

MODEL FOR OUTSOURCING RAIL NETWORK ASSET USING LONG-TERM SERVICE CONTRACTS

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ABSTRACT

There is a growing trend for asset intensive industries to outsource maintenance services. Various industries such as mining, sugarcane, jute and steel plants outsource their rail assets using service contracts. Outsourcing reduces upfront investments in infrastructure, expertise and specialised maintenance facilities. The service providers for such service can be one of their rail operators or manufacturers of rail or third parties, interested in investment for rail infrastructure. Estimation of costs for these contracts is very complex and it is important to the user and the service providers for economic variability. The service provider's profit is influenced by many factors such as the terms of the contract, reliability of rails, the servicing strategies, costs of resources needed to carryout maintenance and to provide such services. 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 failures rectification and their implication on business. Three strategies for short-term and long-term service contracts are proposed in this paper considering the concepts of outsourcing assets to the service providers. Conceptual models are developed for estimating servicing costs to those contracts.

KEY WORDS

Service contract, Rail track, Maintenance, Outsourcing.

1. INTRODUCTION

Large industries such as mining, jute and sugarcane and steel plants need to use rail networks for transportation of material over wide geographically distant areas. There is a growing trend for these asset intensive industries to outsource these assets and maintenance services of their rail assets since it is expensive and complex for those non- railway industries to install and manage these huge network services. Outsourcing reduces upfront investments in infrastructure, expertise and specialised maintenance facilities (Murthy and Ashgarizadeh, 1995). The service providers for such asset can be one of their rail operators, manufacturers of rail or third parties, interested in investing for rail infrastructure. Estimation of costs for these contracts is very complex and it is also important to the users/owners and the service providers. 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 failures and their implication on business. These costs depend on the servicing strategies to be taken during the contract period. Servicing strategy can be developed by understanding the reliability and its analysis Failure data are in many cases time or usage dependent for

certain conditions. In a probabilistic sense, rail failure is a function of tonnage accumulation in Million Gross Tones (MGT) for certain conditions.

Conceptual models are developed to predict failure /break of rail and estimate costs for service contracts. The outline of this paper is: in Section 1 an introduction of outsourcing and service contracts are provided. Section 2 deals with the Rail failure and degradations and models for predicting failures. Service contracts together with various servicing strategies are discussed in Section 3. In section 4 cost models for long-term service contracts are proposed. In final section, the summaries and scope for future work are discussed.

2. MODELLING FAILURE OF RAIL TRACK

2.1. Rail Failure

Degradation or failure of rail track is a complex process and it depends on the rail materials, traffic density, speed curve radius, axle loads, Million Gross Tonnes (MGT), wheel rail contact, rail track geometries and importantly the servicing strategies. The rail profile and curves make large contributions to rail degradation. Traffic wear, rolling contact and plastic deformation are the growing problems for modern railways (Chattopadhyay et. al.(2003)). Modelling cost of outsourcing servicing need predictive models for rail degradation and failure.

2.2. Modelling Rail failure or Degradation

Rail defects start developing due to the steel, axle load, maintenance of rail and wheel and material fatigue due to traffic movement. Ageing takes place in the line due to tonnage accumulation on track resulting from traffic movement. It is realistic to assume that initiated defects left in the system will continue to grow with increase in cumulative MGT. Rail failures/breaks can be 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. That means 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 rail failures. As a result, the number of failures till an accumulated MGT is a function of usage MGT, m , and is a random variable and can be modelled using non-homogeneous Poisson process with 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,

$$F(m) = P\{m_1 \leq m\} \text{ where, } m_1 \text{ is the MGT to rail failure.} \quad (1)$$

Here we have,

$$f(m) = dF(m)/dm \quad (2)$$

This can be modelled as:

$$F(m) = 1 - \exp(-(\lambda m)^\beta) \quad (3)$$

and

$$f(m) = \lambda \beta (\lambda m)^{\beta-1} \exp(-(\lambda m)^\beta) \quad (4)$$

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

$$\Lambda(t) = \frac{f(m)}{1 - F(m)} = \frac{\lambda\beta(\lambda m)^{\beta-1} \exp(-(\lambda m)^\beta)}{1 - (1 - \exp(-(\lambda m)^\beta))} = \lambda\beta(\lambda m)^{\beta-1} \quad (5)$$

Rail track is normally made operational through repair or rectification of the failed segment and no action is taken with regards to the remaining length of the rail in case of detected defects and rail breaks. Since the length of failed segment replaced at each failure is very small relative to the whole track, the rectification action having negligible impact on the failure rate of the track as a whole, Barlow and Hunter (1960). Based on these rail failure/break models, in the following sections we discuss the potential servicing strategies and cost models for those service contracts.

