

Cost Estimation for Maintenance Contracts for Complex Asset/Equipment

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Abstract - Maintenance contracts are becoming more and more popular to the owners of complex and critical items as maintenance through contracts reduces upfront investments in infrastructure, expertise and specialised maintenance facilities. In recent years, maintenance contracts have received significant attention due to increased profits for the service providers and reduction of risk for owners through expert services provided by the service providers. To make maintenance contracts more effective, there is a need to develop mathematical models and understand future costs that could be built into the contract price. In this paper, a conceptual model is developed for estimating cost of outsourcing maintenance of complex and critical asset/equipment taking into account both corrective and preventive maintenance as servicing strategies.

Keywords – Maintenance Contract, Rectification, Cost Model

I. INTRODUCTION

A maintenance contract is the outsourcing of maintenance actions where defects/failures are rectified by an external agent for an agreed period of time. The agent (service provider) in turns charges a price for such service. The service providers can be one of their asset operators or manufacturers of the asset or independent third parties, interested in investing for asset infrastructures.

For expensive and complex assets/equipment (e.g. power generation plants, rail networks used by large industries such as Mining, Jute, Sugarcane, and Steel plants for transportation of material over wide geographically distant areas etc), the maintenance services need to have expertise and specialised facilities. Often it is found to be expensive for the owner of such asset/equipment to have well built infrastructure, specialised maintenance facilities and specialists in house. Outsourcing maintenance service reduces upfront investments in infrastructure, expertise and specialised maintenance facilities [1]. This has resulted in a growing trend for the owners of asset intensive industries to outsource the management of maintenance activities of their complex assets to external agencies. As a result, maintenance contracts have become a billion dollars annual business [2]. Typically, at least half of that goes into the service provider's pocket as profit, with less than 20% spent on the repair or replacement of products. There is a great need for cost estimation of maintenance contracts in

order to balance the service provider's profit and the owner's total costs to make maintenance contracts more effective. This can be achieved through the development of mathematical models for understanding future costs to be built into the contract price. Failure to do so may result in loss to the service provider or the user/owner because of uncertainties associated with system failures and their implication on business.

Estimation of costs for such contracts is complex and it is important to both the user and the service provider for economic viability. These costs depend on the reliability of the asset/equipment and the maintenance strategies (e.g. corrective maintenance, planned preventive maintenance, and/or inspection procedures) to be considered during the contract period. Maintenance strategy can be developed by understanding the reliability. Failure data are in many cases time or usage dependent for certain conditions. In a probabilistic sense, asset/system failures are functions of usage and/or age.

Only a few cost models for maintenance contracts have been proposed by academic researchers in recent years. Blischke and Murthy (2000) proposed a policy for service contracts with scope for negotiation. Murthy and Yeung (1995) proposed stochastic models for expected profit. Murthy and Ashgarizadeh (1995) developed a model to characterise the optimal strategies for a single customer and single service provider. Ashgarizadeh and Murthy (2000) extended this to multiple customers. Rinsaka and Sandoh (2006) proposed a mathematical model for setting suitable charge of service contract in the case where a manufacturer offers an additional warranty service under which the failed system is replaced by a new one for its first failure, but minimal repairs are carried out to the system for its succeeding failures before the contract expires. Unfortunately, all these models considered corrective maintenance (CM) only (rectification only on failure) as maintenance strategy and they ignored planned preventive maintenance (PM) actions during the contract. This type of contract is dangerous in cases such as maintenance contracts for the rail industry. If a derailment occurs due to rail break/failure, it will not only cause a loss of billion dollars but it will also cause loss of valuable lives or serious injuries to survivors. Inclusion of preventive maintenance in maintenance strategies may prevent this type of accidents in most of the cases, since a planned preventive maintenance can prolong the reliability of the asset/equipment through proper inspection and on - time maintenance. Therefore,

for real life situations, servicing strategies for repairable systems should involve both corrective maintenance (CM) and planned preventive maintenance (PM).

In this paper, a conceptual cost model for repairable complex asset/equipment is developed to estimate the costs for maintenance contracts taking into account both corrective and planned preventive maintenance as service strategies over the contract period. The outline of this paper is: in Section I, an introduction of maintenance contract is provided. Section II discusses different potential servicing strategies to be considered during the contract period. In section III, a cost model for service contracts is formulated. In the final section, a summary and contribution of this paper, and scope for future work are discussed.

II. VARIOUS SERVICING STRATEGIES

Maintenance strategies for repairable systems involve both corrective maintenance (CM) and planned preventive maintenance (PM). Corrective maintenances are unscheduled actions intended to restore the system/asset to its operational state through corrective actions after occurrence of failures (defects). In contrast, planned preventive maintenance actions are carried out to reduce the likelihood of failures or to prolong the reliability of the asset/equipment and/or to reduce the risk of failures (Murthy and Jack, 2003).

