	0.90774
10%	25.899.671	0.90798
20%	25.942.076	0.91415
30%	24.051.562	0.91415
40%	23.965.104	0.91268
50%	24.003.625	0.91245
60%	24.251.473	0.91106
70%	22.039.771	0.89779
80%	25.633.754	0.91601
90%	22.493.848	0.9017
100%	30.796.328	0.9252

Based on the results of data processing only 1 scenario is acceptable because the other proposed maintenance scheduling scenarios do not meet the requirements of the company to be

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considered, while the proposed maintenance scheduling is scenario 11 fitness function 3 with a total cost of Rp 30,796,328 and reliability values more than 90% which is equal to 92.52%. And the following is the result of optimizing scenario maintenance scheduling 11 fitness function 3.

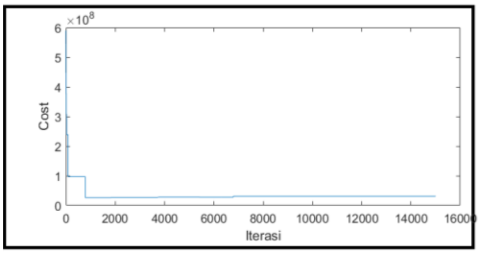

Fig. 7: Convergence in Total Costs Aspects to Iteration Fitness 3

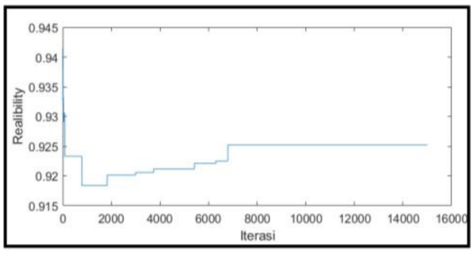

Fig. 8: Convergence in Reliability Aspects to Iteration Fitness 3

Table 8: Preventive Maintenance Schedule Fitness function 3

Preventive maintenance Schedule												
Period	1	2	3	4	5	6	7	8	9	10	11	12
Action	-	M	M	M	M	-	M	M	M	M	-	-
Period	13	14	15	16	17	18	19	20	21	22	23	24
Action	M	-	M	M	-	M	M	-	M	M	M	M

Note : ' - ' = Do nothing, M = Maintenance, R = Replacement

Based on the table above, there is a proposal for treatment scheduling by carrying out maintenance in the 2nd month, 3rd month, 4th month, 5th month, 7th month, 8th month, 9th month, month 10, 13th month, 15th month, 16th month, 18th month, 19th month, 21st month, 22nd month, 23rd month 24th month.

3.4 Comparative Analysis of Proposed Schedules and Existing Schedules

Based on the results of the initial conditions scheduling and proposal scheduling, it was found that the comparison was as follows:

Table 9: Comparative Analysis of Proposed Schedules and Existing Schedules

Existing Schedules	
Total Cost	Rp 40.947.181
Activity	12 times preventive maintenance and 32 times corrective maintenance

Proposed Policy for the 24th Future Period			
	Fitness Function 1	Fitness Function 2	Fitness Function 3

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Total Cost	Rp 28.664.706	Rp 29.757.758	Rp 30.796.328
Reliability	91.78%.	92.47%	92.52%
Activity	14 times maintenance	16 times maintenance	17 times maintenance
Total Cost Efficiency	35%	27%	26%

Based on the table above, it can be seen that the total cost of the previous maintenance policy was Rp. 40,947,181, and the maintenance activities carried out were 12 times preventive maintenance and 32 times corrective maintenance. Whereas the proposed maintenance policy for the next 24 periods has 3 proposals based on the fitness function. The first proposal is to use fitness function 1 by issuing a total cost of Rp. 28,664,706 and a reliability value of 91.78% with scheduling activities is to do machine maintenance for 14 times. The second proposal is to use fitness function 2 by issuing a total cost of Rp. 29,757,758 and a reliability value of 92.47% with scheduling activities is to do machine maintenance for 16 times. The third proposal is to use fitness function 3 by issuing a total cost of Rp 30,796,328 and a reliability value of 92.52% with scheduling activities is to do machine maintenance for 17 times.

REFERENCES

Alhilman. J., Atmaji. F., Athari, N. (2017). Software Apllication for Maintenance System. *Fifth International Conference on Information and Communication Technology*.

Ebeling, C. E. (1997). *An Introduction to Reliability and Maintainability Engineering.* Singapore: The McGraw-Hill Companies Inc.

Hyunchul, K., Nara, K., & Gen, W. (1994). A Method for Maintenance Scheduling Using GA Combined with SA. *Computers Ind. Engineering, 27*, 477-480.

Kramer, O. (2017, January). Genetic Algorithm Essentials,. Springer International Publishing.

Marquez, C. M. (2007). *The Maintenance Management Framework: Models and Methods for Complex Systems Maintenance 1st.* Springer Publishing Company.

Moghaddam, K. (2015). Preventive maintenance and replacement optimization on CNC machine using multiobjective evolutionary algorithms. *International Journal of Advanced Manufacturing Technology*, 2131-2146.

Moghaddam, K. S. (2010). *Preventive maintenance and replacement scheduling : models and algorithms.* Louisville: University of Louisville.

Moghaddam, K.S., & Usher, J.S. (2009). Maintenance scheduling of Multi-Component Systems Using Multi-Objective Simulated Anneling. *Industrial Engineering Research Conference* (pp. 2189-2194). Lousville: Institute of Industrial and Systems Engineers (IISE).

Molaei, S., Esfahani, M.M.S., & Esfahanipour, A. (2014). Using Genetic Algorithm to Robust Multi Objective Optimization of Maintenance Scheduling Considering Engineering Insurance. *Shiraz Journal of System Management, 2*, 1-19.

Suyanto. (2005). *Algoritma Genetika dalam MATLAB.* Yogyakarta: ANDI.

Usher, J.S., Kamal, A.H., & Syed,W.H. (1998). Cost Optimal Preventive Maintenance and Replacement Scheduling. *IIIE Transaction*, 1121-1128.