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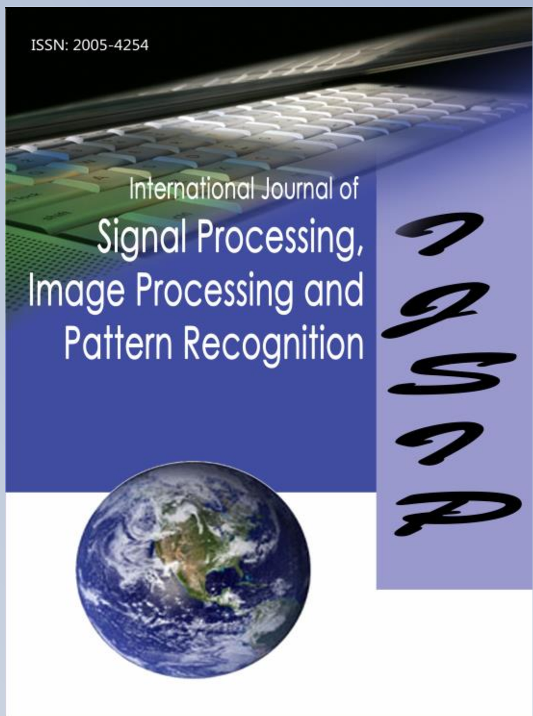

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Optimization of Time Delay based Preventive Maintenance using Markov Decision Process

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Abstract

In operating Indonesian Navy Vessels (KRI), users often find some indicators leading to the prediction that the system experiences a decline in performance or a breakdown, and requires repair at great expense. To support the reliability-based maintenance system, an analysis is required to determine the exact breakdown rate and the state of the system based on time delay. In time-delay-based maintenance, before experiencing a breakdown, the system will show a decline in performance. However, time-delay-based maintenance is difficult to apply in the field since it requires the appropriate data to form the model. In this study, time-delay-based maintenance is applied in combination with policy patterns in the operation and observation, using Markov Decision Process. By applying time-delay-based preventive policy, it can be concluded that the policy pattern 1, 2, and 3 in this study can minimize operational and maintenance expenses when KRI experiences a breakdown in general.

***Keywords**: Time delay; Preventive maintenance; Markov decision process; Reliability.*

1. Introduction

Some efforts to ensure the readiness of KRI are doing appropriate and optimal treatment, maintenance, and repair. They aim to maintain the reliability of KRI to function in accordance with operational needs. Currently, the Indonesian Navy (TNI-AL) applies Planned Maintenance System customized to the maintenance handbook by the manufacturer or Material General Guidance of the Indonesian Navy (TNI-AL PUM) of 1983. Nowadays, scientific development gives contribution to more accurate inspections of preventive maintenance. By taking advantage of operating experience and high maintenance, it is possible to establish reliability-based maintenance system. To support the operation of KRI using reliability-based maintenance system, analysis is required to determine the exact breakdown rate and the state of the system based on time delay. Several previous studies have widely discussed time-delay-based systems, such as Christer and Waller [1] and Das and Acharya [2], and accelerated pattern of breakdown, as modeled by Putro [3] using Accelerated Failure Time.

In time delay model, the difficulty lies in how to determine the estimated distribution of time delay h and the starting point u. Therefore, to facilitate the research, the object studied is considered new, despite having been repaired previously [4]. These difficulties are reasonable since time delay model is organized based on sufficient initial data. In the period u, the data is obtained from the registration of breakdown indicators, while the distribution model in the period h, with an assumption that the system is new, is obtained

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from the results of previous studies, collective data of identical systems, data from the manufacturer, or data from an institution providing a formal report to the public.

In Indonesia, the distribution of data in period h is difficult to obtain since the reliability model is not applied. Furthermore, it is also difficult to obtain data from the manufacturer since the manufacturer does not release the result of reliability test of a particular unit or system. The data from an agency such as IAEA (IAEA TECDOC-478.1998) cannot be applied directly as well since the states or circumstances (room temperature, humidity, and etc.) at the time of the testing are not necessarily similar to those in the field.

