Modelling Total Cost of Ownership of Rail Infrastructure for Outsourcing Maintenance Services

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Modelling Total Cost of Ownership of Rail Infrastructure for Outsourcing Maintenance Services

ABSTRACT

In the recent years, outsourcing maintenance services has become a part of the strategy for cost and risk management. Outsourcing reduces upfront investments in infrastructure, expertise and specialised maintenance facilities. However, decision on this need to take into account the total cost of ownership rather than the usual practice of procurement cost. The primary objective of this paper is to develop models for prediction of total cost of ownership and estimation of contract price for outsourcing maintenance services of rail infrastructure. Total cost of ownership model is developed considering procurement, maintenance, inspection and risks associated with operation of rail network. Contract price for outsourcing services is modelled considering million gross tonnes of traffic under specific design, operation and maintenance conditions.

Keywords: Total cost of ownership, outsourcing services, rail infrastructure

1.0 Introduction

Rail networks play an important role for transportation of material over wide geographically distant areas. It is expensive and complex for industries to install and mange complex and capital intensive assets (Murthy and Ashgarizadeh, 1995). Outsourcing reduces upfront investments in infrastructure, expertise and specialised maintenance facilities. There is a trend from asset/ infrastructure focussed approach in decision making to service focussed approach. In determining the worthy of outsourcing services, one need to analyse each case based on costs and benefits. Total cost of ownership (TCO) aims to understand the cost of acquisition, operation, and maintenance. Estimation of this cost is complex. There is a need to develop mathematical models for understanding future costs to build it into the contract price. Failure to do so may result in loss to the service provider or the user because of uncertainties associated with reliability, availability, maintainability, safety and security (RAMSS) and their implication on business. For Heavy haul Rail operation usage can be modelled as a function of tonnage accumulation in Million Gross Tones (MGT) for certain design, operating and maintenance conditions.

This paper is on development of total cost of ownership model and contract price for outsourcing services out of rail infrastructure. The outline of the paper is as follows: in Section 2, total cost of ownership is discussed. Section 3 deals with the development of mathematical models for total cost of ownership and contract price for outsourcing services of rail infrastructures. In final section, the summaries and scope for future work are discussed.

2.0 Total Cost of Ownership

From its origins in defence equipment procurement in the US in early 1960s, the use of total cost of ownership has extended to other areas of the public and private sectors (Kumar et al, 2006). It can be used to assist in budgeting, cost control, and range of other activities including maintenance, leasing and replacement decisions of complex assets. It covers acquisition (purchase or lease), operation, and maintenance and support costs, Kumar et al(2004). Following elements are major components of this model:

- *Capital costs*:
- *The discount rate*:
- *Operating and maintenance costs*:
- *Disposal cost*:
- *Life of the asset*:

  The useful lifetime of an asset can be defined as the lifetime of the asset and assumed to be terminated in some finite, random time horizon. Termination of this type of life can also results from the technological obsolescence, ownership change, technical or commercial reasons. The estimated life (Chattopadhyay and Rahman, 2008) of an asset can be as follows:
  - Technical life/ Physical life – the period over which the asset might be expected to last physically (up to the period when replacement or major rehabilitation is physically required).
  - Technological life – the period until technological obsolescence dictating replacement due to the development of technologically superior alternatives.
  - Commercial life/ Economic life – the period, over which the need for the asset exists, the period until economic obsolescence dictates replacement with an economic alternative.
  - Ownership life – the period until the owner desires or legal ownership is retained or replacement change of ownership occurs.

3.0 Total Cost of Ownership for Rail

Cost of acquisition, maintenance services, inspection to detect the potential rail breaks, risks associated with derailment, and cost of disposal at the end of the lifecycle of rail are considered in this proposed model and given by C_{TW}

$$C_{TW} = C_A + C_S + C_I + C_R + D$$

Where,

C_{TW} : Total cost of ownership
C_A: Cost of procurement or acquisition
C_S: Cost of maintenance over the lifecycle
C_I: Inspection cost
C_R: Cost of risk associated with accident due to derailment

D: Cost of disposal of the discarded rail. Sometimes this disposal cost could be an earning from the sell of the scrapes/discarded asset.

3.1 Modelling costs of maintenance over the lifecycle

Rail infrastructure maintainers use both Corrective maintenance (CM) by cutting damaged or broken rails and welding and Preventive maintenance (PM) by lubrication and rail grinding. These strategies are classified as per degree of restorability of the rail as shown in Figure 1.

