Optimal Availability for Equipment Under Imperfect Maintenance by Considering Threshold Reliability

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Abstract

Maintenance actions have an important role in maintaining product availability, reliability, and quality in the production process. Strategies for carrying out maintenance actions have evolved over time, and technological advances and research are developing rapidly. Matter It aims to build a more efficient and reliable system. Equipment performance that continues to decrease over time without effective maintenance falls into the extreme damage category. Increasing age and use cause a decrease in the function of the equipment. To assess reduction due to age and reduction due to use, this study employs a hybrid hazard rate. Maintenance is carried out when the equipment reaches a predetermined reliability threshold. After several uses, the preventive system will be replaced. Until now, there has been no research to determine maintenance actions that optimize availability with a specified reliability threshold. This research will try to model a maintenance policy strategy that optimizes availability with predetermined threshold values. The goal is that the owner can evaluate the performance of the equipment so as to avoid the risk of loss of equipment availability due to maintenance actions. At the end, a numerical experiment is given to illustrate the implementation of the proposed model.

Keywords
Maintenance, Availability, imperfect PM. Threshold, Reliability

1. Introduction
Equipment is an important part of the production process. equipment with a high level of availability is needed to win the competition with its competitors. Increasing age and use of production equipment causes the system to experience a decrease in performance so that maintenance is needed. Maintenance actions result in reduced production time and can reduce equipment availability. For this reason, a strategy is needed in managing treatment actions. The strategy in carrying out maintenance actions is expected so that the equipment can work optimally by increasing the reliability of the equipment, preventing failure and in order to reduce maintenance costs.

Maintenance actions can be carried out with preventive actions (PM) and corrective actions (CM) according to Barlow & Hunter (1960). Preventive measures to reduce the risk of failure and improve operational conditions. While corrective action is to repair the equipment so that it returns to operation. When the system reaches the reliability threshold preventive maintenance is performed. and replacement after several preventive times. Maintenance actions result in the system being "as good as new" or "as bad as old".

A lot of research done in the field of maintenance. This shows the importance of a maintenance strategy. In order to obtain an optimal strategy policy, the optimization model development is carried out. Other researchers produced many variations of maintenance optimization models. Unlike the model in this study. This research will model a preventive maintenance policy that optimizes availability by considering the reliability threshold determined by the owner. The goal is to be able to evaluate strategies for carrying out maintenance on equipment, so as to avoid the risk of loss of equipment availability due to maintenance actions. Reliability thresholds are determined so as to maximize availability. This study uses the Weibull distribution for the initial damage rate. Then this study will also use the hybrid hazard rate proposed by Lin et al. (2001). System degradation considering age and usage is the reason for using a hybrid hazard rate. Another optimization model has been put forward by researchers with different considerations.

According to Nakagawa (1981) and Nakagawa & Kowada (1983) minimal repair is the most commonly used corrective action to restore equipment that has failed. Repairs made with minimal repair put the equipment back in operation but the failure rate of the equipment will not change (Yeh, 2009). Preventive measures are classified into two main categories, namely perfect PM and imperfect PM (Jack & Murthy, 2007). Preventive maintenance actions lead to two different system conditions, namely "as Good as New" or "as Bad as Old" system conditions (Khatab, 2014). Imperfect PM methods are Age Reduction Method (ARM) and Failure Rate reduction Method (FRRM). At ARM the PM level is explained by a reduction in product age with the aim that the age of the equipment after maintenance is younger than before. Whereas PM level FRRM is explained by the failure rate of equipment with the aim of reducing failures after carrying out maintenance. (Nakagawa 1981).

2. Literature Review

Maintenance

An activity known as maintenance tries to fix or restore damaged systems or components to pre-existing conditions within a set amount of time (Ebeling 1997). The concept of maintenance, on the other hand, is defined by Supandi (1990) as all the actions required to preserve or preserve quality so that it continues to operate as intended. According to Dhillon (1979), performing maintenance is a necessary task in some circumstances, with the primary goal being to restore the equipment to a state that allows it to function. Additionally, maintenance is a process used to maintain a piece of equipment, whether it be a single piece or the entire apparatus, and restore it to its functioning state. The notion of maintenance is also a maintenance program that will be implemented, and there are numerous. The concept of maintenance also refers to a maintenance plan that will be followed, in which various forms of maintenance procedures will be applied to the item.
The two types of maintenance activities are described by (Corder A 1992). both planned and unexpected maintenance. A maintenance task that is carried out according to plans that have been created in advance is referred to as planned maintenance. Preventive maintenance and corrective maintenance are both included in planned maintenance. Meanwhile, unscheduled maintenance happens because it happens unexpectedly. Corrective maintenance and preventive maintenance are both included in the maintenance form.