3.0. SERVICING STRATEGIES UNDER CONTRACT PERIOD

A service contract is the outsourcing of maintenance actions where item/system failures are rectified by an external agent for an agreed period of time. The agent in turn charges a price for such service. The agent's profit is influenced by many factors, such as item/system reliability and servicing strategies to be taken during the period, and the policies of the contract. Blischke and Murthy (2000) proposed a policy for service contract with scope for negotiation. In the recent years service contract has received significant attention due to increased profit through selling those services and reduction of risk from owners due to better maintainability provided by the experts in the trade. 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 service provider. Ashgarizadeh and Murthy (2000) extended this to multiple customers. Their models considered corrective maintenance (CM) only that implies rectification only on failure. They ignored to include planned preventive maintenance (PM) actions during the contract. But the repairable systems like rail network need corrective maintenance in case of failure, as well as preventive maintenance to retain the reliability and reduce the risk of failures. In case of rail network, both Corrective maintenance (CM) and Preventive maintenance (PM) take into account different types of servicing strategies which can be used based on the failure mode and type. These strategies are classified as per degree of restorability of the rail as shown in Figure 1.

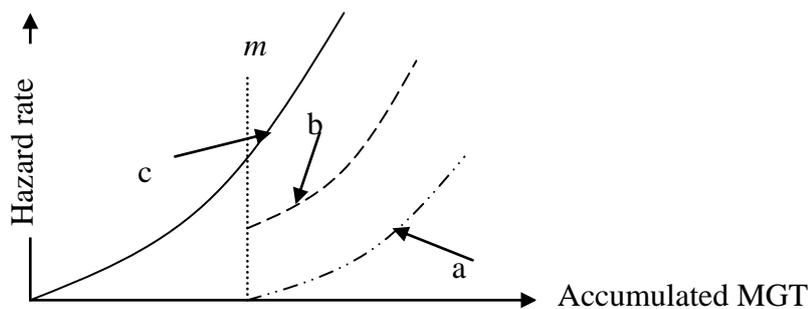


Figure 1: Failure rate with effect of various maintenance actions (Rahman and Chattopadhyay, 2005)

Rail servicing strategies are:

1. *Replacement*: a replacement of the segment is made when the segment is totally failed or out of service. Replacing the whole segment turns failure rate of the segment to origin if replaced with new one (see curve 'a' in Figure 1). This implies that a replacement of segment restores the full reliability and turned hazard rate to zero for that segment.
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 segment is one of the examples of minimal repair for rail. It makes insignificant improvement of the segment and the condition after maintenance is “as bad as old” (curve ‘c’ in), since the hazard rate of other portion remain unchanged.

4.0. MODELLING COSTS OF SERVICE CONTRACT

Total costs of service contract may include the cost of planned preventive maintenance and corrective maintenance in the form of minimal repairs and failure replacement, cost of inspections and condition monitoring, cost of risks, and penalties for failure to meet agreed safety, reliability and availability of requirements.

Therefore,

The total expected costs of service contract

$$C_T = C_s + C_i + C_d + C_r + C_p$$

Where,

C_s = total expected costs of maintenance services

C_i = expected costs of inspection

C_d = costs of downtime

C_r = cost of risks associated

C_p = penalties for failure to meet contract agreements.

In this paper, we are aiming to develop conceptual cost models for service contracts that focussing only on the maintenance services during the contract period. These models can be further extended by adding inspection, downtime, risks associated with such contracts and incurred penalties due to failure to meet contract agreement

In modelling cost of service contracts, we propose three different policies where rectification of rails takes into account both corrective maintenance and planned preventive maintenance. The corrective maintenance could be replacement of whole segment in case of complete failure of the rail or a minimal repair of a part of the segment. Preventive maintenance actions are done at constant intervals which retains the rail reliability to some extent. Three service contract policies are:

