Evaluating Track Structures: Life Cycle Cost Analysis as a Structured Approach

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Summary

In many countries restructuring of 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 system the effects of decisions should be systematically evaluated. Life cycle cost analysis (LCCA) can provide a framework for this evaluation.

At TU Delft two LCCAs were performed in recent projects on the comparison of different track structures. The first LCCA was part of a research study for the Madrid Regional Government (*Comunidad de Madrid*). The Comunidad de Madrid is responsible for a large extension programme of the Madrid Metro network. Several track structures were evaluated on their expected life cycle costs in co-operation with the Comunidad de Madrid and Madrid Metro. A block system track proved to be the best choice considering the life cycle costs. The LCCA provided also insight into the decisive factors determining this outcome.

Another LCCA was set up in co-operation with Strukton Railinfra, the largest Dutch railway contractor. During the last few years much technical research has been conducted in the Netherlands on the embedded rail structure (ERS). Innovations in the production process, e.g. using paver-technology, and laboratory experiments caused renewed interest in this track structure. Strukton Railinfra needed more insight into the financial feasibility of the structure; ERS is only an attractive option for (new) railway lines if it performs well in financial terms: extra investment must pay out. A decision-support tool was developed to combine technical thresholds estimated by experts and financial data. For the comparison of ERS and ballasted track the data related to a 3-km test track, constructed for Netherlands Railways, was used. ERS proved to result in a 20% life cycle cost decrease according to the agreed estimates of different experts. This result has been a reason to continue the research on ERS. More insight into some risk factors needs to be gained, but there is likely a market for ERS.

The LCCAs proved to be a good vehicle for communication between the experts involved and showed the most important aspects for data collection. Especially for evaluation of new technologies life cycle cost analysis can provide a framework to obtain a systematic approach being accepted by the actors involved. In a situation where infrastructure management has become a function performed by a separate entity that has to cope with increasing performance requirements, LCCA can serve as a tool to make decisions more systematically.

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1. Introduction

Policy makers increasingly consider railways to be an important part of the overall transportation system. In the European Union this change is illustrated well by the official EU transportation policy: railways are considered promising as an alternative for congested, polluting road traffic. However, in order to realise that objective, the performance has to be improved on aspects such as availability, reliability, cost-effectiveness, safety and comfort. In many countries, such as the Netherlands, policy makers have chosen to separate the railway operations from the infrastructure management. This 'vertical separation' should facilitate competition in the rail transport market and should distinguish responsibilities more clearly [EU 1991; Vincent et al 1996].

In the Netherlands the Dutch government has established three so-called task organisations: an infrastructure manager *(NS Railinfrabeheer)*, a capacity manager *(Railned)*, and an organisation for traffic control *(NS Verkeersleiding)*. The outplacement of these organisations out of the organisation of Netherlands Railways (NS) is scheduled for the year 2000. For the management of the High Speed Line South, which is to be taken into service in 2005, yet another arrangement has been made: a private sector based Infrastructure Provider (IP) will be selected to construct and manage the railway system for a period of 25 years. The IP will receive a quarterly fee for the realised system availability – a penalty system will be applied for availability performance [HSL South ITC 1999].

The environment created by changing railway policy has an impact on the actual position of infrastructure management. The infrastructure manager, responsible for design, construction, maintenance, renewal and upgrading of the infrastructure, has a clearly defined role and is confronted by increasing performance requirements of the other 'actors'. Budgets are reduced, as availability has 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. This approach is lacking in an organisation where maintenance and renewal has long been planned and executed according to personal experience and skills (not to say that this is automatically a faulty way of working) [Swier 1997].

In order to establish a continuously high performance level of the infrastructure it is important to systematically consider the long-term effects of decisions: for instance, expected costs for different levels of performance (availability, etc.) must be made explicit for making agreements with the central government. This causes maintenance to become an important factor for considering investment, maintenance and renewal cost balanced**…**

In this paper *life cycle cost analysis* is put forward as a framework on which decision making should be based in order to realise the above-mentioned (paragraph 2). Life cycle cost analysis (LCCA) is a technique to systematically identify and value life cycle costs (LCC). The life cycle costs are made up by costs of construction, maintenance, renewal (*cost of ownership*) and costs related to track availability and reliability (*cost of operation*). Also cost effects on other assets, e.g. substructure, noise protection measures and tunnel diameter should be considered. Although expectations on maintenance are often hard to make due to uncertainty, especially for new technologies, there are several ways to deal with this uncertainty in the analysis.

