LIFE CYCLE COST OF RAILWAY TRACK – AN OVERVIEW

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ABSTRACT

Several cost models have been used in the field of railway infrastructure over the years, but the usage of LCC (Life Cycle Cost) in infrastructure is quite limited. These cost models while taking decisions on maintenance and renewal actions rarely consider the whole life cycle perspective of the infrastructure. The important aspect of life cycle costing is to understand the factors that influence the LCC and the parameters that are needed to estimate it. This paper discusses the need of LCC for railway infrastructure and the current models in practice. It also discusses the cost model being followed at the Swedish National Rail Administration (Banverket) for its new investment and upgrading projects. Finally, a process for life cycle costing estimation is illustrated.

KEYWORDS
Railway infrastructure, Life cycle cost

1 INTRODUCTION

Railway infrastructure is a complex system. An important aspect of the rail infrastructure is that the assets have a long useful life. So once installed, it is very difficult to modify the initial design. Thus the performance of the infrastructure depends on the maintenance and renewal decisions taken during its life cycle. In many countries restructuring railways and increasing efficiency requirements cause a changing environment for infrastructure management. Responsibilities for parts of the railway system are often handed over to different actors. In order to guarantee optimal long-term results for the railway systems the effects of decision should be systematically evaluated (Zoeteman, 1999). The infrastructure manager, responsible for design, construction, maintenance, renewal and upgrading the infrastructure, has a clearly defined role and is confronted by increasing performance of the actors. Budgets are reduced, as reliability, availability have to be increased without endangering the traffic safety. A systematic approach is needed for communication with the capacity manager and central government and for guaranteeing defined levels of performance. As in the current scenario most of the maintenance and renewal decisions are based on past experience and expert estimations, a need for Life cycle cost (LCC) approach arises. A life cycle costing approach coupled with Reliability, Availability, Maintainability & Safety (RAMS) analysis will provide a way to optimise the maintenance strategy, considering the short term budget requirements as
well as long term costs of ownership. Figure 1 shows the three parameters that influence the performance of the track infrastructure. The capacity may be expressed in usable train paths during a certain time span. The substance of the infrastructure refers to the average remaining life time of its components. Finally, the quality of the infrastructure represents track’s geometry quality and components quality. Managing the infrastructure comes to set those three parameters at their most appropriate level, in order to maximize efficiency. Capacity may be adjusted through investment policy, infrastructure substance through renewal policy and quality through maintenance policy.

![Diagram showing three parameters: Capacity, Substance, Quality](image)

Figure 1: Three basic parameters of rail infrastructure influencing performance (Putallaz, 2003)

These three parameters can not be adjusted independently. An old infrastructure (low substance) requires more maintenance (to increase quality) where as a bad geometry (low quality) increases the wear on the infrastructure (lower substance). Similarly, more engineering works (maintenance & renewal) require more track possessions (less capacity) where as more traffic (high capacity) induces more wear to the infrastructure. Thus, while adjusting these performance parameters simultaneously cost aspect of each activity should be considered without compromising on the RAMS criteria set for the infrastructure. Hence, life cycle cost is used as a tool to take cost effective decisions on investment, renewal and maintenance in order to adjust these three parameters to optimise infrastructure performance.

**2 LIFE CYCLE COST THEORY**

Life cycle cost (LCC) is a way of thinking where attention is paid to the total costs that occur during a product’s entire life cycle. The total costs can be observed from diverse points of view i.e., from the view point of system’s supplier or of the system’s user or owner, or even more broadly from the point of view of society. LCC is actually more a way of thinking than merely a costing tool because in addition to the management costs, it focuses on the long term performance of products by employing a variety of management accounting methods. A basic assumption providing motivation for the LCC approach is that it is usually possible to affect the future costs of a product beforehand, either by planning its use or by improving the product or asset itself (Markeset and Kumar, 2004). Life cycle cost can be also defined as all costs associated with the system life cycle (Blanchard, 1995)

- Research and development cost
- Production and construction cost
- Operation and maintenance cost
- System retirement and phase out cost
In order to be able to estimate life cycle costs, the factors influencing the performance of the railway infrastructure have to be identified as well as their relationships. The driving factor causing failures and maintenance is the degradation of the asset. Track degradation depends on many factors, such as initial quality of construction, the quality of the substructure (settlements and crushing of ballast bed) and the loads on the track. Besides asset degradation, there are other factors that also influence the life cycle costs, such as the RAMS standards applied, the amount of preventive maintenance, market prices of labour, materials and machines, and the operational characteristics of the line (such as axle loads, traffic intensities and the duration of train free periods). The Infrastructure Manager can manage some of these factors directly (e.g. maintenance strategy) or with the co-operation of transport operators (e.g. quality of rolling stock) and government (e.g. negotiated grant). Exogenous factors, such as the condition of the soil and the interest rate, will also influence life cycle costs (Zoeteman, 2001).

