Optimal Maintenance Policy for Fishing Vessel Equipment Using Delay Time Analysis

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Abstract

Delay time analysis is a pragmatic mathematical concept readily embraced by engineers which has been developed as a means to model maintenance decision problem. This paper considers an inspection period using delay time analysis for fishing vessel equipment. We assume that delay time distribution is Weibull and inspections are perfect. In this paper, we determine the optimal inspection period which minimize the expected downtime per unit time.

Keywords. Delay time, Downtime, Optimal maintenance policy, Weibull distribution

1. Introduction

The preventive maintenance(PM) is maintenance activities performed before equipment failure. PM activity involves the repair, replacement and maintenance of equipment in order to avoid unexpected failure during use. The optimal PM can reduce production down time, or cost of failure, has been recognised by industry. The term "optimum" means "minimizing the expected cost rate per unit time or the expected down time per unit time".

There are many situation where the availability of the equipment is more important than the cost of maintenance. Indeed, the consequences of the downtime of equipment may exceed any measurable cost. In such cases, it is more appropriate to minimize the downtime per unit time than to minimize the expected cost rate per unit time. This paper considers the optimal inspection period which minimizes the expected downtime per unit time.

Delay time analysis is a pragmatic mathematical concept readily embraced by engineers which has been developed as a means to model maintenance decision problem. A number of maintenance policy using the delay time analysis have been proposed in the literature. These policies are typically to determine the optimum interval to minimize the average cost or expected downtime. Christer et al(1998) describe a subjective data based case study carried out at a company manufacturing copper products. On the basis of the data analysis and delay time modelling, improved PM policy and procedures were proposed to increase the effectiveness and efficiency of PM. Christer(1999) reviews the cumulative knowledge and experience of delay time modelling. Leung and Kit-leung(1996) investigate the possibility of improving the effectiveness of the maintenance policy for the gearboxes.

Operating and failure data that has been gathered from a fishing vessel is used to apply the delay time analysis. However, the fishing industry seems to lack reliable statistical data and sensor based monitoring of equipment is almost non-existence. Hence, the modelling of PM for fishing vessel equipment is a very difficult task.

In this paper, we consider an inspection period using delay time analysis for fishing vessel equipment. If inspection period T is small, the downtime per unit time would be

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large because the system would frequently be unavailable due to inspection, and if T is large, the downtime per unit time would be that under a breakdown maintenance policy.

This paper considers the situation where each inspection is a perfect and delay time distribution is Weibull. The expression to compute the expected downtime per unit time is derived. We also obtain the optimal inspection period T^* which minimizes the expected downtime per unit time.

Section 2 describes the assumptions and concept of delay time model. In Section 3, we present the expressions for the expected downtime per unit time using delay time analysis. Section 4 presents the solutions for the optimal inspection period for fishing vessel equipment when the delay time follows a Weibull distribution.

2. Delay Time Maintenance Model

2.1 Assumptions

1. An inspection takes place every T time units and requires d time units.
2. Inspections are perfect in that any defect present will be identified.
3. Defects identified will be repaired within the inspection period.
4. Defects arise at constant rate λ per unit time.
5. The probability density function for delay time of faults $f(h)$ is independent of the initial point u.
6. Failures are repaired immediately with downtime d_b.

2.2 Delay Time Concept

The interaction between maintenance concept and equipment performance may be captured using the delay time concept. Let the system be maintained on a breakdown basis. The time history of failure events is a random series of points.

Before a component breaks down, there will be telltale signs of reduced performance or abnormalities. The time between the first identification of abnormalities(initial point) and actual failure time(failure point) will vary depending on the deterioration rate of the component. This time period is called the delay time of the defect.

h

Figure 1. The delay time of a defect

Figure 1 shows the delay time for a defect. Had an inspection taken place at point (A), one defect could have been identified and the seven failures reduced to 6. Likewise, had inspection taken place at point (B) and (A), 4 defects could have been identified and the failures reduced to 3. Figure 1 demonstrated that provided it is possible to model the way defects arise, that is the rate of arrival of defects $\lambda(u)$, and their associated delay time h, then the delay time concept can capture the relationship between inspection frequency and the number of system failure.

3. Expected Downtime Per Unit Time

This section determines expected downtime per unit time to be incurred while operating an inspection policy of period T. To derive the expected downtime per unit time, we first consider the probability $b(T)$ that a fault arising causes a breakdown given inspection period T.