2.2 Corrective Maintenance

Corrective maintenance is defined as maintenance and care actions performed after a facility or piece of equipment suffers damage or malfunctions (Assauri 2008). Tampubolon (2004) argues that corrective maintenance is a type of repair. According to (O'Connor & Patrick 2001), the MTTR (mean time to repair) can be used to compute corrective maintenance. The time to repair encompasses a number of tasks that are typically broken down into three groups: preparation time, active maintenance time, and delay time.

2.3 Preventive maintenance (PM)

Preventive maintenance, in the perspective of O'Connor & Patrick (2001), consists of maintenance and care procedures used to avoid unexpected damage and identify conditions or conditions that might result to production facilities being damaged during the production process. As a result, all production facilities that receive maintenance (preventive maintenance) will make sure that their work is continuous and always want to be in a condition that is ready to be used for any operation or production process at any time. Furthermore, the consideration of the time to failure (TTF) distribution of the components that need to be maintained and the failure rate of the existing system can increase the efficiency and economy of preventive maintenance, according to O'Connor & Patrick (2001). Activities of maintenance or care to stop unexpected deterioration that results in production facilities being damaged when employed in the production process. To operate manufacturing facilities classified as "critical units," preventive maintenance is necessary.

2.4 Availability

A ratio called availability describes how much of the time is really used for device or equipment operating operations. By removing equipment or machine downtime, availability is the ratio of operating time. Ebeling (1997) defined availability as the potential for equipment to carry out its intended duties. The formula for availability is as follows.

$$A\,(i) = \frac{Up\ Time}{Up\ Time + Down\ Time} \tag{1}$$

3. Methods

3.1 Conceptual Model

The value of the equipment that can operate (Up time) and the value of the equipment that cannot operate have an impact on availability (Down Time). The equipment can function while its reliability value is R=1 and it cannot function when its reliability value is R=0. The equipment's time to failure value specifies the conditions under which it can function. While the value of the repair time determines the state of the equipment that cannot function. To conduct out maintenance procedures, reliability threshold must act as an alarm. The equipment must perform maintenance procedures frequently, which results in limited equipment availability, as the reliability threshold increases. The equipment availability level is great, however, the lower the reliability threshold, the longer the equipment functions. Low reliability thresholds, however, can degrade equipment more seriously. In doing maintenance tasks, a plan is required to achieve high availability. The expectation is that maintenance operators would perform maintenance tasks at the proper periods.

This study was conducted so that the owner could determine the best method for performing maintenance. This concept is designed to provide an optimum period for conducting equipment repair and to completely eliminate the possibility of poor availability caused by maintenance activities. When the equipment reaches the defined reliability threshold, preventive repairs will be performed. In addition, the system will replace a number of its current maintenance procedures with new items (preventive replacement). Minimal repair (CM) with a duration of time less than or equal to the specified time limit will be used as the maintenance action. After a failure, the equipment only needs basic repair to resume operating. Then imperfect repair (PM) is carried out to avoid equipment failure.

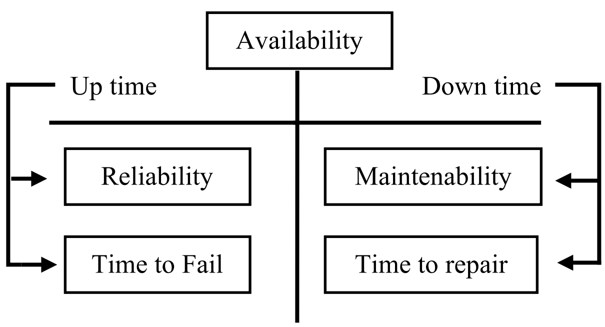

Figure 1. Conceptual Model

3.2 Research Description

This study aims to obtain a maintenance policy that optimizes availability within a specified reliability threshold. Optimal conditions will be obtained when the owner has equipment with maximum availability. The following is a description of the model to get optimal conditions:
The availability value is influenced by the reliability threshold for carrying out maintenance actions.
The higher the reliability threshold value, the lower the availability value.