As a way to illustrate the use of LCCA two cases are presented, both related to the choice of a track structure. The choice for a track structure is a very important one in the design process, since a change of track structure is hardly possible during the service period of a railway line. It is an important factor in infrastructure costs and availability. The first LCCA was performed for evaluating track structures for use in the Madrid Metro extension programme (paragraph 3). In the second case the financial feasibility of the Embedded Rail Structure, developed by NS, was investigated being compared with standard ballasted track (paragraph 4). Conclusions are drafted in paragraph 5.

2. Life cycle economic analysis for rail infrastructure

Rail infrastructure, like other production goods, requires huge investments (fixed costs) and the components have rather long life spans. Flexibility in changing the system after train services have started is limited and for this reason the 'running costs' of a system design should be considered early: modifications in the design are relatively easy and inexpensive. Incorporating the running costs in decision-making processes has been the objective of life cycle costing [Flanagan et al 1989].

A life cycle cost (and benefit) analysis is a first step in the process of identifying, evaluating and managing life cycle costs. In a regular LCCA study a time horizon is set together with the decision maker; for instance for the HSL South project, potential contractors are interested in a period of 35 years: 5 years of construction, 25 years of maintenance, and a usability guarantee of 5 years. The costs to be investigated are selected according to a cost-breakdown structure (CBS). To use the HSL South again as an example: the penalty regime for a low availability (due to speed restrictions and malfunctioning) requires for the contractors the inclusion of availability performance for comparing track structures. After this has been set, the availability of data must be considered. In many cases data has to be gathered from different actors for a successful analysis e.g. from the construction department, the maintenance department, technology suppliers and the capacity manager (prognosis on traffic growth and tonnage development). This is one of the reasons for the importance of a feasible data collection plan i.e. selecting decisive factors for the life cycle costs and experts to consult, because new technology 'expert opinions' and field or laboratory tests are the only way to estimate the quality decline. The (computer-based) calculation model largely depends on the data available. The consequential uncertainty can be compensated to some degree by performing sensitivity analysis: tonnage growth and thresholds can be varied in order to study whether this influences the choice and to identify important cost factors. This can be input for a more extensive risk analysis.

The time value of money is in LCCAs an important parameter. Future costs caused by maintenance are valued at a lower rate than current costs: a discounting process makes the cash flow, occurring in different years, comparable with the construction costs (present value). The construction costs have to be financed longer (there is no revenue during construction) and are more important to the decision maker.

3. CASE 1: Decision-support for track structure selection for the Madrid Metro

Since 1994 an extension of the Madrid Metro network is being realised: 35 kilometres of double track (in tunnel) are constructed. In 1998 both at the responsible Regional Government (*Comunidad de Madrid*) and at the Metro Company (*Metro de Madrid*) questions arose on the track structure to be used. Ballasted and block system track have both a long history in Madrid. Block systems, such as Stedef and Edilon systems[3], have been in use since the 1970s. For the new extensions the Edilon system was considered (figure 1).

Advantages of the Edilon system are the fixation of track geometry, the absence of components that require a lot of maintenance e.g. ballast, and the controlled elastic support and quality of the blocks [Esveld et al 1998]. Another advantage is that the blocks can easily be transported and replaced manually (in opposite to sleepers). However, requirements on the construction process are high: the quality of the corkelast compound and concrete blocks must be guaranteed and the fixation of the rail must be done accurately. Investment in the Edilon system is less than 15% more; the blocks are produced near Madrid and the production is relatively inexpensive.

[3] The Edilon system is constructed top-down: first the rails and the blocks are positioned and then the blocks are cast in concrete. A Corkelast compound, mixture of cork and polyurethane, is used to provide a controlled amount of elasticity. In Madrid prefab Corkelast is used in the blocks.