Considering the aforementioned obstacles, approaches with corresponding methods are required. One of the methods in the optimization of maintenance policy is Markov Decision Process. In this study, we present an optimization of time delay based preventive maintenance using Markov decision process. We further take an example of a system whose data correspond to time delay model. The data obtained is divided into several states and optimized with Markov Decision Process by considering breakdown and operational expenses. The results will be used as an input for consideration in decision making.

The rest of this paper is organized as follow: Section 2 describes fundamental concepts of time delay and Markov chain. Section 3 describes the proposed method. Section 4 describes the obtained results and following by discussion. Section 4 concludes this work.

2. Rudimentary

According to Levitt [5], maintenance is a treatment to keep or maintain the state of a system. It also means to make required adjustments or replacements to ensure the state is in accordance with the available operational planning. Generally, maintenance is a series of activities (both technical and administrative) needed to maintain and keep a product or a system in a safe, economical, efficient and optimal state. According to Antony [6] in his book *Maintenance Management Techniques* translated by Hadi [7], in terms of time of execution, maintenance is categorized into planned and unplanned maintenance. Planned maintenance is performed to anticipate any breakdown to the equipment in the future. Planned maintenance is a scheduled one. It tends to be passive and only resolves problems on a regular basis, but sometimes it can be reactive. Unplanned maintenance is performed after a system experiences a breakdown and is intended to restore the system to its functional state.

According to Ebeling [8], reliability can be defined as the probability of a system whose performance and function are in accordance with the requirements at a certain period of time. The correlation can be illustrated mathematically by determining a continuous random variable T stating the time of system breakdown ($T \geq 0$). The probability of occurrence of breakdown when $T<t$ is expressed by $F(t)$, with the Cumulative Distribution Function (CDF), is as follows:

$$F(t) = P\,\{T \leq t\} = \int_0^t f(t)dt \quad (1)$$

The function of reliability is expressed in the following equation:

$$R(t) = 1 - P\,\{T \leq t\} = 1 - F(t) \quad (2)$$

In analyzing system reliability, the term Mean Time to Failure (MTTF) is often used to characterize the reliability. The MTTF is expressed in the following equation:

$$MTTF = \mu = \int_0^\infty tf(t)dt \quad (3)$$

How easy an item experiences a breakdown and lasts up to time *t*, known as the rate of breakdown, can be expressed in the following equation:

$$r(t) = \frac{f(t)}{R(t)} \quad (4)$$

In analyzing system reliability, it is quite important to identify one of the functions of *r*(*t*), *R*(*t*), or *f*(*t*). By identifying one of the functions, the other two functions can be determined.

2.1. Time Delay

Maintenance with the time delay analysis was first introduced in 1973 by Christer and Wang [9] and Wang [10-12]. It continues to develop to be applied in many industries [13-15]. Time delay model appears based on the observation that a component does not experience a sudden breakdown [16-17]. It is different with the probability concept of breakdown rate, where the breakdown can be measured by the amount of damage to the components per unit time in an experiment. In time delay model, the breakdown is measured based on the initial data when the breakdown occurs, then the probability of total system breakdown is identified and modeled. Therefore, the probability/possibility of the extent to which the system can still function is obtained.

Before a component is damaged, there will be some indicators showing a decline in performance. In the time delay model, the breakdown is divided into two stages: the identification at the point u and the occurrence at the point *t* with time delay of *h*. In time delay model, the difficulty lies in how to determine the estimated distribution of time delay *h* and the starting point *u* (See Figure 1). Therefore, to facilitate the research, the research object is considered new despite having been repaired previously [4].