- Maintenance actions are carried out with preventive replacement and preventive repair
- The more often you do preventive replacement, the higher the availability.
- The longer the component is used (preventive replacement), the more maintenance (preventive repair) will be done on the equipment.
- A growing number of preventative maintenance procedures lead to lower availability.

4 Mathematic Model

This study uses variations in the level of hazard after PM following Lin, Zuo, and Yam (2001) with a hybrid hazard rate, the act of performing imperfect PM maintenance causes the system to be degraded. During the PM cycle, namely the time to carry out Tk maintenance (k=1,2,3…) by following the hybrid hazard rate as follows:

$$h_{k+1}(t) = \beta_k h_k(t + \alpha_k T_k) \quad t \in [0, T_{k+1}[, k = 1,2,3,,,,, \tag{2}$$

The age coefficient is expressed as αk and the age reduction coefficient is expressed as βk so that 0 ≤ α1 < 2 <…1 and 1 ≤ β1< 2 <·.. For t[0,T1[,h1(t) is the hazard level of the system initially assumed new. Then the hazard level function hk(t), for k=1,2, is as follows:

$$h_k(t) = B_k h_1(A_k + t) \tag{3}$$

In this study, the weilbul distribution combined with the failure distribution is used. using the shape and scale parameters, which are indicated by the following equation, respectively.

$$h1 = \frac{\beta}{\alpha}\left(\frac{t}{\alpha}\right)^{\beta-1} \tag{4}$$

The model is created by calculating the equipment's maximum availability using journals (Khatab, Ait-Kadi, & Rezg, 2014). To define a value that will determine maintenance, the equipment dependability threshold is established. The time frame for doing maintenance tasks is k. The maximum bound for carrying out maintenance procedures is the reliability threshold value. Corrective and preventative maintenance actions each have a impact on the reliability threshold value.

The Tk th PM value represents the time value for performing maintenance tasks while taking into account maximum reliability. The failure distribution that is employed has an impact on Tk.

$$T_k = \eta\left[(\frac{A_k}{\eta})^{\varepsilon} - \frac{\ln(R_{th})}{B_k}\right]^{\frac{1}{\varepsilon}} - A_k \tag{5}$$

Preventive repair measures will be implemented when the equipment age exceed the specified Rth reliability level. Due to the influence of the decreased age and decreased degradation coefficients, the system hazard level is decreased to a specific value. While PM (preventive repair) is performed when the system approaches the reliability threshold, corrective maintenance is performed whenever the system fails. Expected duration of corrective and PM, shown by Tc and Tp, respectively. The system gets replaced by a new this after N cycles of preventive maintenance. Tr is used to represent duration. The best maintenance strategy involves determining the reliability threshold (Rth) and maintenance cycle that maximize availability. The following equation can be used to calculate the maximum availability value with the supplied reliability threshold value.

$$Av(N) = \frac{\sum_{k=1}^{N}\left(\int_0^{Tk} Rk(t)dt\right)}{(N-1)(Tc(1-Rth) + TpRth) + \sum_{k=1}^{N}\left(\int_0^{Tk} Rk(t)dt\right)} \tag{6}$$

Algorithm 1:
Step 1: determine the rth value and Compute solutions *Tk* of Equation (5).
Step 2: Use solutions in Step 1 to solve Equation (6)
Step 3: Based on Steps 1 & 2, choose *N* to maximise the function given by Equation (6),
Step 4: From results of Steps 1 & 2 together with the optimal number *N* from Step 3, compute *Tk (k* = 1, . . . , *N)*,