Service contract policy 1: Under this policy, the rail life is considered longer than the contracted period (MGT) and the contract period L is prefixed. The contract will be terminated when the contract time reaches L or complete failure of the segment which comes first. In this case no replacement is necessary during the contract period which implies that $R > L$. where L and R are the contract period and the first replacement (renewal). (See Figure 2). Preventive maintenance (PM) are planned to carry out at constant interval. Between two successive preventive maintenances there could be one or more minimal repairs. This policy could be applicable for short term contract. Details cost analysis of this policy can be found in (Rahman and Chattopadhyay, 2005)

Service contract policy 2: Under this policy, the contract period is up to first replacement of rail due to complete failure of the segment. This implies that it has not any trade off or salvage value at the end of the contract period. In this case we assume $L = R$. (see Figure 2). In this case the contract period is random variable and ceased when the rail segment is economically beyond any service.

Legends

- τ reliability of restoration in MGT
- $\lambda_1(m)$ failure intensity distribution after 1st PM
- $\lambda_2(m)$ failure intensity distribution after 2nd PM
- $\lambda_3(m)$ failure intensity distribution after 3rd PM

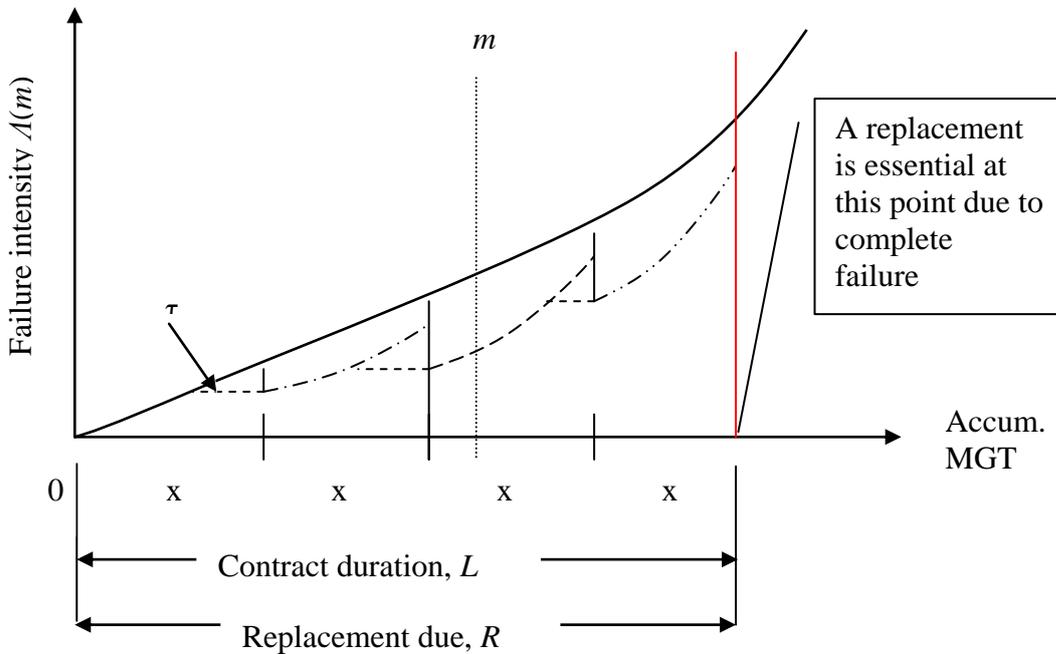


Figure 2: Failure intensity for various servicing strategies for *Service contract policy 2*.

Service contract policy 3: Under this policy, replacement/s due to complete failure of the segment (renewals) is covered during the contract period (see Figure 3).

Before a replacement, there may be one or more PM actions and there may also be a number of minimal repairs between two successive PM. R is random variable and $R \leq R^*$, where R^* is the optimal replacement interval and if it fails completely before R^* it is replaced. This policy is applicable for long term service contract.