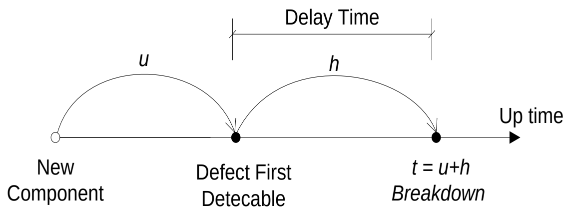

Figure 1. Time Delay Model

It is expected that maintenance or examination to identify and prevent any breakdown is performed during the time span *h*. This concept is proven useful to help a modeling of the effects of periodic examination on the rate of system breakdown. For example, abnormality is found in the first identification (point-*u*), initial time at the point *u* has the form of

PDF - *G*(*u*) and *CDF* - *G*(*u*).

Meanwhile the delay time h has the form of

PDF - *f*(*h*) and *CDF* - *F*(*h*)

and is independent towards u, where $u + h \leq t$. Therefore, the probability of occurrence of breakdown is expressed by $P(t)$, with Cumulative Distribution Function (CDF) as follows:

$$P(t) = \int_0^t g(u)F(t-u)du \quad (5)$$

Therefore, the reliability function is expressed in the following equation:

$$R(t) = 1 - P(t) \quad (6)$$

2.2. Markov Chain

Some analytical techniques can be used to evaluate the reliability of a system [18-25]. Although these techniques can be applied either to the repairable and non-repairable components, they assume that the repair process is performed quickly or in a relatively short time than the operating time of the component [26-31]. In other words, these techniques do not take time to repair into consideration in the evaluation of system reliability. It is not applicable for all systems. Generally, non-electric systems have an opposite character of the aforementioned assumption. Therefore, a technique capable of including time to repair into the evaluation process of system reliability is required. A technique capable of accommodating time to repair into the evaluation of system reliability is Markov Model [32-35]. Markov process is a stochastic process where the past has no influence on the future if the present is known [36-39]. There are several requirements so that Markov method can be applied in the evaluation of the system reliability. These requirements are:

- The character of the system should be lack of memory, where the future state of the system is not affected by the previous state (independent).
- The system should be stationery or homogeneous, meaning that the system behavior is always the same all the time. The state is identifiable. The possible states on the system should be clearly identifiable as 100% success or failure.

Generally, Markov Chain can be classified into Discrete and Continuous Markov Chains. Markov chain is discrete when the displacement of a situation occurs with fixed discrete time interval. Markov Chain is continuous if the displacement of a situation occurs with a time span with continuous random variables.

3. Proposed Method

The continuous changing rate of breakdown that cannot be predicted will affect system reliability and eventually affect the schedule of system maintenance and operation. In this study, we observe time-delay-based system maintenance to obtain optimum results from several alternative policies using Markov Decision Process (See Figure 2).

