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An integration of multi-criteria decision making techniques with a delay time model for determination of inspection intervals for marine machinery systems

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ABSTRACT

For certain critical equipment items in marine machinery systems, the optimum maintenance strategy would be a scheduled on-condition operation. This involves inspection of the equipment items in order to monitor their performance degradation and, invariably, carry out repair or replacement tasks. The main challenge with this type of maintenance approach is the determination of the appropriate interval for performing the inspection task. This paper presents a methodology which integrates multi-criteria decision making (MCDM) tools with a delay time model for the determination of optimum inspection intervals for marine machinery systems. With this approach, multiple decision criteria are modelled with the delay time concept and aggregated with MCDM tools such that different criteria can be applied simultaneously in the ranking of different inspection interval alternatives. The applicability of the proposed methodology is demonstrated using the case study of a water cooling pump of the central cooling system of a marine diesel engine.

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1. Introduction

The need for effective maintenance cannot be over-emphasized, especially in the marine industry where equipment failure can result in severe and potentially irreversible damage to personnel, equipment and the environment. Having an effective maintenance scheme in place can eliminate or reduce accidents on ocean going vessels used for the movement of global commodities. This will result in an increase in vessel availability, reduced downtime and, invariably, improved company productivity.

Maintenance is defined as a combination of activities to retain a component in, or restore it to, a state in which it can perform its designated functions [12]. These activities generally involve repairs and replacement of equipment items of a system that may either be performed based on the condition of the system or based on a definite time interval. Basically there are three types of maintenance; (1) corrective maintenance, (2) preventive maintenance and (3) condition based maintenance.

In the condition based maintenance methodology there are basically two approaches for monitoring the condition of an item of equipment or component; continuous and periodic. For the continuous monitoring type, the condition of equipment is continuously monitored using some form of measurement and/or diagnostic tools. The challenge of this approach is that it is quite expensive and on this basis many maintenance practitioners prefer the periodic monitoring technique which is more cost effective. However the major difficulty in the periodic monitoring approach is in the timing of the inspection interval of the condition monitoring activity because of the possibility of failures occurring between inspections [18]. In the course of monitoring the state of an item, if a defect is found a repair or replacement task is scheduled and if possible it is executed immediately in order to prevent the equipment from further deterioration. If inspections are not carried out then slowly developing defects will go unnoticed and can lead to catastrophic system failure with severe economic loss for the company. However even if inspection tasks are performed, if they are not properly timed then defects can still occur between successive inspections. It is thus obvious that the determination of the optimal inspection interval is central to the effective operational monitoring of

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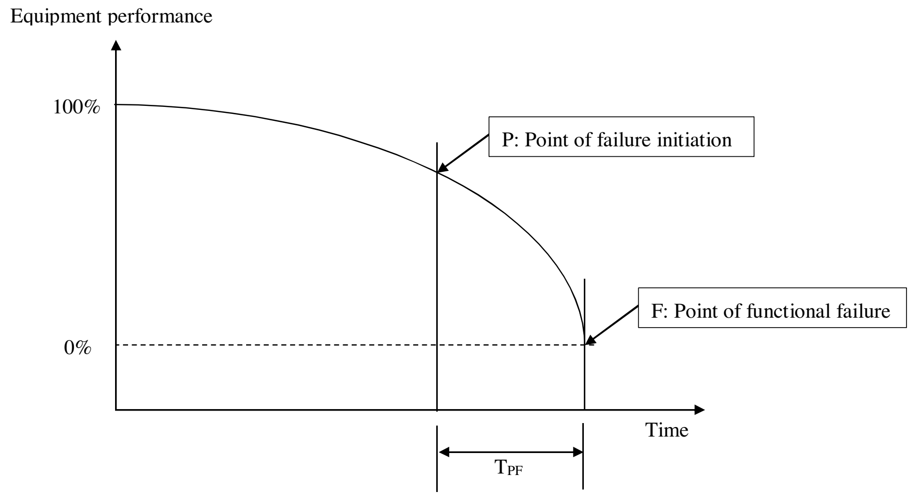

Fig. 1. P-F interval [27].

any mechanical system. In conventional practice, the inspection interval is determined by maintenance practitioners relying on experience and/or on the equipment manufacturers' recommendation and the results from this approach are far from optimal and also conservative [9].

