Preventive Maintenance Supply Chain Management Optimal Scheduling on VMACL Machines by Implementing Simulation Annealing Algorithms

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Abstract— **PT. Braja Mukti Cakra uses various types of engines to produce parts for truck cars. Vertical Lathe Automatic Chucking Machine (VMACL) is a machine that has the highest frequency of damage when compared to other machines. To reduce damage costs, preventive maintenance is well scheduled. This scheduling problem solving is done using the Annealing Simulation Algorithm. The results of the analysis give direction that the scheduling that must be done are: The maintenance action schedule for the Lifter component is at month 1,6,7,22,24,34, for the Insert component at 4,15,18,27,33 months, and for the Door component at the 2nd month, 12,13,16,17,30,36. Replacement actions for the Lifter component were carried out in the 4,5th month, 1,17,20,29, for the Insert component in the 9,19,22,23,35 months, and for the Door component in the 1,20,27 months. . Scheduling for 36 months using the Simulated Annealing Algorithm will cost IDR. 84,119,244.60 and produce greater reliability than the previous reliability of 58.44%.**

Keywords— *VMACL, reduce damage costs, preventive maintenance, Annealing Simulation Algorithm.*

1. Introduction

Over time, humans use various kinds of technology to help their work. The technology must of course always be treated so that results can be maximized. One example of the technology used is a machine. Therefore, the machine must be properly scheduled so it can reduce the occurrence of damage and continue to function properly [1]-[3]. Maintenance that is carried out regularly is one of the ways companies can do to maintain the function of the machine so as to reduce the chance of the machine to be damaged [4]. This type of treatment is preventive maintenance (PM), which is a plan that involves routine inspections to prevent damage [5].

Determination of PM scheduling, Moghaddam (2010) conducted a study using Genetic Algorithms and Simulated Annealing Algorithms [6]. The objective function in the Simulated Annealing Algorithm is multi-objective. The aim is to obtain results that maximize reliability and minimize total costs. Research related to preventive maintenance (PM) can be seen at [7]-[10]. In this study, conducted to determine the optimal PM. Bouzidi-Hassini et al. (2015), determine the scheduling of engine maintenance by considering the resolution of one machine used as well as the multi-machine resolution used. If the maintenance process is carried out as a whole then multi-machine resolution is used [11]. Besides that, Touat et al. (2017) using genetic algorithms and fuzzy logic methods to solve the problem of scheduling PM machines [12]. In the study of Pang et al. (2018) uses a scatter simulated annealing algorithm to minimize the total delay and total turnaround time for bi-objective PM scheduling problems at a station [13]. Also, Lin et al. (2019), consider many chromosomes in genetic algorithms to obtain the best PM scheduling [14].

PT. Braja Mukti Cakra uses a variety of machines to produce parts for truck cars. Vertical Machine Automatic Chucking Lathe (VMACL) is a machine that has the highest frequency of damage when compared to other machines. To reduce the occurrence of damage, PM needs to be done in the form of periodic inspections, cleaning, replacement of parts, and lubrication which is carried out on a well scheduled basis [15]-[18]. Based on the description above this study is interested in scheduling an optimum PM using the Simulated Annealing Algorithm by considering reliability.

2. Material and Method

In this section, we provide the material and methods used in the study, as follows:

2.1. Material

The data used is data from the Maintenance Section of PT. Braja Mukti Cakra concerning damage to the Vertical Machine Automatic Chucking Lathe in the January 2017 period to July 2018. In this study three components were used, namely the Lifter, Insert and Door components.

2.2. Method

In this section, we discuss the issue of preventive maintenance scheduling on VMACL machines, using the Simulated Annealing Algorithm. Discussions include: VMACL, damage, preventive maintenance, Simulated Annealing Algorithm, reliability.

3 Mathematical models

This section discusses distribution compatibility test, parameter estimation, Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR), simulated annealing algorithm and Multiobjective Optimization Model on Simulated Annealing

3.1 Goodness of fit test of Weibull Distribution (Mann's test)

3.1.1 Hypothesis tests

H_0 : The time between damage / repair time data follows the Weibull distribution pattern.

H_1 : Breakdown time / repair time does not follow the Weibull distribution pattern.

