State of the art in railway maintenance management: planning systems and their application in Europe*

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Abstract - *Infrastructure managers increasingly have to deliver to defined performance levels (e.g. reliability and life cycle costs), as a result of increasing pressures from governments and transport operators. Systematic analysis of the long-term performance and cost impacts of design and maintenance decisions is therefore becoming a 'part of the game'. Estimation tools are gradually becoming available, but their application in practice is still scarce. A significant problem is the quality of underlying database systems. Moreover, the variation in starting points and calculation methods is large. It is suggested to establish a forum for maintenance engineering in the European railways.*

Keywords: Rail infrastructure, computerized maintenance planning, life cycle costing

1 Introduction

The setting, in which construction and preservation of railway networks is performed, changes rapidly. Since the 1980s, initiatives have been taken in many countries to introduce market forces in railway systems; the European Union followed in the 1990s, after North America and Japan in the 1970s and 1980s. The European reform model consists of the separation of the former infrastructure departments of the 20^{th}-century railways; in many countries, this transition is still in progress. The new infrastructure managers (IMs) are being appointed with an entirely new responsibility. Transport operators and governments increasingly ask them to deliver specified performance levels in terms of infrastructure availability and reliability, while they have to negotiate heavily on necessary input factors such as government funding. It can be expected that performance-based costing regimes, or 'performance payment regimes', may, ultimately, result from these changes; an interesting, far-reaching example is the contract between Infraspeed, the provider of train slots on the Dutch high-speed line HSL South, and the government.

The new IMs have to deal with a number of obstacles in meeting the current expectations of other actors. Firstly, despite much research, not all infrastructure deterioration processes are already well enough understood to "translate" them into quantitative relationships between investment and maintenance decisions and infrastructural quality effects; this might result in longer-term effects being underestimated [1]. Secondly, the long-term, capital-intensive nature of rail infrastructure conflicts with the preference of many governments and shareholders for short payback periods on investments and quick performance improvements. Decisions have a high degree of irreversibility, and consequences of bad decisions (e.g. low construction qualities or insufficient preventive maintenance) have to be coped with for a long time. Thirdly, although the IM should be the actor which is capable to consider such long-term effects appropriately, many incentives in the organizational structure urge not to do so (e.g., historic organizational and institutional boundaries, such as allocated budgets, standard operating procedures, established relations with other actors, and regulations).

These obstacles have urged IMs to review, among other things, current working practices, information systems and tools. This paper will focus on the R&D efforts on computerized planning and decision support systems for supporting a life-cycle approach in railway design and maintenance processes. Section 2 will first discuss the principles and approach of 'maintenance management'. Section 3 will present the state of the art in R&D in Europe, discussing a range of systems in use and under development. Section 4 ends with a number observations and conclusions on the state of the art.

2 Maintenance planning

Maintenance can be defined as the combination of all technical and administrative actions, including supervising actions, to retain a technical system in, or restore it to, a state in which it can perform a required function [2]. A

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Maintenance Concept is the centerpiece in a proactive approach to asset maintenance. It defines the appropriate tasks and activities needed in relation to the importance of particular assets (i.e. criticality of failures). The concept steers the maintenance planning process and is updated regularly on the basis of new information (following a 'Plan, Do and Check' cycle). The concept is developed in several steps: (1) generation of maintenance strategies for individual assets, (2) definition of clustering rules, which optimize the frequencies of activities on the basis of scale or scope effects, and (3) definition of rules for assigning time windows to maintenance packages on the basis of opportunities that occur in the middle and short term. The maintenance strategies are based on the analysis of degradation and failure behavior of each asset (type). In a life-cycle approach, maintenance engineering is already used to modify the design of (new) assets.

Computerized maintenance management systems (CMMSs) are inevitable to support the practical use of such Maintenance Concepts, in the case of complex, linear assets such as railway networks. This is because (components in) different railway assets, such as track segments, are economically and structurally interdependent. Scale effects are involved in their maintenance and renewal, while their degradation is often structurally related; moreover, because operations have to continue on the rail network and because budgets are often restricted, all kinds of constraints have to be considered in the planning of infrastructure maintenance. A CMMS is, ideally, able to generate an optimal work planning under these constraints and using measured, empirical data on asset degradation. They can thus improve the maintenance process in the following ways [3]:

- optimal allocation of resources across the network;
- improved understanding of reasons for performing or deferring work;
- the ability to predict future resource requirements (long-range budgeting);
- a reduced risk of neglecting to maintain a critical location; and,
- a systematic, objective approach for proposing production plans and bills of materials.