Inspection tasks, as a maintenance approach for an equipment item, can only be beneficial if there is a sufficient period between the time that a potential defect is observed and the actual time of failure of the equipment. Hence the time that elapses between the point of failure initiation and the point when the failure becomes obvious is vital in estimating the inspection interval. This phenomenon is referred to as the P-F interval within the classical Reliability Centered Maintenance (RCM) frame work and is illustrated in Fig. 1. [22] Moubray defined RCM as "*a process used to determine what must be done to ensure that any physical asset continues to function in order to fulfil its intended functions in its present operating context*." Different maintenance strategies such as corrective maintenance, scheduled overhaul, scheduled replacement and scheduled on-condition task are integrated in achieving this goal.

In Fig. 1, point P is the point of failure initiation, F is the point where the actual failure occurs. The time that elapses between points P and F is referred to as the P-F interval (T_{PF}). In classical RCM, the P-F interval principle is applied in determining the frequency of the condition monitoring of equipment and it was suggested that an inspection interval (T) be set at $T \leq T_{PF}/2$ Arthur, 2005. The author however stated that one major challenge of the use of the P-F approach is that there is usually no data to evaluate the P-F interval (T_{PF}) and in most cases the evaluation is based on experts' opinion. [22] Moubray on the other hand, suggested five ways of determining the inspection interval based on P-F but the author concluded that: "*it is either impossible, impractical or too expensive to try to determine P-F intervals on an empirical basis*".

Apart from the use of the P-F approach, the delay time concept has been employed by many authors in the field of maintenance engineering in the modelling of inspection intervals [30]. The introduction of this concept can be traced to Christer [6]. The delay time categorises the failure process of machinery into two phases; the first phase is the time period from when the machinery is new to the time that it starts showing signs of some degradation. The second phase is the time period from when it starts showing some sign of performance degradation to the time when the machinery eventually fails. The elapsed time between when the machinery first shows signs of performance degradation and when it eventually fails is referred to as the delay time. The delay time concept is illustrated in Fig. 2.

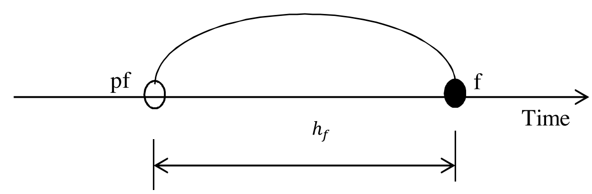

Fig. 2. The Delay Time concept (pf- Point of failure initiation, f- point of functional failure, h_f −delay time).

In Fig. 2, h_f represents the delay time; pf represents the time of the initial machinery performance degradation and f represents the time that the machinery eventually failed. The most appropriate time to perform a maintenance inspection is within the machinery delay time and if it is performed then, the fault will be detected and if the necessary preventive maintenance, such as repair or replacement of the machinery, is executed failure will be averted. However if inspection is not carried out then the machinery degradation will continue until failure occurs at point f.

From the above, it is obvious that the Delay Time concept introduced by Christer is the same as the P-F interval principle described within the framework of the classical RCM. However the major difference is that each approach uses a different mathematical model in the evaluation of the time that elapses between the point of failure initiation and the point when the failure becomes obvious. For the delay time concept, as proposed by Christer, a statistical distribution, such as a Weibull or an exponential distribution was utilised, while the subjective technique was applied in determining the P-F interval within the framework of the classical RCM. Additionally, in the delay time approach a different mathematical modelling technique was used in the determination of optimal inspection intervals.

Christer and Waller [7] applied the delay time concept in the development of two inspection maintenance models for determining the inspection frequency for a complex industrial system. Two different models; cost function and downtime function, were constructed with the assumption that inspection is perfect. The cost function model shows the relationship between the inspection interval and the cost for performing inspection at that particular time while the downtime function model shows the relationship between inspection interval and the resulting downtime for performing an inspection at that particular time. The study was further extended by introducing a model to cater for imperfect inspection.

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