The performance of the railway infrastructure is defined as the level of safety, riding comfort, noise, vibrations, reliability, availability and the costs of ownership (see Figure 2). Safety and noise standards indirectly influence the life cycle costs, since they determine the tolerances and thresholds for design and maintenance parameters. Physical design directly determines the costs of ownership. The design also influences the asset degradation together with other conditions, such as traffic intensities and axle loads, the quality of substructure and the effectiveness of performed maintenance. The quality degradation determines the required volume of maintenance and renewal (MR). The chosen maintenance strategy influences the amount of MR. A factor that determines the MR volume as well is the annual budget available for MR. The realised MR volume causes expenditures and planned possessions. Besides, maintenance strategy also has a direct impact on the life cycle costs. Subsequently, the incident management organisation, the realised MR volume and the transport concept determine the train delay minutes caused by the infrastructure and these train delay minutes can be converted into penalties for the infrastructure managers.

Cost models used in the decision support systems or maintenance management systems should be able to provide means to evaluate and compare the costs and benefits of different maintenance strategies and options. In order to carry out an economic analysis, it is necessary to make adjustments to costs and prices to ensure that they are all measures in the same units and represent real resources costs.

Figure 2: Factors influencing the performance of track infrastructure (Zoeteman, 2001)
Life cycle cost can be presented in three different ways (Zoeteman, 2001)

- **Total present value (TPV):** is the sum of all discounted cash flows. In the LCC method it mostly concerns costs; incomes can be expressed as negative costs. The larger the TPV, the less attractive the investment compared to alternative investments or maintenance.
- **Internal rate of return (IRR):** shows the profitability of an investment compared to alternative investments or maintenance strategies.
- **Annual equivalent or annuity (ANN):** is the sum of interest and amortisation, which has to be paid every year to finance the investments and maintenance. With the annuity, projects of different life spans can be compared.

**Discounting**

Investments made at different times have different economic values. To take these into account, all future costs are discounted to convert them to present values of cost. Total Present Value (TPV) is given by:

\[
TPV = \sum_{i=0}^{n} \frac{C_i}{(1+r)^i}
\]

Ci = sum of all costs incurred in year i  
\(r\) = discount rate, i = year of analysis

Net present value (NPV) is the difference between the discounted benefits and costs over the analysis period. A positive NPV indicates that the investment is justified at a given discount rate:

\[
NPV = \sum_{i=0}^{n} \frac{b_i - C_i}{(1+r)^i}
\]

bi = sum of all benefits incurred in year i

**Internal rate of return (IRR)**

Although NPV is the appropriate decision rule for determining whether or not investments are worthwhile, comparing the NPV across all potential projects to see which would offer the best investment choice is not practical. In this case IRR can be used. The IRR is the discounting rate at which the present value of costs and benefits are equal i.e., NPV = 0. The higher the IRR, the better the investment. If it is greater than the discounting rate, then the investment is economically justified.

\[
NPV = \sum_{i=0}^{n} \frac{b_i - C_i}{(1+r)^i} = 0
\]

IRR is determined by solving the above equation for \(r\).

**Annual equivalent or annuity (ANN)**

Annual performance fee (ANN) is calculated from the flowing formula. It determines the cost incurred every year to maintain the track.

\[
ANN = \frac{(1+i)^n * i * TPV}{(1+i)^n - 1}
\]

To check the robustness of LCC models, basically two methods are used:

- **Sensitivity analysis:** The disadvantage of sensitivity analysis is that only one variable is tested at a time. Hence possible interactions between factors are not revealed.
• Uncertainty analysis: In this approach the input parameters of the LCC model are considered to be random variables from which samples are drawn. Simulation techniques are used to determine the interaction of input parameters with the outcomes.

Harmonisation

Life cycle cost of the track infrastructure depends mainly on two aspects of infrastructure i.e., network configuration and complexity and network utilisation. The complexity of network is determined by the equipment and density of installations. Complexity is a predominant parameter for investment and cost of maintenance. Some major indicators are:

• Density of switches
• Length of lines on bridges and tunnels
• Lengths of double track lines
• Degree of electrification

In addition configuration parameters like curvature, axle loads and speed level have their impact on life cycle expenditure.