Figure 1 Block track in construction and in use (*Metro de Madrid*)

The approach to include maintenance needed much attention. Madrid Metro could not supply regular replacement/renewal thresholds; repair and small-scale replacement at night-time are common practice. The maintenance organisation proved to be rather labour-intensive. This largely determined the model design: data was available from the Annual Reports of the Maintenance Department over the last couple of years. A financial model, which used average (mostly annual) quantities of repair and replacement, productivity figures, labour and material costs, was developed [Zoeteman 1998a]. Although these reports were rather detailed, not all factors influencing maintenance, such as design standards and components used (e.g. fasteners), could be distinguished. More troublesome was the fact that the replacement of blocks was not assigned to the different block systems. For this reason upper estimates were made for the replacement of Edilon blocks together with the maintenance staff. For a selected new line expected maintenance was estimated with the help of maintenance staff. The expected total present values of the block system and the ballasted track were calculated over 50 years with a discount factor of 5%. The expected effect of using the Edilon block system was *at least* a reduction of 10% of the LCC (excluding inflation) in all the investigated scenarios; the sensitivity analysis was needed due to the uncertainty in the data.

It was clear that the collection of reliable maintenance data caused problems, e.g. the use of average figures: the importance of systematic data storage is needed to improve the value of LCCA. However, since the analysis was done in close co-operation with the Comunidad and the Metro Company, the results were satisfying for the Comunidad and the study confirmed that a choice for block track was the best, as far as could be anticipated. A lot of investment in Madrid was also used for realising a straight tunnel floor by pouring in concrete: a possible integration of the track structure with the substructure could result in more savings.

An important finding is that the choice for the track structure strongly depends on the local situation, e.g. labour costs and construction costs. Furthermore, the conditions during construction and the quality of the subgrade (tunnel floor) are important parameters.

4. CASE 2: Life cycle cost assessment of the Embedded Rail Structure

In the Netherlands renewed interest has arisen on the Embedded Rail Structure (ERS), a track structure that was developed in the 1970s. In the 1970s a short test track was made using prefab slabs and it was in the 1980s that the structure was introduced in level crossings for heavy road traffic. A new, 'industrial' production method, using a paver has become sufficiently reliable and accurate (see figure 2). In the ERS also a corkelast or likewise compound is used for attaching the rail to the concrete supporting bed; the main advantage of ERS is providing continuous support in contrast to discrete systems, such as Rheda and Shinkansen slab track (figure 2).

A better rail fatigue performance is expected based on laboratory tests and dynamic behaviour calculation models leading to an increased life span[4]. Moreover, the structure has the lowest height and weight, safety is considered less endangered by the occurrence of rail defects (due to the support provided to the rail) and noise can be reduced due to the elastic support. Possible risks of using ERS include settlements in the subgrade and faults in the construction process and material requiring corrections. Other research issues include the production circumstances, e.g. temperature range, the installation of trackside equipment, e.g. cables, and the maintainability (replacement rate of rails). Replacement of rails is well feasible, but takes more time. This can be a problem for the track availability on lines with high traffic intensities.

Figure 2 Construction of Embedded Rail with paver
(Test track near Best, the Netherlands; source: Strukton Railinfra)

Although ERS is, for high-speed services, a non-proven technology, the great impetus about ERS research also reached Strukton Railinfra, the largest railway contractor in the Netherlands. Strukton needed more insight into the possible financial feasibility: ERS is rather expensive compared to ballasted track, although there are still optimisation possibilities [Esveld 1999]. The construction price is comparable to prices that are mentioned for Rheda track (900 to 1000 Euro). Although this price needs to drop further for large-scale application, an LCCA was performed at Strukton Railinfra in order to investigate whether the extra investment pays out already.

In order to investigate the life cycle costs for this new track structure, a prototype decision-support system was to be developed based on the concept of combining expected thresholds and cost data. The railway track was divided in a number of 'building blocks' such as rails, sleepers, ballast bed, etc. For every building block the most important indicators were selected for determining the quality and maintenance of the building block, e.g. rails *standard deviation of top / track tamping* and *rail wear or cumulative tonnage / rail replacement*. As load is one of the most determining factors for maintenance and renewal, quality decline is mostly dependent on cumulative tonnage and harmonisation policy (figures 3 and 4). Important cost data to be collected are the discount rate to be applied, unit costs of maintenance and renewal (day/night/weekend), length of maintenance slots, average distribution of maintenance work over days, nights and weekends, and productivity rates (hours/km).

