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Assessing maintenance contracts when preventive maintenance is outsourced

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ABSTRACT

In some companies, corrective maintenance is conducted in-house but preventive maintenance might be outsourced. This raises a need to optimise some parameters such as the number of contracts from a perspective of the equipment owner. This paper considers a maintenance policy for such a situation, analyses the roles of the parameters in a PM model, proposes approaches to defining bonus functions, and finally discusses special cases of both the PM policy and the bonus function. Numerical examples are also given to explore the impact of parameters on the expected lifecycle cost rate.

1. Introduction

The issues of the optimum strategies of maintenance outsourcing have been studied by a number of authors [1–13]. Existing research has been focused on either outsourcing both preventive maintenance (PM) and corrective maintenance (CM) or outsourcing CM only. Little attention, however, has been paid to the problem of outsourcing PM, which is discussed in this paper.

1.1. Prior work

In the literature, the types of maintenance outsourcing that have been studied so far include: Type-1 outsourcing: outsourcing both CM and PM [1–9], and Type-2 outsourcing: outsourcing CM only [10–13].

Type-1 outsourcing: Both CM and PM are outsourced. PM policies in the context of outsourcing both PM and CM have been discussed by a number of authors (see [1–6], for example). [7,8] use incentive contracts to induce the contractor to select the maintenance policy that optimises the total profit of the manufacturer and the contractor. In addition to the consideration of CM and PM, [9] considers inspection policies and optimises the contract parameter under different scenarios.

Type-2 outsourcing: Only CM is outsourced. Assuming that a sequence of CM contracts will be made to maintain a piece of equipment and that the service market can provide different kinds of CM contracts to the equipment owner,[1] [10,11] propose methods for determining the optimal series of CM contracts for the equipment's lifetime. [12,13] present decision models for selecting CM contracts based on multi-criteria decision making theory, taking into account different variables such as cost and downtime.

Existing work can be categorised with Table 1.

1.2. Problems

In practice, however, there is a possibility that only PM is outsourced but CM is conducted in house. This has been reported from time to time, for example, in [14] where a case about outsourcing PM on power cables is presented.

When outsourcing PM, one might consider the following two options:

Option 1: PM on a piece of equipment will be outsourced to one agent within the lifecycle of the equipment;
Option 2: PM on a piece of equipment will be outsourced to a number of agents within the lifecycle of the equipment and the quality of PM actions conducted within a contract period can be different.

Remarks on Option 2: Most companies periodically review (common periodicity is 3–5 years) their maintenance procedures,

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[1] In this paper, we call the provider of maintenance service as an *agent*, and the recipient of the maintenance service as an *equipment owner*.

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Table 1
A summary of some existing papers.

Type of outsourcing	Type of penalty[a]	Decision variables	References
PM & CM	Penalty-1 & Penalty-2	PM policy	[1–3]
PM & CM	Penalty-1 or Penalty-2	PM policy or else	[4–6,9]
CM	Penalty-1	CM contracts	[10–13]

[a] Penalty-1: penalty for repair not being carried out within specified time limits; Penalty-2: penalty for equipment failures.

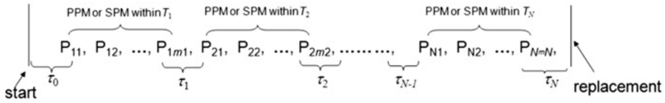

Fig. 1. A PM model (T_k, the length of the k-th contract, PPM (periodic PM), SPM (sequential PM), P_{ki}, the i-th PM action in the k-th contract).