Both CM and PM take into account different types of servicing actions which can be used based on the failure mode and type. These actions are classified as per degree of restorability as shown in Figure 1.

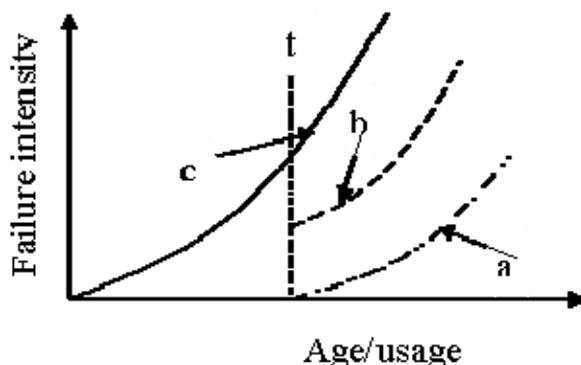


Fig 1: Failure rate with effect of various maintenance actions (Chattopadhyay and Rahman, 2004)

The asset/equipment is considered to fail at point t due to the malfunctioning of one or more components. And various servicing actions can be adopted at this point to restore the functionality of the asset/equipment. The probable servicing strategies applicable for maintenance are:

- (i) *Replacement*: the failed system can be replaced with a new identical system or with a used but good one. This turns failure rate of the item to zero if replaced with new one (see curve 'a' in Figure 1). This implies that a replacement with new and identical system restores the full reliability and turned failure rate to zero. If replaced with used, good system, it restores the part reliability and the failure rate falls to any point between 'as good as new' and 'as bad as old' depending on the age and usage condition of the replaced item/system.
- (ii) *Overhauling or perfect repair* is a restorative maintenance action that enables the system to be "as good as new" condition as it turns failure rate close to zero (See curve 'a' or close to curve 'a').
- (iii) *Imperfect repair* restores a substantial portion and like replacement with used, good item, the failure rate falls in between "as good as new" and "as bad as old" (see curve 'b') depending on the type and quality of the repair works.
- (iv) *A minimal repair* is the repair/replacement of only the failed component/s and other components of the item/system remain untouched. This makes insignificant improvement of reliability and the condition after maintenance is called "as bad as old" (curve 'c' in), since the failure rate of other components remain unchanged (Barlow and Hunter, 1960).

III. ESTIMATING COST OF MAINTENANCE CONTRACT

This Section demonstrates the development of a conceptual cost model considering a simple maintenance contract policy in which, *the contract terminates when contract period reaches a time or usage level L*. The contract includes provision for corrective maintenance - rectification on failure as well as constant interval preventive maintenance actions to prolong the system reliability. This can be presented graphically by the Fig 2. Preventive maintenance actions are carried out at constant interval x , each PM restores the reliability of the asset to some extent. Between two successive preventive maintenances there could be one or more minimal corrective actions.

The following assumptions are made for model simplification purpose

- Failure rate increases with time /usage
- All corrective rectifications other than replacement are minimal repairs.
- Preventive maintenance actions are taken at constant interval (x)
- PM restores life to some extent.
- The level of restoration depends on the type and quality of the maintenance performed.
- Age restoration after each preventive maintenance (PM) is constant.

- All cost factors are constant over the contract period.

Total cost of contract over the contract period L can be expressed as

$$C_T = C_m + C_i + C_r + p \quad (1)$$

Where,

- C_T : Total cost of maintenance contract
- C_m : Cost of maintenance over the contract
- C_i : Inspection cost
- C_r : Cost of risk associated with accident
- p : Penalty Costs for not conforming to the contract and failure to meet agreed safety, reliability and availability standards.

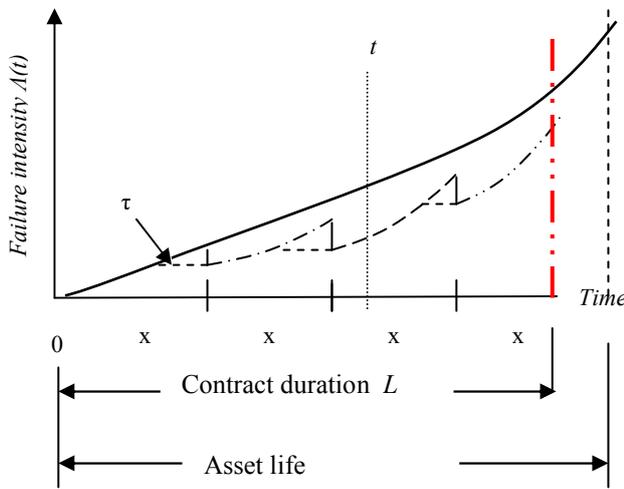


Fig. 2. Graphical representation of the service contract Policy model 1

A. Estimating Maintenance Cost (C_m)

Expected total cost of maintenance service
 = (Expected total cost of all minimal corrective repairs over the contract
 + Expected cost of preventive maintenances over the contract L) $/(1+r)^n$