The utilisation of networks has a strong impact on the cost of maintenance and on the components’ technical life until replacement. Some major indicators are:

• Average frequencies of trains per year
• Average gross tonnage per year (freight and passenger)

It is difficult to generalise the LCC per kilometre of track because of its variability in terms of complexity and utilisation. Harmonisation model is used to compare the cost data of different track configurations and utilities in best possible way (Stalder, 2001). Various aspects of harmonisation model are given by:

• Single vs. multiple track: Maintenance and renewal of single-track lines require more work per kilometre than for double or multiple track lines (e.g. for work site logistics, preparatory work). Based on a detailed analysis of SNCF (French National Railway Company) data and surveys of other railways, it can be concluded that the cost of maintenance per track kilometre in single track is typically 40% higher than in double track. So this aspect should be taken care of when estimating LCC per track kilometre.

• Switch densities: Switches in main track have a major share in the cost of road bed and track maintenance (with high impact on signalling and power supply). With switch densities varying between main tracks, the need for harmonisation is evident.

• Track utilisation: Maintenance and renewal as well as lifetimes of track elements depend heavily on the utilisation of networks. Data analysis has proven that maintenance expenditures can best be harmonised according to train frequencies, in particular because of the strong correlation between track access times and maintenance cost. Renewal expenditures are harmonised according to gross tonnage which has a great impact on wear and tear of the track.

3 LCC MODELLING

For the maintenance management of railway asset, cost modelling of railway infrastructure has three major purposes:

• Estimate costs of a maintenance/renewal work
• Assist in the selection of the best maintenance option/strategy in terms of economic return under specified time and financial constraints
• Assist in the scheduling of maintenance works in the most effective way.

Various cost models are available which are applicable to infrastructure maintenance and renewal. In
1997, the rule based expert system ‘ECOTRACK’ was delivered that should enable IMs (Infrastructure Managers) to plan maintenance and renewal on the basis of well defined technical and financial rules (Zaalberg, 1998). ECOTRACK defines a five step process for generating maintenance and renewal work plan. Inputs are track measurements, MR work histories and a rule base. The first three steps are based on an analysis of the track condition with a gradually increasing level of detail. In the initial diagnosis the rough MR needs are calculated, while the system points the user at desirable, additional data for more detailed diagnosis. In the detailed diagnosis the work plan for each component is refined. Finally, the preliminary work program is improved in terms of clustering renewal works, which are close in time and space. Finally, the fifth level allows a number of statistical analyses. Relatively more attention has been given in Europe to the development of decision support systems for the life cycle cost. A first LCC example comes from Veit who developed a model to calculate internal rates of return for different maintenance strategies. Applications include an analysis of track maintenance cost impacts from different locomotives and revision of existing MR practices (Zoeteman, 2006). Zoeteman developed and applied a decision support system named LifeCycleCostPlan in several case studies (Zoeteman, 2001). Inevitably, expert judgement is an important part of the input. LCC models named as QM4C and MOVE were developed not based on degradation models but on historic cost and performance data from the existing railway networks, which have been aggregated for different types of assets (see Levi, 2001;Swier, 2004). Some models such as TMCOST (Andersson, 2002) and LCCRailTrack (Danzer, 2004) include deterioration functions. LCCRailTrack is based on markov multistate model. The possible states of railway track as well as the chances of transfer from a less worse to a worse deterioration state need to be estimated by users; a disadvantage may be that this markov model does not further consider the history of the track segments.

Estimation and minimisation of traffic disruption can be considered as a special area of railway research, requiring mathematical algorithms and simulation models. Studies have been undertaken in the last years to develop (Zoeteman, 2006):

- Optimal maintenance execution plans i.e., scheduling consecutive MR machine runs in order to minimise integrated costs of track works and possessions.
- Optimal clustering and timing of small MR works into regular maintenance slots

Life cycle cost model developed by Vatn (2002) considers the punctuality cost in the model. The basic punctuality information entered is the ordinary speed of the line and any speed restrictions due to degradation. The program then calculates the corresponding increase in travelling time. The model also calculates the economical gain due to increased life length by maintenance actions.

It can be noticed that most of the existing models in railways are not taking care of all aspects especially the risk aspects of life cycle costing. Cost modelling on traffic disruption, train punctuality, environmental cost (noise, vibration etc), and customer (end user) dissatisfaction is still in early stages, which can have a major impact on the maintenance and renewal decisions. Another aspect of LCC is the comparison of costs in different network configurations and circumstances under which they are operated. “International Benchmarking of Track Costs” was a part of an UIC (International Union of Railways) benchmarking project with an aim to compare the LCC of different countries via harmonisation models. This harmonisation models can also be used to compare the LCC of track sections with different configurations and complexities.