Following the argument of Christer and Waller(1984), we suppose that a fault arising within the period $(0, T)$ has a delay time in the interval $(h, h + \Delta h)$, the probability of this event being $f(h)\Delta h$. This fault will be repaired as a breakdown repair if the fault arises in the period $(0, T - h)$; otherwise as an inspection repair as shown Figure 2.

Assuming that the process of faults arising follows a homogeneous Poisson process, that is, uniformly distributed, the probability of a fault arising before $(T - h)$, given that a fault will arise, is equal to $(T-h)/T$. It has been calculated that a fault is repaired as a breakdown and has delay time in $(h, h + \Delta h)$ is given by

$$(T - h) \times f(h) \times \Delta h/T$$

Summing up all possible values of h, we can obtain the probability of a fault arising as a breakdown $b(T)$ as follows.

$$b(T) = \frac{1}{T}\int_0^T (T - h)f(h)dh \tag{1}$$

The expected downtime per unit time to be incurred while operating an inspection policy of period T is obtained by

$$D(T) = \frac{Total\ downtime}{Cycle\ length}.$$

Therefore,

$$D(T) = \frac{d + \lambda T b(T) d_b}{T + d}, \tag{2}$$

where d, d_b and λ are the downtime owing to an inspection, average downtime for breakdown repair and arrival rate of defects per unit time, respectively.

Figure 2. Breakdown and inspection repair

The optimal inspection period T^* is the corresponding value of T such that expected downtime $D(T)$ is minimized.

4. Optimal Inspection Period for Fishing Vessel Equipment

The application of the delay time concept is demonstrated for a hydraulic winch operating system on a fishing vessel. The following information was gathered for this particular system, which included a combination of logged records and reports complemented by expert judgement.

Inspection down time (d)=0.0416days

Downtime for breakdown repair (d_b)=4.5days

Total operating hours of winch(for 25 voyages)=56days

Arrival rate of defects (λ)=0.535days

Suppose that the delay time has a Weibull distribution, i.e., $f(h) = \alpha\beta^\alpha h^{\alpha-1}e^{-(h\beta)^\alpha}$ for all $h \geq 0$, where $\beta > 0$ and $\alpha > 0$ are the scale and shape parameters, respectively.

By using the equation (2) and above data, the expected downtime per unit time is given by

$$D(T) = \frac{0.0416 + 0.535T\left(\frac{1}{T}\int_0^T (T-h)\alpha\beta^\alpha h^{\alpha-1}e^{-(h\beta)^\alpha}dh\right)4.5}{T + 0.0416} \tag{3}$$

From the graph in Figure 3, the optimal inspection period, T^*, is determined to be 0.3788days when $\alpha = 3$ and $\beta = 1$. This inspection frequency will cause a minimum down time of 0.127978days.

Figure 3. Optimal inspection period based on minimum $D(T)$

Table 1 lists the values of T^* and its resulting expected downtime per unit time $D(T^*)$ for various choice of α when $\beta = 1$. The optimal period T^* is determined so that the expected downtime per unit time is minimized for the given values of α and β. Table 1 shows that as the value of α increases, the values of T^* increase, which is anticipated. On the contrary, the values of $D(T^*)$ decrease.

Table 1. Optimal inspection period T^* and its expected downtime per unit time $D(T^*)$ with $\beta = 1$.

α	T^*	$D(T^*)$	α	T^*	$D(T^*)$
0.5	0.08856	0.610929	3	0.3788	0.127978
1	0.1575	0.351344	4	0.4563	0.102452
2	0.2806	0.182864	5	0.5177	0.0880512

Table 2. Optimal inspection period T^* and its expected downtime $D(T^*)$ with $\alpha = 3$, $\beta = 1$ and $d_b = 1$.

d	T^*	$D(T^*)$	d	T^*	$D(T^*)$
0.01	0.3973	0.0325893	0.30	0.9508	0.309456
0.05	0.5943	0.102019	0.50	1.1098	0.399751
0.10	0.7102	0.161461	0.70	1.2619	0.46352
0.20	0.8506	0.246794	0.90	1.4558	0.511241

Table 2 lists the values of T^* and its resulting expected downtime per unit time $D(T^*)$ for various choice of d when $\alpha = 3$, $\beta = 1$ and $d_b = 1$. Table 2 presents that as the inspection down time increases to downtime for breakdown repair, the value of T^* and $D(T^*)$ are increase.

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