Preventive maintenance considering OEE threshold for lease equipment

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Abstract. Under a leasing contract, a lessor offers equipment with maintenance service included to a lesseein order to induce cooperation with lessee. Maintenance are provided for keeping the equipment on its prime performance, rectifying failure, and restoring it for the operational state. Nevertheless, maintenance always leads to an total maintenance cost some experts have conducted numbers of work overcoming this problem. Most of them tend to assume downtime as a threshold for determining preventive maintenance. This paper proposes Overall Equipment Effectiveness (OEE) as a threshold of OEE services to measure of maintenance performance. It also investigates an optimal OEE threshold for performing preventive maintenance (PM) actions on leased equipment. A virtual age reduction method is used to determine the PM degree and build maintenance cost function. During a leasing period, PM actions are performed when OEE equipment reaches the threshold value. The Failure equipment is corrected with minimal repair and PM is carried out with imperfect repairs. A mathematical model of expected total cost is developed to determine an optimal maintenance policy. The result showed that maintenance policies yields minimize total cost maintenance. An interesting discussion on maintenance policies can be drawn based on our numerical experiment results.

Keywords: *lease equipment, preventive maintenance, repair, OEE*

1. INTRODUCTION

In 1990, Mobley stated that maintenance activities cost is occurred in 15 and 40 percent (average 28 percent) of total production costs. Eti & Ogaji, (2006) mention that maintenance cost accounts for 40 percent of the operational budget. Cross, (1988) and Komonen, (2002) also explained explained that maintenance costs are estimated at 25 percent of overall operating costs. These can be concluded that maintenance cost is high enough and substantial problem that must be solved soon. In addition, maintenance activities require special skills to organize and improve the machine.

It is considered that ownership in certain equipment is inefficient for businesses. Therefore, there is a tendency to rent rather than purchase equipment (Nisbet & Ward, 2001). Outsourcings have been developed since 1970. It was driven by the company's desire to focus on core business. Maintenance is considered as an inefficient activities and requires special skills that make the company takes outsourcing as better initiative for their bussiness (Jaturonnatee, 2006). In 1990 the companies reduced their machine ownership \ (owned equipment). For this year, the Company outsourced equipment with maintenance activities.

In general, leased equipment considers two types of maintenance measures, corrective maintenance (CM) and preventive maintenance (PM). While corrective maintenance of equipment failed to return to its operational status,PM increased the operational status of the leased equipment. This action reduces the possibility of equipment failure. Some researchers have discussed leased equipment (Hamidi, Liao, & Szidarovszky, 2016; Mabrouk, Chelbi, & Radhoui, 2016; Schutz & Rezg, 2013; Yeh, Chang & Lo, 2011; Yeh, Kao, 2011; Chang & Lo, 2011; Yeh, Kao, & Chang, 2009; Yeh & Chang, 2007; Jaturonnatee, 2006; Pongpech & Murthy, 2006). In their research they determined the threshold limit of engine failure, optimal PM interval, duration of lease and lessor profit. The main criteria in determining the policy is cost minimization. Jaturonnatee, (2006) developed a PM sequential scheme with minimal repair on a new machine. His research determined the number of PM actions, the PM degree, and the optimal time interval. He also modeled the action of PM with failure rate reduction method (FRRM), however this developed model is not easy to implement.

Referring to the method used, some studies use failure rate reduction method / FRRM PM (Jaturonnatee, 2006; Pongpech & Murthy, 2006; Yeh & Chang, 2007). FRRM reduces the failure rate of equipment with a fixed amount or amount equivalent to the current failure rate after the action (Finkelstein, 2008). In addition, other studies use the age reduction method (ARM) (Hamidi et al., 2016; Schutz & Rezg, 2013; Zhou, Xi, & Lee, 2007). ARM is the age of equipment restored younger than the present age with a fixed amount after each PM action (Finkelstein, 2008). The majority of researchers used total maintenance cost as the optimal decision (Hamidi, Liao, & Szidarovszky, 2016; Mabrouk, Chelbi, & Radhoui, 2016; Chang & Lo, 2011; Yeh, Chang, & Lo, 2011; Yeh et al., 2009; Jaturonnatee et al., 2006; Pongpech & Murthy, 2006). For cost minimizing, Yeh & Chang, (2007) used a failure rate as a threshold whilereliability is used by Schutz & Rezg, (2013) and downtime is used by Mabrouk et al. (2016) Thus, maintenance activities not only affect total maintenance cost but also downtime, failure rate, reliability, and Overall Equipment Effectiveness (OEE).