α = 5%

3.1.2 Test Statistics

$$\mathrm{M} = \frac{\mathrm{k}_1 \sum_{i=k_1+1}^{r-1} [(\ln t_{i+1} - \ln t_i)/M_i]}{\mathrm{k}_2 \sum_{i=1}^{k_1} [(\ln t_{i+1} - \ln t_i)/M_i]} \quad (1)$$

Where:

$$\mathrm{k}_1 = \frac{\mathrm{r}}{2} \qquad \mathrm{k}_2 = \frac{\mathrm{r}-1}{2} \qquad \mathrm{M_i} = Z_{i+1} - Z_i$$

$$Z_i = \ln[-\ln(1 - \frac{i-0{,}5}{n+0{,}25})]$$

Degree of freedom F_{tabel} are $\mathrm{v}_1 = 2k_2$ and $\mathrm{v}_2 = 2k_1$

3.1.3 Tests criteria

Reject H_0 if $M_{count} > F_{tabel} = F(\alpha, v_1, v_2)$, else accept H0

3.2 Goodness of fit test of Exponential Distributions (Bartlett Test)

3.2.1 Hypothesis tests

H_0 : The time between damage / repair time data follows the Exponential distribution pattern.

H_1 : The time between damage / repair time data does not follow the Exponential distribution pattern.

α = 5%

3.2.2 Test Statistics

$$\mathrm{B} = \frac{2\mathrm{r}[\ln\left(\left(\frac{1}{\mathrm{r}}\right)\sum_{i=1}^{r} t_i\right) - (\frac{1}{r})\sum_{i=1}^{r} \ln t_i}{1 + (r+1)/(6r)} \quad (2)$$

3.2.3 Tests criteria

Accept H_0 if $X^2_{1-\frac{\alpha}{2},r-1} < \mathrm{B} < X^2_{\frac{\alpha}{2},r-1}$ and else reject it.

3.3 Parameter estimation

Using the Maximum Lihihoodood Estimation method, the estimated parameters β and θ for the Weibull distribution data are as follows:

$$\hat{\beta} = \frac{n}{\sum_{i=1}^{n-1}\left(\ln \frac{t_n}{t_i}\right)} \qquad \hat{\theta} = \frac{t_n}{n^{\frac{1}{\beta}}}$$

Estimated parameter λ for exponentially distributed data is as follows.

$$\hat{\lambda} = \frac{r}{\sum_{i=1}^{r} t_i + (n-r)t_r} \quad (3)$$

3.4 Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR)

The Mean Time to Failure (MTTF) for the average damage time distributed by Weibull, is formulated as follows:

$$MTFF = \hat{\theta}_{TTF}\,\Gamma(1+\frac{1}{\hat{\beta}_{TTF}}) \quad (4)$$

Whereas MTTF for Exponential distribution, is formulated as follows:

$$MTTF = \frac{1}{\hat{\lambda}_{TTF}} \quad (5)$$

The Mean Time to Repair (MTTR) for the Weibull distribution is formulated as follows:

$$MTTR = \hat{\theta}_{TTR}\,\Gamma(1+\frac{1}{\hat{\beta}_{TTR}}) \quad (6)$$

Whereas the MTTR for Exponential distribution is formulated as follows:

$$MTTR = \frac{1}{\hat{\lambda}_{TTR}} \quad (7)$$

3.5 Simulated Annealing Algorithm

The simulated annealing algorithm can be performed as follows:

a) Determine the initial temperature (T0), namely by first determining the initial temperature, final temperature, and cooling rate.
b) Determine a new solution
c) Evaluate new solutions using the following criteria.

$$\Delta E = E(X_{i+1}) - E(X_i) \quad (8)$$

Where,

ΔE= difference in objective value
$E(X_{i+1})$ = the objective value of a new solution
$E(X_i)$ = the objective value of initial solution
Solution is accepted if the difference in objective value ≤0. Or with probability $P(\Delta E) = e^{-\Delta E/T} > r$ New solutions can still be selected.

d) Reducing the temperature, if the final temperature has not been reached, then the temperature is lowered by a predetermined cooling rate.

e) Determine the best scheduling solution by stopping the algorithm when the final late temperature is reached.

3.6 Optimation Model of Multiobjective in Simulated Annealing

3.6.1 *The Minimum Total Cost*

The Minimum Total Cost function can be calculated by taking into account the following three components:

a) Failure Cost
$F_i = (\text{downtime cost} + \text{labor cost})\text{ x MTTR} + \text{component cost}$
b) Maintenance Cost
$M_i = (\text{downtime cost} + \text{labor costs})\text{ x MTTR} + \text{component maintenance cost}$
c) Replacement Cost
$R_i = (\text{downtime cost} + \text{labor costs})\text{ x MTTR} + \text{component replacement cost}$

3.6.2 *Maximum Function of Reliability*

Maximum function of reliability for ith component jth period is as follows:

$$Max\ Reliability = \prod_{i=1}^{N}\prod_{j=1}^{J} \exp(\lambda_i((X^1_{i,j})^{\beta_i} - (X_{i,j})^{\beta_i})) \quad (9)$$