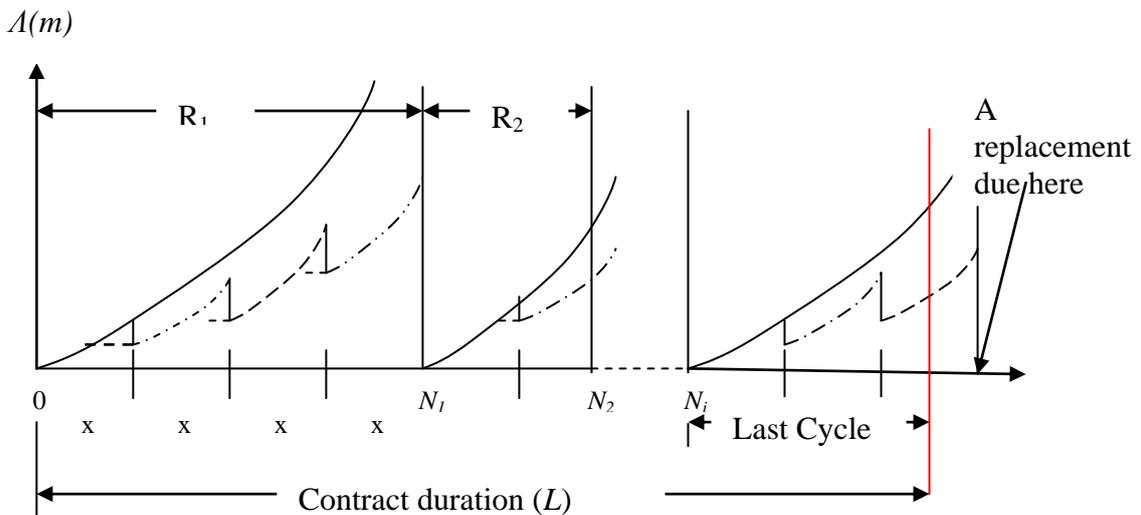


Figure 3: Failure intensity for various servicing strategies for *Service contract policy 3*

Formulation of Models:

In modelling service contracts, we consider a number of assumptions.

4.1. Assumptions

The following assumptions are made for all the cases.

- Failure rate increases with accumulated MGT.
- Servicing actions restores life of 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.
- Preventive maintenance actions are taken at constant interval (x) till each replacement throughout the contract period.
- An item is replaced only when it fails completely otherwise minimal repairs are preferred.
- All replacement is made with new and identical rail.
- All cost factors are constant over the contract period.
- Money discount is 1 throughout the contract period (this assumption is true when contract period is short).

4.2. Notations

Failure intensity $\Lambda_{pm}(m) = \Lambda(m - k\tau)$ (6)

where,

$\Lambda_{pm}(m)$: Failure intensity at accumulated MGT, m , with maintenance.

$\Lambda(m)$: original failure intensity at m when no maintenance is performed.

N : number of times the planned servicing is performed during the contract period

M : number of replacements corrective actions.

L : Duration (length) of service contract

k : number of times PM is carried up to m .

τ age restoration after each PM. $\tau = \alpha x$, where, α is the quality of the maintenance, α ranges from 0 to 1.

When $\alpha = 1$ signifies– ‘as good as new’ and $\alpha = 0$ is ‘as bad as old’.

C_{re} cost of replacement

C_{mr} cost for each minimal repair.

C_{pm} cost for each PM

C_{cl} expected cost for the last cycle.

4.3. Expected costs for service contract per Segment

Modelling costs for Service contract policy 2

Contract period is terminated at first complete failure or discarded due to unserviceable situation

Expected total costs of service contract

= Total sum of expected cost of minimal repairs + Expected total cost of preventive maintenance during the contract.

Expected total cost per unit time

= ((Expected total cost of minimal repairs

+ Expected cost of preventive maintenances) during the contract period) / Length of service contract.

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

$$= C_{mr} \sum_{k=0}^N \int_{kx}^{(k+1)x} \Lambda_{pm}(m) dm \quad (7)$$

Now substituting equation 6 in equation 7, expected total cost of minimal repair can be given by

$$C_{mr} \sum_{k=0}^{N_i} \int_{kx}^{(k+1)x} \Lambda(m - k\tau) dm \quad (8)$$

When failures are modelled as per NHPP then, the failure intensity is given by:

$$\Lambda(m) = \lambda^\beta \beta m^{\beta-1} \quad (9)$$

Therefore, from eqn. 9 and eqn. 8, we get

Expected cost of minimal repair

$$\begin{aligned} &= C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^\beta \beta \int_{kx}^{(k+1)x} (m - k\tau)^{\beta-1} dm \right\} \\ &= C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^\beta x^\beta \left[(k - k\alpha + 1)^\beta - (k - k\alpha)^\beta \right] \right\} \end{aligned} \quad (10)$$