5. Numerical Example

The algorithm described above is implemented into a computer program using the Matlab programming language. The reliability threshold (Rth) will be determined by numerical testing using the equipment's data while considering for the maximum possible availability. The factor that influences is the period of time needed for maintenance. Corrective, preventive, and replacement maintenance are the three categories of maintenance time (Tc, Tp, Tr). The duration of time needed to complete maintenance is determined by maintenance technicians and existing performance data. To conduct numerical experiments, the following information is used :

Table 1. Collect data Journal

Notation	Data	unit
X	350	Scale Weilbull Distribution
Y	(1,5), (2,5)(3,5)	Shape Weilbull Distribution
δrp	10,50,100,500	Days
δrp	2	Days

experiment with numbers The purpose of my evaluation was to assess the research model's performance in establishing reliability thresholds and maintenance strategies with the highest possible availability. The value of cp is the ratio of corrective to preventive maintenance time. The time between the start of utilizing the equipment at time t=0 and the time the equipment executes a preventive replacement is known as the replacement period (rp) (t). ratio between replacement and preventive maintenance times. based on the formula that states that the availability value decreases as rp increases. Numerical experiments were conducted to change the ratio of cp to rp using the values of Tc, Tp, and Tr as determining factors.

Table 2. Result of numerical example

δ_{rp}	Rth = 95			Rth = 90			Rth = 85		
	Av	k^*	*Tk*	*Av*	k^*	*Tk*	*Av*	k^*	*Tk*
β = 1,5									
10	99.70	3	48.31	99.52	3	78.07	99.36	3	104.23
50	99.00	6	48.31	98.39	6	78.07	97.87	6	104.23
100	98.18	7	48.31	97.10	7	78.07	96.16	7	104.23
500	92.26	9	48.31	88.06	9	78.07	84.67	9	104.23
β = 2,5									
10	99.33	3	106.68	99.11	3	142.27	98.94	3	169.21
50	97.75	6	106.68	97.02	6	142.27	96.47	6	169.21
100	95.95	7	106.68	94.67	7	142.27	93.72	7	169.21
500	83.91	9	106.68	79.64	9	142.27	76.68	9	169.21
β= 3,5									
10	99.03	3	149.80	98.81	3	184	98.66	3	208.26
50	96.75	6	149.80	96.04	6	184	95.54	6	208.26
100	94.42	6	149.80	92.97	6	184	92.11	6	208.26
500	78.16	9	149.80	74.45	9	184	72.02	9	208.26

5. Results and Discussion

5.1 Numerical Experiment Analysis

Based on the table several things that can be analyzed as follows:

A preventive maintenance strategy that maximizes availability while following to defined reliability thresholds. The samples were selected by setting the parameters (,rp,Rth)= based on the outcomes of the numerical experiments that were performed (1,5,10,95). It demonstrates that, at a given reliability threshold, 95% of the equipment has a breakdown rate of 1.5 and that, if it were to be replaced every 50 days, the preventative repair time would be 3 and the maximum availability would be 99.70%.

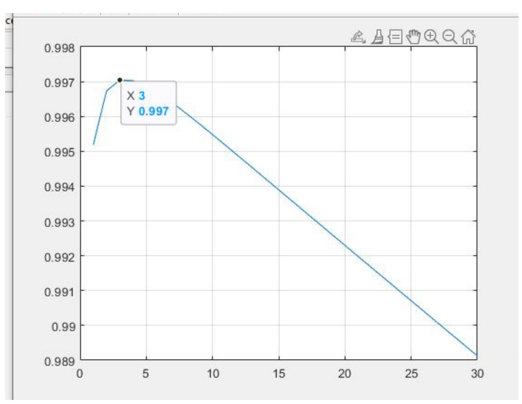

Figure 2. Maximize Availability

✓ Variation in the level of time to do preventive replacement.
The number of preventive repairs (k*) will be determined by the characteristics of the system being produced and the duration of preventive replacement (rp). Preventative repair actions are performed in increased frequency the more a preventive replacement action is already in place. The relationship between the variance of preventive replacement and preventive repair is shown in the following graph.