Where, r is the discount rate over the period n and $n = 1, 2, 3,$

Expected cost of minimal repair

$$C_{mr} \sum_{k=0}^{N+1} \int_{kx}^{(k+1)x} \Lambda(t - k\tau) dt \quad (2)$$

Expected cost of preventive maintenance during the contract

$$N C_{pm} \quad (3)$$

The total expected maintenance cost C_m can therefore be expressed as

$$C_m = \left[C_{mr} \sum_{k=0}^{N+1} \int_{kx}^{(k+1)x} \Lambda(t - k\tau) dt + N C_{pm} \right] / (1+r)^n \quad (4)$$

Where, failure intensity $\Lambda_{pm}(t) = \Lambda(t - k\tau)$

$\Lambda_{pm}(t)$: failure rate at time t , with maintenance.

$\Lambda(t)$: original failure rate at time t when no maintenance is performed.

N : number of times maintenance is performed (including replacement).

x : fixed time interval of maintenance.

k : k th PM, $k = 1, 2, 3, \dots$

τ : restoration out of maintenance action.

$\tau = \alpha x$ here, α is the quality of the maintenance

B. Estimating Inspection Cost (C_i)

Total inspection cost (C_i) over the contract can be given by

$$C_i = \left\{ \sum_{j=0}^{N_i} c_i / (1+r_i)^j \right\} \times r / \left\{ 1 - \left(\frac{1}{(1+r)^n} \right) \right\} \quad (5)$$

Where,

$$N_i = \text{Integer} \left[\frac{L}{I_f} \right]$$

N_i is the expected number of inspection during the contract, and r_i is the discounting rate associated with inspection interval. I_f is the inspection interval and r is the annual discount rate.

C. Estimating Risk Costs (C_r)

The risk cost associated with system failure and accident is based on the probability of inspection detecting potential failures and failures not being detected by inspection, accident and associated costs. This can be expressed as

$$C_R = \frac{\sum_{n=0}^L E[N(t_n, t_{n+1})] * [P_n(B) * b + (1 - P_n(B)) * (P_n(A) * a)]}{(1+r)^n} \quad (6)$$

Where,

a is the expected cost per accident;

b is the expected cost of repairing potential failure based on NDT

$P_n(B)$ is the probability of detecting potential failure using NDT,

$P_n(A)$ is the probability of undetected potential failure leading to accident during the interval between n th and $(n+1)$ th periods

$E[N(t_{n+1}, t_n)]$ is the expected number of failure over the interval of n th and $n+1$ th year.

D. Total cost of maintenance contract and the Service providers premium charge (C_T)

Therefore, the expected total cost of contract can be obtained by adding all the above costs. The service providers can charge a premium for such service by adding a profit with the total cost of servicing divided by the contract period (number of years/months or usage in thousands hours or Million gross tonnes). This can be expressed by

Total cost of maintenance contract:

$$C_T = \left[C_{mr} \left(\sum_{k=0}^{N+1} \int_{kx}^{(k+1)x} \Lambda(t - k\tau) dt \right) + C_{pm} N_i \right] / (1+r)^n + \left\{ \sum_{j=1}^{N_i} c_i / (1+r_i)^j \right\} \times r / \left\{ 1 - \left(\frac{1}{(1+r)^n} \right) \right\} + \frac{\sum_{n=0}^N E[N(t_{n+1}, t_n)] * [P_n(B) * b + (1 - P_n(B)) * (P_n(A) * a)]}{(1+r)^n} + p \tag{7}$$

Service provider’s premium charge per unit time can be expressed by

$$P_c = \frac{C_T + P}{L} \tag{8}$$

where, L is the contract period of the Asset and P is the total profit marked up by the service provider.

These equations can be solved by using Mathematical softwares such as MATLAB, MAPLE when data is available.

IV. CONCLUSION

Maintenance contracts are generally the most economical method for servicing or maintaining highly technical, scientific or complex asset/equipment because of the nature of the asset/equipment and the need to keep its downtime to a minimum. Complex and expensive asset/equipments are normally best maintained or serviced by original equipment manufacturers (OEM) or by authorized service organizations or third party experts interested in investing in infrastructure.

Estimation of costs for maintenance contracts is a complex process and is important for both the user/owners and the service providers for economic viability [9]. Owners may pay a larger sum of money

than actual maintenance costs. Alternatively, the service providers may be required to spend an excess amount of money because of the unreliable system performance. This situation occurs when the reliability of the asset or equipment and/or the maintenance cost parameters have not been modeled properly.

In this paper conceptual cost models for maintenance contract and the service provider’s premium charge for complex repairable item are proposed which takes into account both corrective maintenance in the form of minimal repairs and planned preventive maintenances as servicing strategies throughout the contract period.

These models can be applied to outsourcing maintenance service for repairable systems. These models can be further extended by including provisions for used items, and utility functions for linking owner/agent’s risk preferences and more complex models could be developed linking downtime.

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