This paper assumes that the distribution failure is Weibull distribution and the repair is performed in minimal repair in case of damage. We proposes the maintenance concept with preventive maintenance reducing. Being different with Yeh et al. (2007) and Schutz & Rezg, (2013), this paper also uses OEE as the optimal threshold determination with ARM shortcuts.

2. LEASED EQUIPMENT

Leasing came from English "to lease" which means renting. It has certain requirements, so it can not be equated with ordinary leases. Leasing or more commonly referred to as a lease is any business financing activities in the form of provision of capital goods for used by a company for a certain period based on periodic payments. It is also accompanied by the right to vote (option) for the company to purchase the capital goods concerned or extend the lease term based on the mutually agreed value (Sawir, 2004). Meanwhile, Zaeni (2006) stated that leasing is any corporate financing activities in the form of providing or renting capital goods for use by other companies within a certain period with the following criterias:

1. Rental payments are made on a regular basis.
2. Lease period is determined in accordance with the type of capital goods in the lease.
3. Right of option, namely the right of the enterprise of the capital goods user to return or buy capital goods at the end of the lease agreement period.

Referring to the explanation, It can be identified due to leasing parties associated namely:

1. Lessee, the corporate user of the goods.
2. Lessor, a financing funding company.
3. Supplier, supplier company of equipment.
4. Insurance companies.
5. Equipment, The critical factor is the reliability of the equipment.
6. Maintenance; Equipment is degraded with age and use, and ultimately fails.
7. Contract; Contracts need to consider the interests of both the lessor and the lessee.

3. PROBLEM STATEMENT

Due to preventive maintenance considering OEE threshold for lease equipment, this section explains the problem statement preventive maintenance.

3.1 Notation

Some equations are used in this paper to describe preventive maintenance considering OEE threshold for leased equipment. Notations used in the equations are listed in the table 1:

Table 1: Notations of model

Notations	Descriptions
L	Lease period
T	Preventive maintenance interval
δ	Mmaintenance degree
Cf	Fixed cost PM
Cv	Variable cost PM
n	Number of PM
Ctot	Total maintenance cost

OEEthr	OEE threshold
Ccm	Cost CM
Cpm	Cost PM
ω	Number of failures
MTTF	Mean time to failure
MTTR	Mean time to repair
OT	Operation time
PT	Process time
CT	Cycle time

3.2 Problem Description

This paper assumes that equipment leased is a new equipment. The lessor must perform corrective action in case of failure and prevent the equipment damage Duration of PM activity on lease term is ignored.

The CM action is performed with minimal repair so that the failure rate does not change and the condition is " Bad As Old " (Ascher, 1968). While PM action is characterized by a decline in system age as stated in to model II, developed by Kijima (1989) known as the ARM (age reduction methode) model. In contrast to FRRM, ARM is characterized by a reduction in functional age itself. After PM, the system functional age can be expressed as:

$$A_i = (1-\delta)(A_{i-1}+T_1) \quad (1)$$

In this paper, preventives are done with imperfect PM so that the maintenance degree has interval [0,1]. The result of the PM imperfect is that equipment is returned to the condition between "as good as new" and "as bad as old".

To reduce the number of possible failures, the lessor can perform PM actions within the lease term. After performing PM, PM action at the time, the equipment failure rate is reduced by a fixed amount $\delta \geq 0$, where $0 < t_1 < t_2 < t_3 < \ldots < t_n < L$. In practice, Yeh et al., (2009) considers the cost function of PM, Cpm (δ) which increases linearly with the maintenance degree δ, the cost model is the non-negative and non-decreasing function of the maintenance degree $\delta \geq 0$. PM can be expressed as follows:

$$C_{pm} = n[C_f + C_v\delta] \quad (2)$$

The combination of maintenance encourages to give the customer a minimal OEE of its equipment. The purpose of this paper is to find the total cost of maintenance action. In addition, this paper determines the OEE minimum because OEE affects total maintenance costs. Meanwhile, the corrective and cost maintenance have more importance than preventive measures.

Furthermore, this paper uses OEE developed by Ilar, Powell, & Kaplan, (2009) (2009) as it focuses more on maintenance activities. Overall Equipment Effectiveness from Ilar et al. (2006) is a model development of previous researchers (Wudhikarn, 2013; Ahire & Relkar, 2012; Kingdom, & Starr, 2010; Gibbons, 2006; Ron & Rooda, 2005; Bamber, Castka, Sharp, & Motara, 2003; Peters, 2003; Al-Najjar, 1999; Anvari, Edwards, Groote, 1995; Raouf, 1994; Nakajima, 1988).