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

Quality of servicing action α can be measured by its effectiveness on the reliability. If a servicing action can extend the expected life from 500 MGT to 550 MGT, then the quality of servicing is given by:

$$\alpha = \frac{L_e - L_0}{L_e} = \frac{550 - 500}{550} = 0.10. \quad (11)$$

Where, L_e = Expected service life with this maintenance action

L_0 = Expected service life without this maintenance action

Expected cost of preventive maintenance during the contract

$$= (N)C_{pm} \quad (12)$$

The total expected cost per unit time $C(L, x, N_i)$ can therefore be expressed as

$$C(L, x, N_i) = \frac{1}{L} \left[C_{mr} \left\{ \sum_{k=0}^N \lambda^\beta x^\beta \left[(k - k\alpha + 1)^\beta - (k - k\alpha)^\beta \right] \right\} + C_{pm} N_i \right]$$

Now an optimum x , optimum number of PM and minimal total expected cost per unit time can be obtained by differentiating equation 12 with respect to x and equating to zero. These optimal values can be obtained by programming in MAPLE.

An optimal contract period L^* can be given by

$$L^* = (N^* + 1)x^* \quad (13)$$

Modelling cost for *Service contract policy 3*

In this case there may be one or more replacements (due to complete failure) needed during the contract period

Here, the Expected total cost per unit time

= (expected cost of minimal repairs

+ expected cost of preventive maintenance + cost of replacement + expected cost of last cycle up to the end of contract) / Length of service contract.

Expected total cost of minimal repairs up to the last cycle

$$= C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^\beta x^\beta \left[(k - k\alpha + 1)^\beta - (k - k\alpha)^\beta \right] \right\} \quad (14)$$

Expected total cost of PM up to the last cycle

$$= (N_i)C_{pm} \quad (15)$$

where $N_i = N_1 + N_2 + \dots$ and N_1, N_2, N_3 are the no. of PMs' before replacement 1, 2, 3,

$$\text{Total cost of replacement} = MC_{re} \quad (16)$$

Therefore the total cost of service contract up to the last cycle can be given by adding equations

$$= C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^\beta x^\beta \left[(k - k\alpha + 1)^\beta - (k - k\alpha)^\beta \right] \right\} + (N_i)C_{pm} + MC_{re} \quad (17)$$

After the last replacement there may be still some period to complete the contract period. The period between the last replacement and the end of contract is called the last cycle. Therefore the expected total cost of last cycle (C_{cl}) can be expressed as

$$C_{cl} = C_{mr} \left\{ \sum_{k=0}^{N_{cl}} \lambda^\beta \beta \int_{kx}^{(k+1)x} (m - k\tau)^{\beta-1} dm \right\} + (N_{cl})C_{pm} \quad (18)$$

Therefore, the total expected cost per unit time $C(L, x, N_i, M)$ can be expressed by adding equations 17 and 18 and is given by equation 19

$$C(L, x, N_i, M) = \frac{1}{L} \left[C_{mr} \left\{ \sum_{k=0}^{N_i} \lambda^\beta x^\beta \left[(k - k\alpha + 1)^\beta - (k - k\alpha)^\beta \right] \right\} + C_{pm}N_i + C_{cl} + MC_{re} \right] \quad (19)$$

Since rail failure is a function of tonnage accumulation in Million Gross Tones (MGT) for certain conditions, rail breaks follows the non-homogeneous Poisson process. Parameters of the developed models can be estimated by using maximum likelihood estimation method and these are given by

$$\hat{\lambda} = \left[\frac{r}{T^\beta} \right]^{\frac{1}{\beta}} \quad (20)$$

and

$$\hat{\beta} = \frac{r}{r \ln T - \sum_{i=1}^r \ln(m_i)} \quad (21)$$

Where, for a set of data, T is the observation period in terms of usage (MGT), m_j is the MGT of rail at its i th failure and r is the total number of breaks over which data was collected.

4.4. A Simulation approach in analysing the Models

The model developed in this paper is complex and is difficult to solve analytically. Therefore a simulation approach is needed to solve this. A flow diagram of the proposed model is presented in the figure 4.