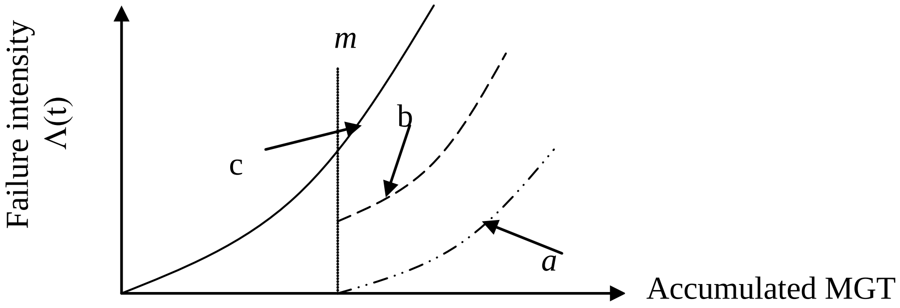


Figure 1: Failure rate with effect of various maintenance actions (Rahman and Chattopadhyay, 2004)

Rail servicing strategies are:

1. *Replacement*: Replacing the whole rail turns failure rate of the segment to zero if replaced with new one (see curve '*a*' in Figure 1).
2. *Imperfect repair:* Rail grinding and lubrication are the examples of this type of servicing strategy. This strategy is normally used in case of planned preventive maintenance. It can restore only a substantial portion and the hazard/failure rate after this action falls in between "as good as new" and "as bad as old (see curve 'b' in Figure 1).
3. *A minimal repair:* a replacement or repair of the damaged or broken portion of the rail is one of the examples of minimal repair. The condition of rail after maintenance is "as bad as old" (curve 'c' in).

Modelling rail failure:

Rail failure/ rail break is modelled as a point process with an intensity function $\Lambda(m)$ where m represents Millions of Gross Tonnes (MGT) and $\Lambda(m)$ is an increasing function of m indicating that the number of failures in a statistical sense increases with MGT (Rahman and Chattopadhyay, 2010). Older rails with higher cumulative MGT passed through the section is expected to have more probability of initiating defects and if undetected then through further passing of traffic can lead to failures. As a result, the number of incidents till accumulated MGT becomes a function of usage MGT, m, and is a random variable and can be modelled using an intensity function $\Lambda(m)$ (Chattopadhyay et al, 2005). Let cumulative MGT of rail, m, be known and $F(m)$ and $f(m)$denote the cumulative rail failure distribution and density function respectively,
These can be modelled as:

$$F\ (m) = 1 - \exp(-(\lambda m)^{\beta}) \qquad (1)$$

and

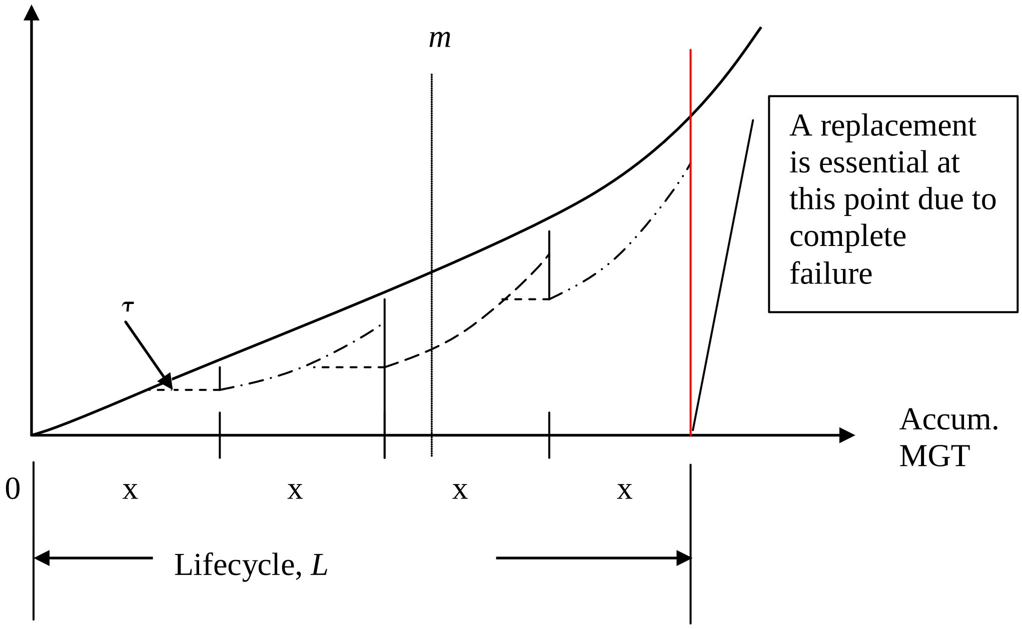
$$f(m) = \lambda\beta(\lambda m)^{\beta-1}\exp(-(\lambda m)^{\beta}) \qquad (2)$$

with the parameters β (Known as shape parameter of the distribution) > 0 and λ (Known as inverse of characteristic function for the distribution) > 0
β greater than 1 indicates an increasing failure rate of the item under study and ageing is predominant in failure mechanism.
Then the failure intensity function $\Lambda(m)$ derived from 1 and 2 can be given by

$$\Lambda(t) = \frac{f(m)}{1-F(m)} = \frac{\lambda\beta(\lambda m)^{\beta-1}\exp(-(\lambda m)^{\beta})}{1-(1-\exp(-(\lambda m)^{\beta})} = \lambda\beta(\lambda m)^{\beta-1} \qquad (3)$$

Rail maintenance services:

Figure 2 is the graphical representation rail maintenance strategy over the lifecycle of rail, with constant interval preventive maintenance action. Each PM improves the reliability of the rail. In between successive PMs, there may be a number of corrective maintenances.