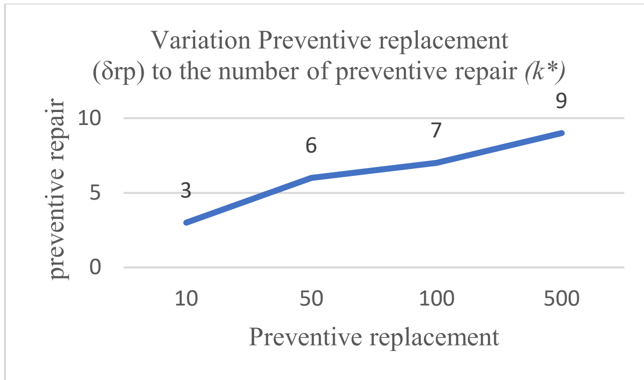

Figure 3. Variation Preventive replacement to the number of preventive repair

✓ Variation of Reliability Threshold to Availability
To maximize availability, the reliability threshold value is determined. The availability of equipment increases with an increase in the reliability threshold value, according to numerical testing results. The relationship between the variance in the reliability threshold and the availability value is shown in the following graph.

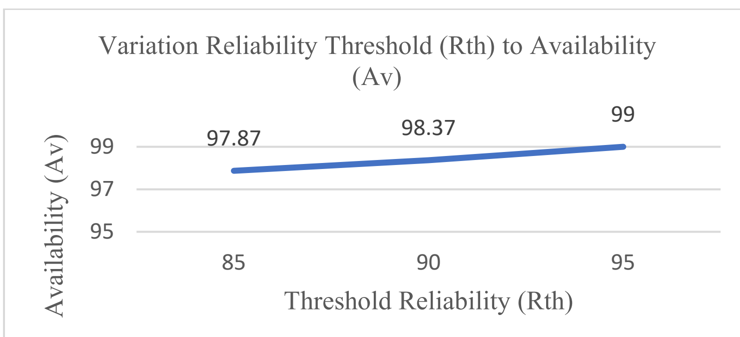

Figure 4. Variasi Reliability Threshold (Rth) to Availability (Av)

✓ Variation Shape Parameter on Availability
Based on the characteristics of the mathematical model, shape parameter variations will affect the availability value. The results of numerical studies indicate that the availability value decreases with increasing form parameter values. This illustrates how the value of equipment availability due to repair activities will be impacted by how quickly equipment gets damaged. The following graph displays the correlation between shape parameter values and availability values.

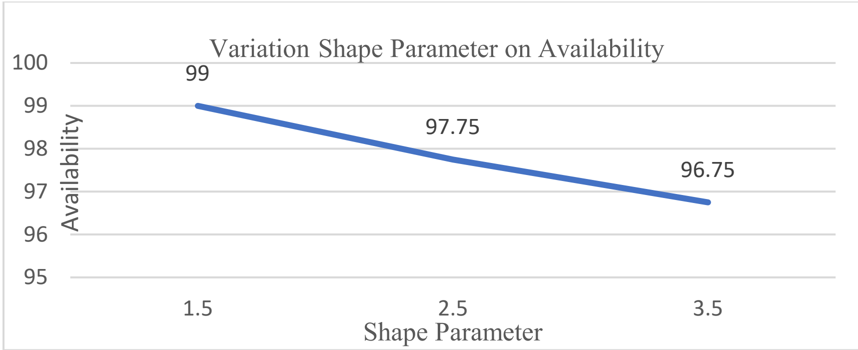

Figure 5. Variation Shape Parameter on Availability

6. Conclusion

1. A mathematical model of maintenance policy that maximizes equipment usage while also optimizing availability by taking the reliability threshold into account. The owner can assess the maintenance action plan implemented. Maintenance operations (preventative repair and preventive replacement) will have an impact on the size of the availability value. The following elements are used in the availability value modeling::
   - Threshold Reliability (*Rth*)
   - Period *Preventive Replacement* (δrp)
   - Period *Preventive Repair* (δcp)
2. The following findings are attained based on the outcomes of the numerical experiment of this study model:
   - The level of equipment availability decreases with the amount of time required for preventive replacement, or 10,50,100,500 (Days).
   - The maintenance time decreases as the specified reliability level, which ranges from 85% to 95%, increases.
   - There are more preventative repairs made and less availability of the equipment the higher the value of the failure rate of the rental equipment (shape parameter), particularly (1.5, 2.5, 3.5).

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