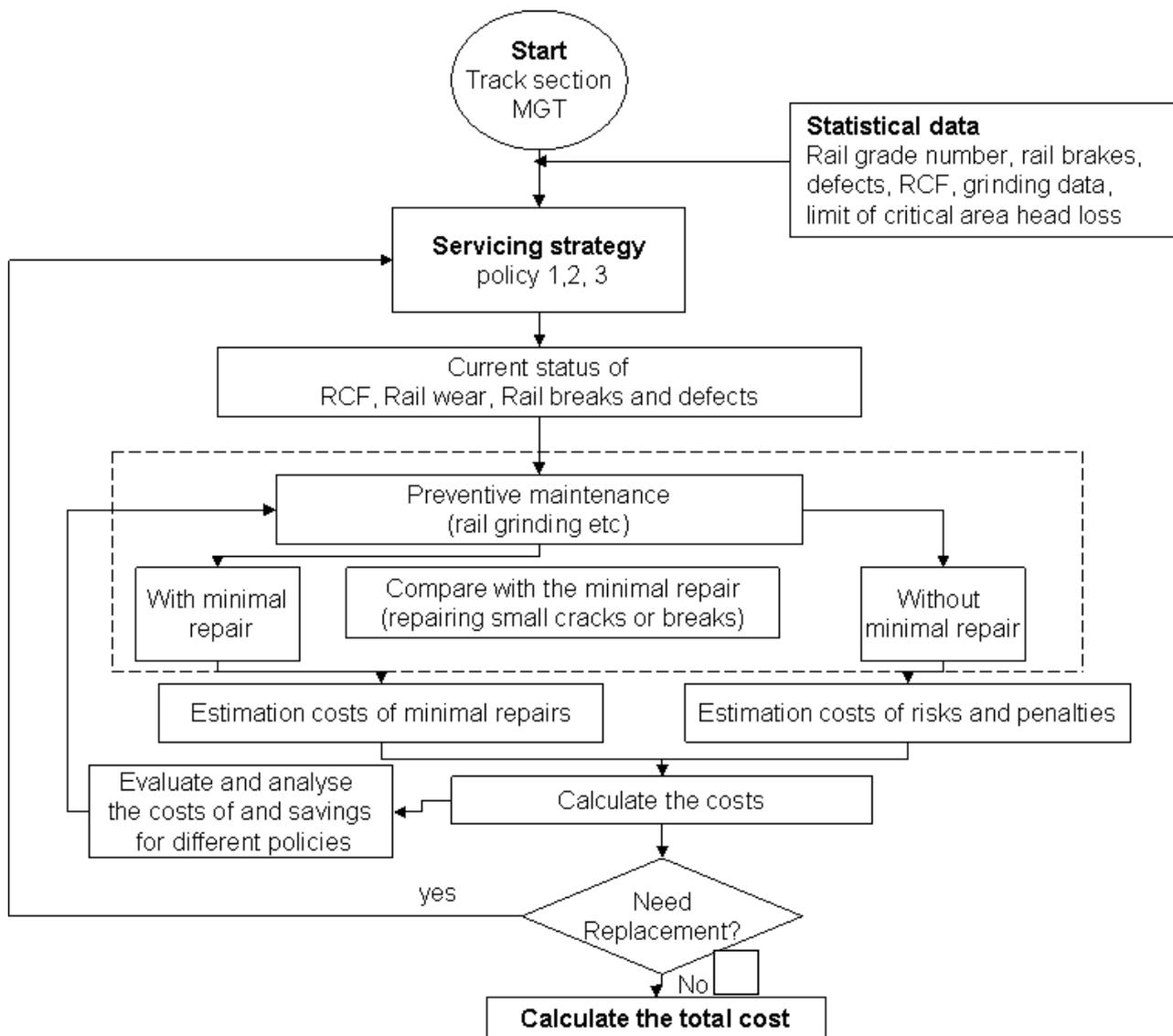


Figure 4: Framework for service contract cost model

The authors are currently working this and the findings will be presented in future publication.

5. CONCLUSION

Three strategies (short-term and long-term) service contracts are proposed in this paper considering the concepts of outsourcing assets to the service providers. Conceptual models are developed in estimating costs. Total costs of alternative strategies and cost per unit of service provided is considered for managerial decision. A simulation model is proposed for complex service contracts. These models can be applicable to outsourcing maintenance service and service contracts for repairable systems. These models can be further extended by including discount rate, provisions for used items, and utility functions for linking customer/manufacturers risk preferences. More complex models could be developed linking risks, downtime and penalties for failure to meet agreed safety, reliability and availability standards. Authors are currently working on these areas and the results would be published in future.

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