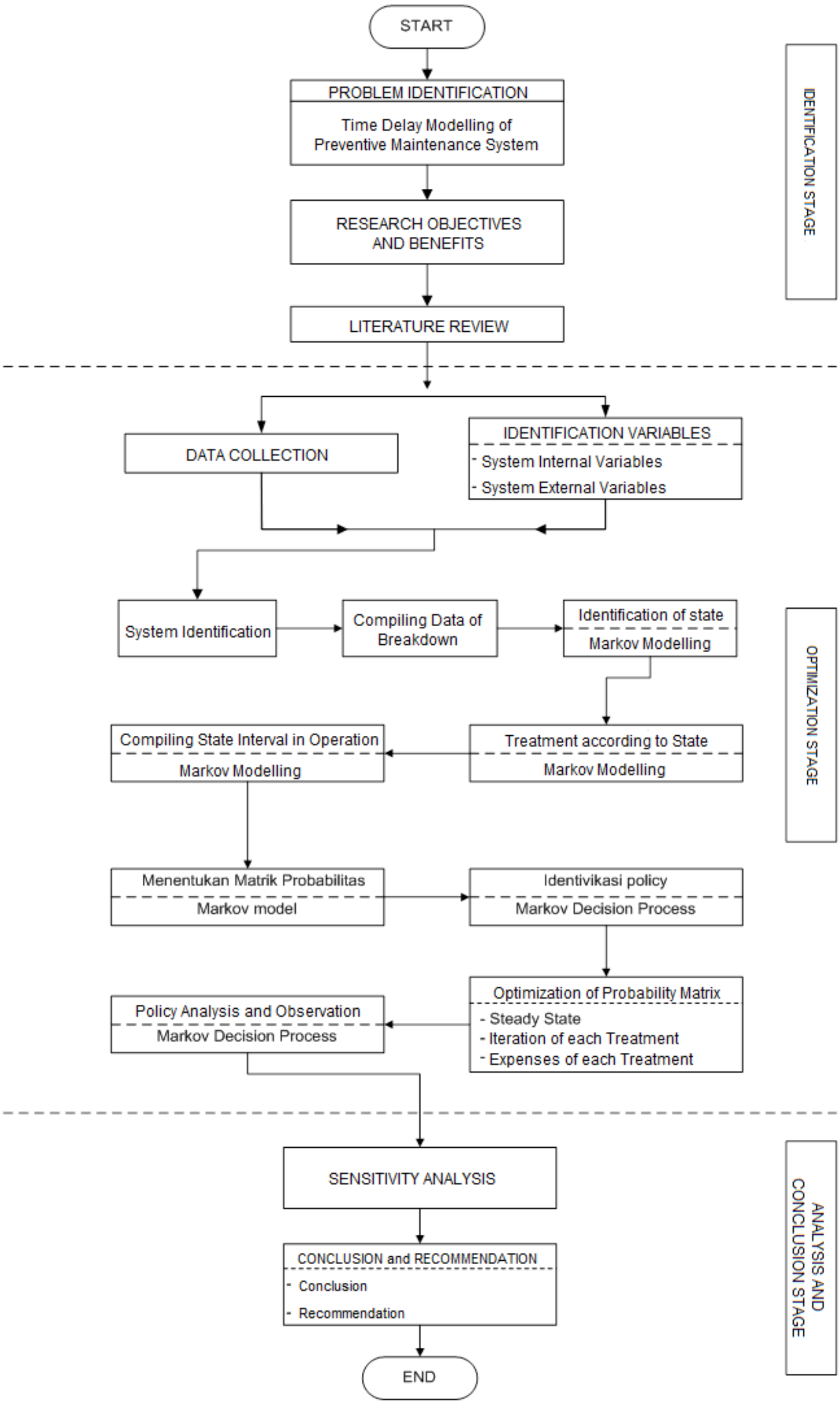

Figure 2. Flow Chart of the Study

4. Result and Discussion

The operational expenses in this study are the operational supporting expense for 78 personnel and the fuel expense during 5 days operation and 2 days of restock at the nearest base. The Author assumes that the fuel consumption is calculated in the event of change of 10-20%, the speed of the engine of 800 rpm, and the operation pattern of 1 week. The state during the operation (See Figure 3) is classified into:

- State 0. A state where the total operational expense in 7 days is IDR 1,243,389,000.

- State 1. A state where the change is 10% and the operational expense in 7 days is IDR 1,437,597,000.
- State 2. A state where the change is 20% and the operational expense in 7 days is IDR 1,908,429,000.
- State 3. A state where the system is unusable and the operational expense in 7 days is IDR 2,256,802,000.

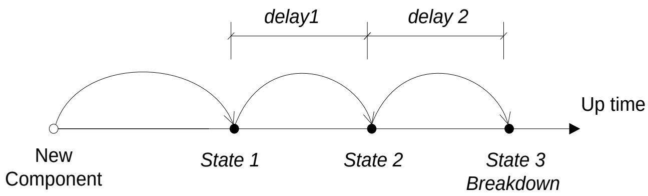

Figure 3. Classification of State

The treatment of maintenance is classified into:

- Treatment A. No treatment (no change in state). Therefore, no maintenance expense.Treatment B. A treatment of small maintenance at a cost of IDR 32,557,172.91.
- Treatment C. A treatment of large maintenance at a cost of IDR 194,753,425.32.