A replacement is essential at this point due to complete failure

Figure 2: Graphical representation of maintenance service for rail

Expected total cost of maintenance service
= (Expected total cost of minimal repairs over the lifecycle
+ Expected cost of preventive maintenances over the designed lifecycle L)/(1+r)^{n}
Where, r is the discount rate over the period n and n =1, 2,3, ….

Expected total cost of all minimal repairs over the contract period can be given by

$$C_{mr}\sum_{k=0}^{N_i}\int_{kx}^{(k+1)x}\Lambda(m-k\tau)dm \qquad (4)$$

When failures are modelled as per NHPP then, the failure intensity can be given from Equation 3

$$\Lambda(m) = \lambda^{\beta} \beta m^{\beta - 1}$$

Therefore, the Equation 4 can be expressed as Equation 5 by substituting value of $\Lambda(m)$ and integrating

Expected cost of minimal repair

$$= C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^{\beta} x^{\beta} \left[(k - k\alpha + 1)^{\beta} - (k - k\alpha)^{\beta} \right] \right\} \tag{5}$$

where, $\tau = \alpha x$, where, α is the quality of PM .

Expected cost of preventive maintenance during the contract

$$= C_{pm} N_i \tag{6}$$

Therefore, the total expected maintenance cost (C_S) over the designed lifecycle can therefore be expressed by adding the Equations 5 & 6 as Equation 7

$$C_S = \left[C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^{\beta} x^{\beta} \left[(k - k\alpha + 1)^{\beta} - (k - k\alpha)^{\beta} \right] \right\} + C_{pm} N_i \right] \Big/ (1 + r)^n \tag{7}$$

Minimal total expected cost per unit time can be obtained by differentiating equation 7 with respect to *x* and equating to zero.

3.2 Modelling Inspection Cost

Discounted inspection cost over the lifecycle can be developed in line with Reddy et al (2007). Let I_f be the inspection interval in MGT and c_I be the mean cost of each inspection. Then the total inspection cost (C_I) over the rail life can be given by:

$$C_I = \{ \sum_{n=1}^{N} c_I / (1 + r\ )^n \} \tag{8}$$

where

$$N = Integer\, [\frac{M_N}{I_f}] \tag{9}$$

M_N is the total accumulated MGT for rail lifecycle up to end of period N and r is the discounting rate associated with the interval of Non Destructive Testing (NDT).

3.3. Modelling Risk Costs

Let *b* be the expected cost of repairing potential rail and *a* be the expected cost per derailment. Then *b* and *a* could be modelled in a similar manner. The risk cost associated with rail break and derailment is based on the probability of detecting potential rail breaks, rail breaks not being detected, derailments and associated costs.

Let $P_n(B)$ be the probability of detecting potential rail breaks, $P_n(A)$ be the probability of undetected potential rail breaks leading to derailments during the interval between nth and $(n+1)$th periods. Then the risk cost is given by:

$$C_R = \frac{\sum_{n=0}^{N} E[N(M_{n+1}, M_n)] \times \left[P_n(B) \times b + (1 - P_n(B)) \times (P_n(A) \times a\right]}{(1+r)^n} \tag{10}$$

Where,
$E[N(M_{n+1},M_n)]$ is the expected number of rail breaks on an emergency basis over the interval of MGTs M_n and M_{n+1}.

3.4 Total Cost of Ownership

The total cost of ownership is obtained by adding the components given by equations (7), (8) and (10) over the designed life of the asset. This can be expressed as

$$\mathrm{C}_{TW} = C_A + C_S + C_I + C_R + D$$

Or

$$\begin{aligned} \mathrm{C}_{TW} &= C_A + \\ &\left[C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^{\beta} x^{\beta} \left[(k - k\alpha + 1)^{\beta} - (k - k\alpha)^{\beta} \right] \right\} + C_{pm} N_i \right] \Big/ (1+r)^n{}_S \\ &+ \sum_{n=1}^{N} c_I / (1+r)^n \\ &+ \frac{\sum_{n=0}^{N} E[N(M_{n+1}, M_n)] \times \left[P_n(B) \times b + (1 - P_n(B)) \times (P_n(A) \times a\right]}{(1+r)^n} + D \end{aligned} \tag{11}$$

Where C_A is the procurement price of rail and D is the one-time earning of money by selling the discarded rail at the time of disposal.

The contract price for outsourcing rail maintenance service can be modelled by

$$P_c = \frac{C_{TW}}{L}$$

Where, L is the designed lifecycle of the rail in million gross tonnes (MGT) of traffic for particular axle load.

4. Contribution and Future Scope

This paper proposed a service based model for prediction of total cost of ownership for rail infrastructure and contract price for outsourcing services by freight line users. This model can be further extended by including provisions for penalty rates for not complying with maintenance standards and/or reducing availability, keeping provision for used items in rectifications/ re-railing, leasing and risk preferences of freight line users.

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