Cost modelling at Banverket

Banverket (Swedish National Rail Administration) uses the following cost modelling technique for its new investment, upgrading and renewal projects. The cost modelling is to provide a system of transport for citizens and the business sector all over the country that is both economically effective and sustainable in the long term. The investment should be inline with the parliamentary transport policy goals. The steps (see figure 3) of the cost modelling are:

1. Conceptual study: It deals with the details and the consequences of the investment.
2. Pre study: It is based on long life span up to 60 years. The calculation in this phase is to show the gains for the society and the consequences.
3. Railway Investigation: This phase deals with exploration of new ground, vibration, noise, pollution, etc.
4. Railway plan: It deals with if any new ground/land is needed.
5. System documentation: It deals with actual cost planning.
6. Construct documentation: Prepares the documents for construction.
7. Construction
8. Delivery

The calculation in the pre-study is socio-economical, and it shows the gains for the society. It is based on long life span up to 60 years. Upgrading follows the same steps as new investment except the conceptual study phase. New investment and upgrading are normally the processes that have a long planning horizon. It has to be put in the 3-years administration plan and also be published in the network statement. The decision for renewal includes from step 4–8. Decision for renewal is based on judgment of asset condition and analyze of the operational situation. The calculation cost is based on historical data. If the renewal can be done within the budget, it is planned and done, but if more budgets needed, normally steps 4–8 are followed, and then this put into the administration plan for next year. New investment and upgrading are handled by the investment division. Renewal is handled both by the investment division and the operation & maintenance division. Operation & maintenance division takes care of all smaller renewals e.g. exchange of turnouts, rail, sleeper etc. In operation and maintenance phase the cost calculations are based on estimation, historical data, and expertise.

As LCC is being used in every step of the process for taking decision, the need is to develop an effective procedure to calculate LCC so as to take correct decisions on maintenance, renewal and investment.

**Figure 3: Cost modelling for new investment projects at Banverket (BV Intranet, BRV)**
4 LIFE CYCLE COSTING PROCESS

In order to develop a robust LCC model, it is imperative to consider all the factors that influence the LCC as well as the risks associated with it. Life cycle costing of the track infrastructure is a continuous process till cost effective solutions are not reached within budget constraints and without affecting safety and availability of the track. The value of LCC, which is generally modelled in the design phase changes when the system enters into the operation and maintenance phase due to change in stakeholders’ requirements and the costs incurred during the operation and maintenance phase become predominant. The operation and maintenance costs become the basis for taking decisions on maintenance and renewal actions of the track. Figure 4 shows the different steps for estimating the life cycle cost of the track infrastructure in the operation and maintenance phase. The input parameters for each step in the LCC process and the corresponding outputs are described in the figure. The initial step is to understand the technical characteristics of a track section as well as the utilisation of the track in terms of tonnage and frequency of trains. For LCC calculation, a track section cannot be generalised because of its complexity and utility vary in different places. So the next step is to define per unit length of track by harmonisation steps mentioned in section 2. Track deterioration depends both on various track as well as vehicle characteristics.

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<th>Process</th>
<th>Output</th>
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<td>Start of LCC analysis of track section</td>
<td>Harmonisation</td>
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<tr>
<td>Track design parameters, Track geometry, Vehicle types, Environmental conditions</td>
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<td>RAM variables</td>
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Figure 4: Process for life cycle cost analysis in operation and maintenance phase
Estimation of total track failures will be done by means of track failure data and degradation models of track and vehicle. Track maintenance volume consists of all the corrective and preventive maintenance as well as renewal activities. This is estimated by means of RAM analysis of the various failure modes. Risks associated with maintenance activities are considered in order to take correct maintenance decisions. Track possession times can be calculated based on the corrective and preventive maintenance actions. Reference time table describes the type of traffic, frequency of trains as well as the train operational hours per day. Track possession time determines the track availability, train speed restriction hours and train delay by means of track failure modes and maintenance cost. Train derailment probabilities are estimated by track failure modes, maintenance volume and track possession time. Finally LCC is calculated by considering all the costs in the life cycle phases as well as the consequential costs. Uncertainty analysis is done to estimate the variable costs in LCC by simulating the several risky RAMS variables in life cycle cost estimates. Finally, Total present value can be calculated by means of discounting rate.

Further, cost-benefit analysis can be done by estimating Net Present Value by calculating the residual value of the asset and the cost saved by increasing the residual life of the asset by proper maintenance actions.

5 CONCLUSIONS

For effective analysis of life cycle cost of the track infrastructure, it is necessary to understand all the factors that influence the LCC as well as the parameters that are required for the analysis. This paper describes the existing cost models for track infrastructure and points out the areas of improvement in those models. A cost model used by Banverket for new investment and upgrading projects has been described. Finally, a process for LCC has been discussed.

REFERENCES