Table 1. Treatment and State

No	OPERATIONAL HOUR		STATE			TREATMENT
	JP	INTERVAL	1	2	3	
1	679	679	1	-	-	A
2	1017	338	1	-	-	A
3	1030	13	1	-	-	A
4	1342	312	-	1	-	A
5	1496	154	1	-	-	A
6	1520	24	-	-	1	C
7	1534	14	1	-	-	A
8	1576	42	-	1	-	B
9	1910	334	-	-	1	C
10	3010	1100	-	-	1	C
11	3613	603	1	-	-	A
12	4220	607	-	-	1	C
13	4962	742	-	-	1	C
14	5776	814	-	1	-	A
15	6210	434	1	-	-	A
16	7274	1064	-	1	-	A
17	8370	1096	-	-	1	C
18	8720	350	1	-	-	A
19	8925	205	-	1	-	A

From the aforementioned data of treatment and state, it is required to make an interval to approach the next state in accordance with Markovian nature. From the data of JP, the system is divided into interval of 1 week or 7 days × 24 hours = 168 hours. The total activities according to the data obtained are 54 weeks. The matrix of probability is obtained based on the treatment and interval. The results are as follows:

- Treatment A.

State	0	1	2	3
0	0.667	0.128	0.077	0.128
1	0.500	0.125	0.250	0.125
2	0.667	0.333	0	0
3	0	0	0	1

- Treatment B.

State	0	1	2	3
0	1	0	0	0
1	1	0	0	0
2	1	0	0	0
3	0	0	0	1

- Treatment C.

State	0	1	2	3
0	1	0	0	0
1	1	0	0	0
2	1	0	0	0
3	0.833	0.167	0	0

In decision making, the possibilities of available policies are inventoried, among others:

a. At state 0, no maintenance / treatment *A* (normal operation).

b. Treatment *C* (heavy maintenance) is only for maintenance at state 3. State 3 cannot apply treatments *A* and *B.*

The table for possible policy is as follows:

Table 2. Policy

Policy	State			
	0	1	2	3
I	A	A	A	C
II	A	A	B	C
III	A	B	A	C
IV	A	B	B	C

From the iteration of each policy (see Figure 4), the operational expense is as follows:

- Policy I IDR 1,455,612,321.43
- Policy II IDR 1,450,404,067.93
- Policy III IDR 1,421,312,993.49
- Policy IV IDR 1,422,239,798.89