OEE according to Ilar et al., (2009):

$$= \left\{ \left(\frac{MTTF}{MTTF + MTTR} \right) x \left(\frac{TCT\ x\ PA}{OT} \right) x \left(1 - \frac{Processtime}{MTTF} \right) \right\} 100\% \quad (3)$$

3. MATHEMATICS

According to Schutz & Rezg, (2013) for the lease period L, *total maintenance cost* (Ctot)) is expressed by a factor δ, with the following equations:

$$C_{tot}(\delta) = C_{cm}\,.\omega(\delta) + nC_{pm} \quad (4)$$

With *number of PM* (Schutz & Rezg, 2013)

$$n = \frac{L - T_1}{\delta . T_1} \quad (5)$$

The interval {Ti} i> 2 is fixed and the same for δ. T1 since the effectiveness factor is constant and the same for each PM interval. The interval Ti varies between from 0 (if δ = 0) and T1 (if δ = 1). When δ is at [0, 1], the duration of Ti interval is determined by the time to reach the OEE threshold from the virtual age of Ai-1. As the virtual age is given by Eq. (1), interval PM is $(T_1 - (1-\delta).T1) = \delta T_1$.

While the expected number of failures according to Schutz & Rezg, (2013):

$$\omega(\delta) = \int_0^{T_1} \lambda(t)dt + (n-1)\int_{(1-\delta)T_1}^{T_1} \lambda(t)dt + \int_{(1-\delta)T_1}^{L-n\delta T_1} \lambda(t)dt$$

$$= \left(\frac{1}{\alpha}\right)^{\beta} \left\{ \left[nT_1^{\beta}\left(1-(1-\delta)^{\beta}\right) \right] + \left(L - n\delta\, T_1\right)^{\beta} \right\} \quad (7)$$

So if the functions 2, 4 and 7 are substituted in function 1, then the expected total maintenance cost is:

$$C_{tot}(n, \delta, T) = C_{cm}\,.\omega(\delta) + nC_{pm}$$

$$= C_{cm} \left\{ \left[nT_1^{\beta}\left(1-(1-\delta)^{\beta}\right) \right] + \left(L - n\,\delta\, T_1\right)^{\beta} \right\}$$

$$+ n(C_f + C_v\delta) \quad (8)$$

Optimal Policy

The PM action is performed when OEE reaches the threshold on the contract. Figure 4.1 provides the decrease and increase in OEE over time. To obtain the optimum policy identified minimum expected maintenance cost, it is necessary to determine the optimal δ, n, and T.
To obtain optimal maintenance schedules policy (T *) Equation. (4.10) is derived as follows:

$$\frac{\partial C_{tot}(n,\delta,T)}{\partial n} = \left[C_{cm}\left(\frac{1}{\alpha}\right)^{\beta}\left\{T_1^{\beta}\left[1-(1-\delta)^{\beta}\right]\right.\right.$$

$$\left.\left. -\beta\,\delta\, T_1\left[L-\delta T_1\right]^{\beta-1}\right\} + \left[C_f + C_v\delta\right] = 0 \qquad (6)$$

$$\frac{\partial C_{tot}(n,\delta,T)}{\partial \delta} =$$

$$= [C_{cm}]\left\{\left[\beta n T_1^{\beta}(1-\delta)^{\beta-1}\right] - \beta n T_1\left[L - n\delta T_1\right]^{\beta-1}\right\}$$

$$+ nC_v = 0 \qquad (9)$$

The preventive maintenance is implemented if OEE reaches OEEthr (85%). When PM is executed at t1 it is expected that the OEE value rises at a certain value and decreases the failure rate function by δ.

Table 1: Numerical results for various combinations of β, α, L and τ.

β	α	L	OEEthr	n	δ	ω	Cpm	Cc	Ctot
2	1	4	85	12	0.8346	1.2204	1290.5	183.0619	1473.56
		5	85	14	0.8306	1.5434	1505.4	231.5146	1736.91
		6	85	17	0.8215	1.9404	1827.9	291.0583	2118.96
2	0.5	4	85	12	0.8346	4.8817	1290.5	732.2478	2022.75
		5	85	14	0.8306	6.1737	1505.4	926.0583	2431.46
		6	85	17	0.8215	7.7616	1827.9	1164.2	2992.10
2.5	1	4	85	12	0.8346	0.6768	1290.5	101.5146	1392.01
		5	85	14	0.8306	0.8756	1505.4	131.3459	1636.75
		6	85	17	0.8215	1.1137	1827.9	167.051	1994.95