and make contracts with agents within these periods. The maintenance levels can be different from period to period [15]. If we assume that a PM contract starts from a PM action and also ends with a PM action, there can exist a time interval between two adjacent contracts and in this interval no agent is contracted. Hence, this option will have a time line containing a series events such as (also see Fig. 1): *a new piece of equipment to start* $\rightarrow \tau_0 \rightarrow T_1 \rightarrow \tau_1 \rightarrow T_2 \rightarrow \tau_2 \rightarrow \cdots \rightarrow \tau_{N-1} \rightarrow T_N \rightarrow \tau_N \rightarrow$ *replacement*, where τ_k $(k=0,1,2,\ldots)$ is the time interval between the end of the k-th contract and the start of the $(k+1)$-th contract, and T_k represents the length of the kth contract. Within different T_k, different agents are contracted to undertake PM. Any failures between PM actions are rectified by the equipment owner himself, but a penalty might be incurred on the failures to the agents. The quality of the last PM conducted by an agent in his contract period can be vitally important, as it can affect the remaining life of the equipment being maintained and therefore affect the optimum choice of maintenance schedules within its subsequent periods. That is, a piece of equipment maintained with good quality of the last PM conducted in a contract period might need fewer PM actions within its remaining lifetime and also fewer failures might occur, whereas a piece of equipment maintained with poor PM quality within a contract period might need more PM actions within its remaining lifetime and more failures might occur. Hence, good quality of the last PM in each contract period can be regarded as a profit to the owner as he will pay less on maintenance within the remaining lifetime of the equipment. In such a case, the owner of the equipment might be willing to pay a bonus to agents for encouraging good PM quality.

As one can see in the following sections, mathematically, Option 1 is a special case of Option 2. Hence, this paper will only discuss Option 2.

Compared to the first three variables listed in Table 1, Option 2 differs from existing research in the following respects:

Type of outsourcing: only PM is outsourced;
Type of penalty: different penalty schemes can be used:

- The quality of the last PM will be assessed and a bonus might be paid for good quality; and
- Penalty for repair not being carried out within specified time limits is not applicable here, as the agent does not undertake any CM upon equipment failures.

Decision variables: the objective is to seek the optimum series of PM contracts with respect to the length T_i of a contract, the time interval τ_i between two adjacent contracts, Penalty-2 and bonus schemes.

Hence, if a series of agents are contracted with the equipment owner, it is possible to introduce a new penalty scheme, as shown in the following:

- failures between PMs can incur Penalty-2 to the agents due to the reliability performance specified in the maintenance contract being violated; and
- a bonus can be offered to the agent if the quality of the last PM in a contract is good.

It should be noted that [7,8] have already used the concept of bonus functions to encourage good maintenance quality in the context of maintenance outsourcing. In [7,8], however, both PM and CM are outsourced, which makes it different from the cases discussed in this paper.

This paper discusses PM policies used in Option 2. The equipment owner outsources PM within fixed periods, in which periodic or sequential PM's might be conducted. He might pay bonus to agents for their good PM quality. The paper investigates the roles of the parameters in a typical PM model, proposes approaches to defining the bonus functions, derives an algorithm to optimise the expected lifecycle cost rate, and discusses special cases of both the PM policy and the bonus function.

The paper considers optimising policies from a perspective of the equipment owner and assumes that costs on CM, PM, and replacement, and the levels of PM are known. This assumption might be rigorous for some cases as some values such as the levels of PM might only be determined by the agents, and unknown to the equipment owner. However, from a perspective of the equipment owner, he needs to assess the optimum values, including contract length, time intervals between adjacent contracts, penalty and bonus, respectively. Hence, such assumptions are necessary.

The rest of the paper is structured as follows. Section 2 presents notation and assumptions. Section 3 derives the lifecycle cost rate, investigates the roles of the parameters in a typical PM model, proposes approaches to defining the bonus on PM actions, derives an algorithm to search the optimal solution, and compares two special PM policies. Section 4 presents data examples to look into the validity of the proposed models. Section 5 concludes the findings.

2. Notation and assumptions

2.1. Notation

The notation is given in Table 2.

2.2. Assumptions

A typical lifecycle of the equipment under study is shown in Fig. 1. Suppose the following assumptions hold.

A.1 The planning horizon is infinite.
A.2 The failure intensity function, $h_{0,0}(t)$, of the equipment before any maintenance intervention is conducted is continuous and strictly increasing.
A.3 The lifecycle of the equipment is defined as the time interval between two adjacent replacements. That is, the time in a lifecycle progresses as: *a new piece of equipment to start* $\rightarrow \tau_0 \rightarrow T_1 \rightarrow \tau_1 \rightarrow T_2 \rightarrow \tau_2 \rightarrow \cdots \rightarrow \tau_{N-1} \rightarrow T_N \rightarrow \tau_N \rightarrow$ *replacement*. T_k is called a the k-th *contract period*. For simplicity, we assume that $T_k = T$ in this paper.
A.4 Within the k-th contract period, m_k PM actions are conducted at time points $(k-1)T + \sum_{i=0}^{k-1} \tau_i + t_{k,1}$,