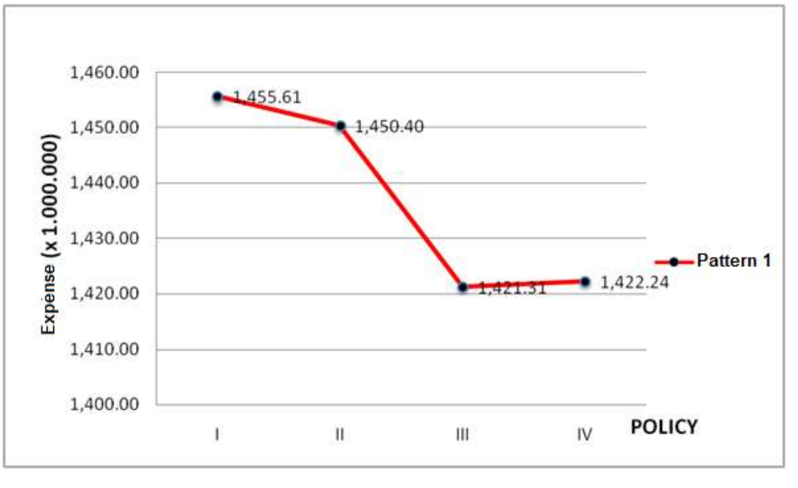

Figure 4. The Expense Chart for each Policy and Operation

The data processing indicates the active role of the crew in the recognition and identification of system breakdown. The system showing indicators of breakdown can be repaired and maintained immediately. As for the operating budget management, it requires some alternative decisions to support the decision, if a KRI cannot carry out its duties in accordance with the operational plan. Therefore, some alternative pattern of policies capable of supporting the implementation of the operation is required. The alternative policies of those 4 policies include:

a. Policy Pattern 1. It is similar to the initial policy, meaning that if KRI conducting the operation is damaged, there must be a substitute imported from the home base in Surabaya.
b. Policy Pattern 2. It is required if the damaged KRI cannot operate and does not get a substitute to continue securing the operational area.
c. Policy Pattern 3. It is required if there are 2 similar KRIs operating alternately with 1 week interval.

The correlation of each policy and the operational expense in each policy pattern is as follows:

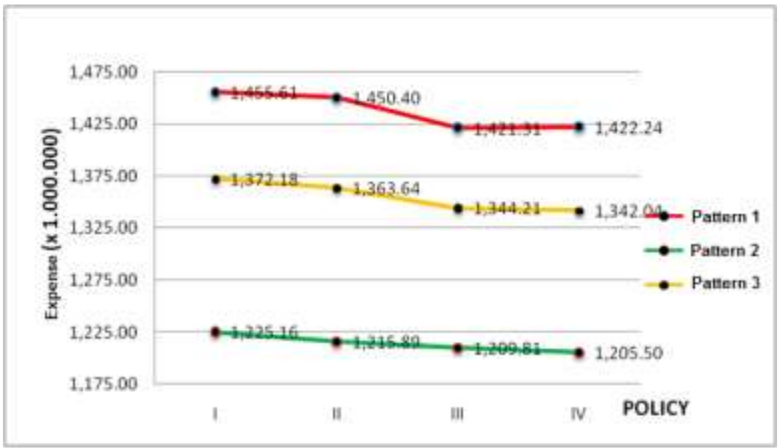

Figure 5. Optimization of each Policy

5. Conclusion and Recommendation

The observation of several policies shows that different treatments towards each state lead to different operational and maintenance expense for KRI. The conclusion is as follows:

a. As shown in Figure 5, implementing time-delay-based maintenance system in the operation of KRI in general can minimize operational and maintenance expenses when KRI experiences breakdown. Policy pattern 1, 2 and 3 are almost identical. Policy pattern 2 and 3 show gradual decline from policy I to policy IV. Therefore, the lowest expense at policy pattern 2 and 3 is for each policy IV, namely service/maintenance with treatment B in state 1 and state 2, as well as treatment C in state 3. The lowest expense at policy pattern 1 is policy III that is actually almost similar to policy IV, as in the probability of treatment B where state 1 and state 2 will be like in the new state (state 0) and a success rate of 100%. In this case, the system will never or unlikely experience any breakdown to the state 2 and 3.
b. In general, policy pattern 2 has the lowest operating expense, meaning that if 1 (one) KRI cannot operate; there will be no substitute to secure the operational area/region. If there is no urgency to secure the operational region/area as well as there is limitation of operational and maintenance expenses, policy pattern 2 can be considered to be applied.

To improve the research findings of this study, the author offers recommendations as follows:

a. This study does not determine the probability of breakdown between the time intervals of breakdown. Thus, there is a need for further research on time-delay-based maintenance and operating systems using the Markov method.
b. If time-delay-based reliability is applied for the Indonesian Navy in particular, there is a need for researches on a similar system to obtain the rate of breakdown in the period h. If it is applied using the data from the manufacturer or standardization agency, there is a need for tolerance in the parameter distribution.

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