[4] With UIC60 at least 1100 to 1300 million tons is expected (for the HSL South). Estimate used by Strukton Railinfra.

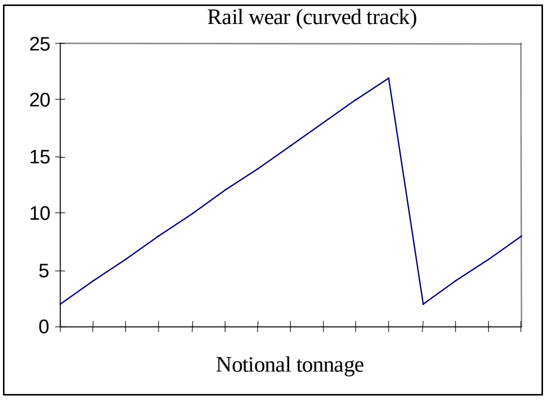

Figure 3 Example change in quality (rail wear)

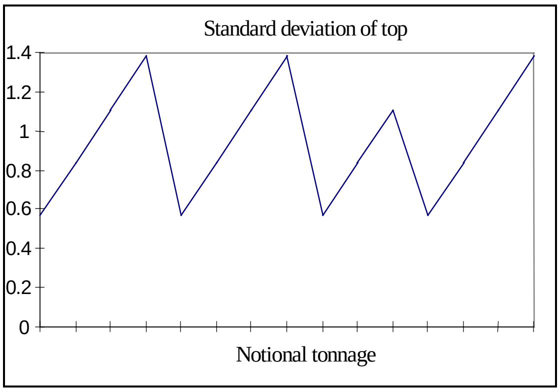

Figure 4 Example change in quality (standard deviation of rail top level), with interaction

The distribution over days, nights and weekends and the common length of a maintenance slot are both important for unit costs, productivity (starting-up and finishing result in fixed time required) and traffic disruption. A final feature of the prototype was to use thresholds depending on tonnage and to use a 'timetable' as input. Calculation of a notional tonnage, variable over the years, makes it possible to investigate the effects of different use/load scenarios: *what* is the effect on costs, *if* different traffic intensities occur. For a fair comparison also insight into the costs of traffic disruption are required; this proved, however, not to be feasible, since detailed traffic data were lacking and project time was short (figure 5).