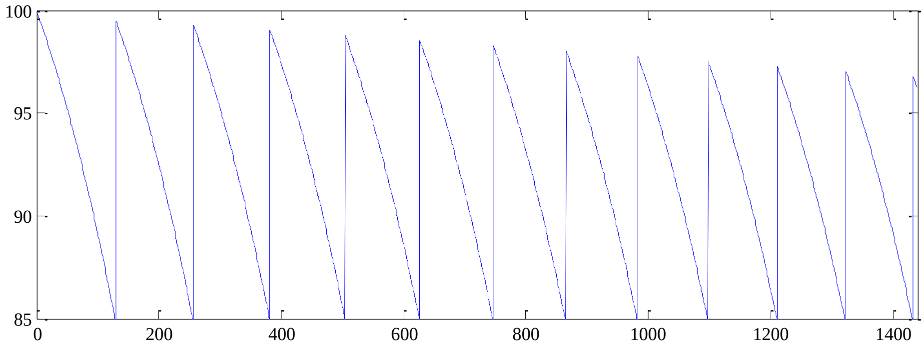

Figure 1: The effect of PM on OEE

The preventive maintenance is implemented if OEE reaches OEEthr (85%). When PM is executed at t_1 it is expected that the OEE value rises at a certain value and decreases the failure rate function by δ. Based on the equation (6) n is affected by the value of δ and δ corresponding to the PM interval $(0, \delta.t_1)$ so that:

$$\left.\begin{aligned} \delta . t_1 \delta &\geq \frac{L - t_1}{n . t_1} \\ \delta . t_1 \delta &\geq L - \left[t_1 + (n-1) . \delta . t_1\right] \end{aligned}\right\} \qquad (10)$$

$$\left.\begin{aligned} 0\, \delta &< \frac{L - t_1}{(n-1) t_1} \\ 0\, \delta &< L - \left[t_1 + (n-1) t_1\right] \end{aligned}\right\} \qquad (11)$$

Consequently, for n constant, the values δ are at the following intervals:

$$\delta = \left\lfloor \frac{L - t_1}{n . t_1}, \frac{L - t_1}{(n-1) . t_1} \right\rfloor \qquad (12)$$

4. NUMERICAL EXAMPLE

Illustrated that the car rental company rents the vehicle for (L) in the beginning of 5 years, PM will be implemented if OEE is 85%. In case of failure,the machine will be fixed in a cycle time of 0.25. It is assumed that the loss time is 0.0008 days and the initial OEE is 100%. From the data provided, it is possible to determine the value that characterizes T_1 duration. This period represents the time between two for consecutive maintenance with new considered equipment.

Table 1 is a summary of numerical results from a combination of rental periods (L), parameters α and β, and length of repair (τ). For example, if the lease period is 4 years (1400 days), the value of α = 0.5, β = 2, C_{cm} =150, C_f = 100, C_v = 50 and the OEE is 85% threshold, it yields the optimal PM at n = 12, and the expected total maintenance cost is 2022.75 units of money and Equipment failure 4.8817 unit. In addition, Table 2 explains that the longer L the number of PM will increase, so the total expected maintenance cost increases as well. Expected total maintenance cost increases due to the increasing amount of equipment failure. See from the maintenance cost, cost Cc will increase due to the repair time is increased. The influence of PM against OEE can be seen in figure 1.

Table 2: PM time and OEE

n	t	OEE (%)
1	129	99.49365
2	256	99.2476
3	381	98.99919
4	504	98.75022
5	626	98.501
6	746	98.25169
7	865	98.00229
8	982	97.75287
9	1097	97.50342
10	1241	97.25395
11	1322	97.00446
12	1432	96.75496

Figure 1 shows that after the PM, the OEE will rise again after a decline in the point of OEE to 85%. This happens until the 11th PM on the contract equipment period. The magnitude of the increase in OEE can be seen in Table 2. While PM is at t_1, t_2 ... t_{11}, when OEE is 85%. This can be seen in table 3. For example, OEE reaches 85% when t_1 = 129 then the lessor will do the first PM. PM when t_1 = 129 resulted in an increase of OEE from 85% to 99.49%. While at the second Pm when t_2 = 256, OEE becomes 99.25%.

In addition, Table 2 shows a decrease in OEE, at t_0 = 100% but after PM, OEE becomes 99.493%, 99.248%, 98.999% and so on. This is influenced by the usage conditions and the age of the equipment so that OEE is not as large as OEE at time t_0.

5. CONCLUSION

This paper discusses the maintenance strategy with PM and CM. Furthermore, this paper obtains some of the properties of the optimal maintenance policy and efficient algorithmic redundancy. The analytical numerical output of the maintenance strategy is influenced by several parameters such as β and α, if β and α increases the level of damage will decrease and vice versa. From the numerical example scenario, PM is required to reduce the cost maintenance and the amount of failure equipment.

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