Where
N = planning maintenance period
J = time interval
$i = 1,2,\ldots,N$ and $j = 1,2, ..., J$

4 Numerical Simulation

From the results of numerical analysis obtained by Mann's Test, the time data between Lifter, Insert, and Door component damage follows the Weibull distribution with parameter values β = 1.00557 and θ = 62.6872 for Lifter components, parameter values β = 1.02081 and θ = 153.987 for Insert components, and parameter values β = 1.03277 and θ = 169.093 for the Door component. The parameter values are obtained by using Software R. While the MTTF value for time data between Lifter component damage is 62.5422, Insert component is 152,685, and door components are 166,986.

Table 1. Damage, Maintenance and Replacement Costs

Failure Cost	IDR 3,821,756
Maintenance Cost	IDR 3,585,291
Replacement Cost	IDR 3,915,986

Tabel 2. Input of MATLAB Software

Input	**Descriptions**	**Value**		
		Lifter	**Insert**	Door
Parameter Distributions	Lambda	0.001595	0.006494	0.005914
	Beta	1.005571	1.020807	1.03277
Cost and Budget	*Failure Cost*	3,821,756	3,585,291	3,915,986
	Maintenance Cost	3766756	3515041	3,895,986
	Replacement Cost	3,841,756	3,856,041	3,935,986
	Fixed Cost	4,122,000		
Required Reliability	Expected Reliability	0.75		
Parameter Algoritma *Simulated Annealing*	Initial Temperature	1000000		
	Final Temperature	0.01		
	Rate	0.98		

Tabel 3. Output of MATLAB Software

component	**Month**											
	1	2	3	4	5	6	7	8	9	10	11	12
Lifter	M	-	-	R	R	M	M	-	-	-	-	-
Insert	-	-	-	M	-	-	-	-	R	-	-	-
Door	R	M	-	-	-	-	-	-	-	-	-	M

Tabel 4. Output pada Software MATLAB

component	**month**											
	13	14	15	16	17	18	19	20	21	22	23	24
Lifter	-	-	-	-	R	-	-	R	-	M	-	M
Insert	-	-	M	-	-	M	R	-	-	R	R	-
Door	M	-	-	M	M	-	-	R	-	-	-	-

Tabel 5. Output of MATLAB Software

component	**Month**											
	25	26	27	28	29	30	31	32	33	34	35	36
Lifter	-	-	-	-	R	-	-	-	-	M	-	-
Insert	-	-	M	-	-	-	-	-	M	-	R	-
Door	-	-	R	-	-	M	-	-	-	-	-	M

Costs for damage, maintenance, and replacement can be seen in Table 1. Also, the results of the analysis conducted using MATLAB Software obtained input as given in Table 2.

By using the input from Table 2, the data will be processed using software and the output will be obtained. The output results obtained from MATLAB Software are given in Table 3.
The results in Table 3, show that the maintenance schedule for the Lifter component must be carried out in the 1.6, 7th month while the maintenance action for the Insert and Door component must be carried out respectively in the 4th, 2nd and 6th month, respectively.

Table 4, also shows that the maintenance schedule for the Lifter component must be carried out in the 22nd and 24th months while the maintenance action for the Insert component must be carried out in the 15th month, 18 the same for the Door component i.e. in the 13th, 16th and 17th months while The Insert maintenance component is carried out in the 15th and 18th months. As for the replacement schedule for the Lifter, Insert and Door components, respectively, it must be done in the 17th, 19,20,22, and 23 months.

Table 5, also shows that the maintenance schedule for the Lifter component must be carried out in the 34th month while the maintenance action for the Insert component must be done in the 27th and 34th month the same for the Door component i.e. at the 30th and 36th months. The component replacement schedule occurs in the 29th month for the 35th month Lifter for Insert and the 27th month for the door.

5 Conclusions

Scheduling for 36 months using the Simulated Annealing Algorithm will cost IDR. 84,119,244.60 and produce greater reliability than the previous reliability of 58.44%.The maintenance schedule for the Lifter component is 6 times in 3 years, for the Insert component is 5 times in 3 years, and for the Door component is 7 times in 3 years. The replacement action for the Lifter component and the Insert component are carried out 5 times and for the Door component 3 times the component replacement is performed.

Acknowledgments

Acknowledgments are conveyed to the Rector, Director of Directorate of Research, Community Involvement and Innovation, and the Dean of Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, with whom the Internal Grant Program of Universitas Padjadjaran was made possible to fund this research. The grant is a means of enhancing research and publication activities for researchers at Universitas Padjadjaran.

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