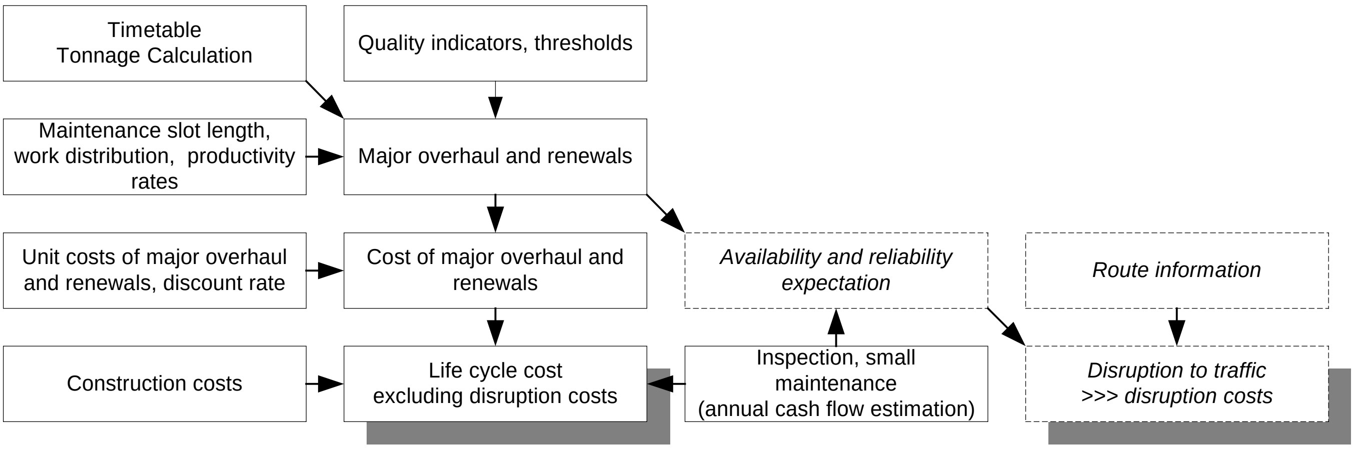

Figure 5 Concept of the Life Cycle Cost Model

The choice has been made to concentrate on the railway track works *only*, although ground works for preparation of the track laying also differ for ERS and ballasted track. The effects of necessary *preparatory work* differ for different subgrades. Although construction costs of the railway track were about 40% higher than ballasted track, the total discounted life cycle costs were calculated to be 20% less than those of the ballasted track used in the Netherlands, which are about 2300 guilders per metre (figure 6). A rail renewal was not needed in the period considered and this means that only some annual maintenance is foreseen. Costs of inspection and

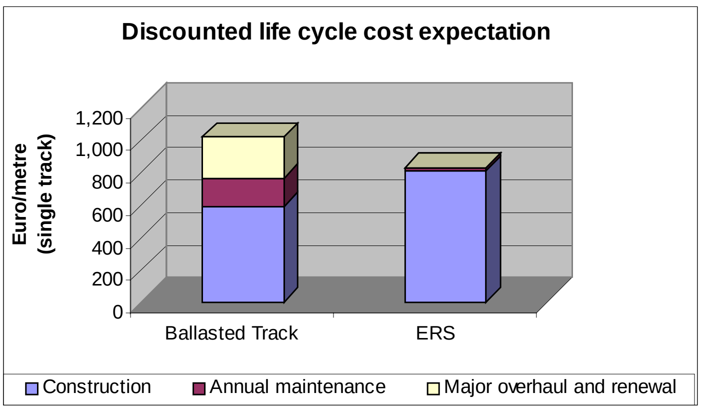

Figure 6 Outcomes for a representative NS situation (present values)

rail grinding were not included in the comparison [Zoeteman 1998b].

The findings for ERS were promising, not only considering the ownership costs but also the expected reduction of traffic disruption due to the low maintenance demand. The study at Strukton Railinfra is continued in relation to the High Speed Line South tender. A more extensive risk assessment is currently being performed in order to get an overall picture of the applicability of ERS. These risks can be expressed as annual costs or specific risks during the life span. A different LCC study for high-speed track assessment confirmed the results so far [Esveld 1999].

Especially the ability of the LCC model to vary factors such as unit costs, productivity, tonnage and thresholds in order to identify the likely changes in outcomes is important for decision making under uncertainty. Sensitivity of outcomes and cost margins available for risk management can thus be found.

5. Conclusions

The choice of a track structure depends on many factors influencing the life cycle cost, such as labour costs, subgrade, maintenance slots regime, traffic intensities and characteristics, maintenance concepts (e.g. balancing maintenance and renewal) and risks. For instance the specifics of high-speed operations will have an impact on the choice. Also the implementation of a new work safety policy in the Netherlands, requiring all maintenance to be performed in out-of-service periods, has a huge impact.

An LCCA can be a way of supporting the decision making in a structured way, considering the above-mentioned factors. For the ongoing discussion on ballasted and slab track life cycle cost analysis could be a means to systematically consider the pros and cons of the track structures involved. Developing a (shared) Life Cycle Cost model for assessing the track structures considering the specifics of a situation is a way to structure the discussion amongst experts e.g. identifying the decisive cost factors and deducting issues for further research. In other words, it can serve as a vehicle for discussions on so-called 'unproven technology', in which 'maintenance' and 'maintainability', given specified safety levels, are often mentioned as key factors.

Systematic decision making is more and more a necessity to guarantee the long-term performance of the track, and the rail infrastructure in general, in a situation where the infrastructure manager has to cope with increasing demands from different actors. Life cycle cost analysis can be an important contribution to this aim.

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