Such systems have become fairly familiar in the related field of road management and are known as 'pavement management systems'. Figure 1 illustrates the steps taken in the pavement management of the Dutch highway system. In the railways, the first systems have been developed in the 1980s and 1990s, focusing on track maintenance; early examples are MARPAS, BINCO, GEV, REPOMAN, TMS, TMAS, and SMIS. Some of these systems assign priorities to maintenance and renewal (M&R) work, through projecting the years, in which track quality in a given track segment will first fail to comply target standards (or thresholds).

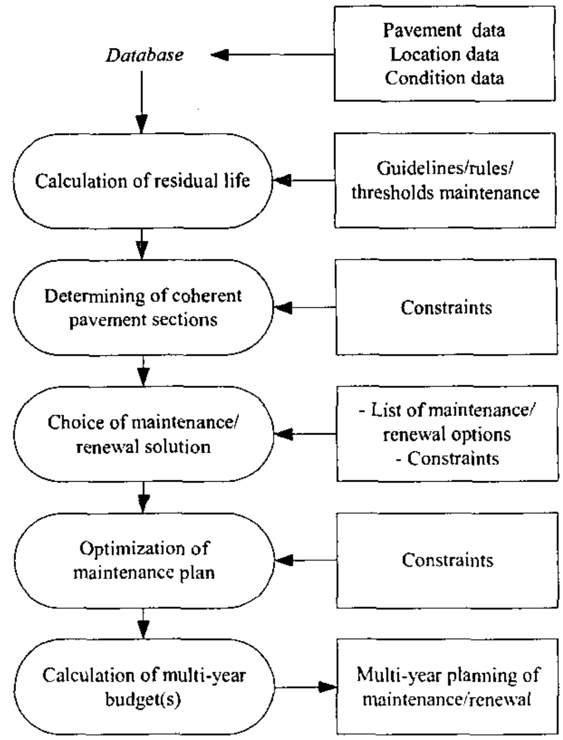

Figure 1: Maintenance planning IVON [4]

Because rail infrastructure, and particularly track, components are expensive and have long life spans, cost-effectiveness of design and maintenance decisions on the long term should be explored and guaranteed. Life Cycle Costing (LCC), an engineering economics technique, can serve to focus design and maintenance strategies on minimized life cycle costs, while meeting functional specifications (e.g. required capacity and reliability of the system). LCC is defined as 'an economic assessment of an item, system, or facility and competing design alternatives considering all significant costs over the economic life, expressed in terms of equivalent currency units' [5]. With LCC, design and maintenance options can be tested on their total costs of ownership and operation, including the additional costs and revenues lost due to failures or planned maintenance (possessions). Decision options to be considered should, however, first comply with the (minimal) functional requirements, e.g., design speeds, axle-loads and curve radii. An early example of a decision support system for LCC is the North American TRACS, which estimates track maintenance and renewal costs as a function of route geometry, track components, track condition and traffic mix. It is based on "engineering-based deterioration models" and has been used at a number of Class I Railways for, at least, the following purposes [6]:

- 'Technology assessment: analysis of the effects of heavy axle-loads on track costs;
- Situation specific costing: analysis of the incremental track costs of an additional unit coal train on an entire route;
- Budgeting: analysis of the amount of rails to be renewed over the next ten years, and the expected maintenance budget over the next five years;
- Rationalization analysis: analysis of the impacts of rerouting traffic on the maintenance costs; and,
- Costing of transportation services: support of contract negotiations for the provision of rail movements for intermodal services, along with a model to estimate energy consumption, required for train movements.'

3 Recent R&D efforts in Europe

This section provides an impression of recent developments around railway CMMSs and decision support systems (DSSs) in the European rail sector. This will be done through a listing and brief description of important systems, developed in the last 10 years. We will reserve observations on this state of the art for the next section. We will also not discuss developments around asset database systems and work order and scheduling systems, such as SAP R/3, MIMS and MAXIMO.

In 1991, the UIC started an important research project, which delivered in 1997 a rule-based expert system, named EcoTrack, which should enable IMs to plan M&R on the basis of well-defined technical and financial rules [7]. The project was financially supported by 24 railways and was performed by a group of experts from about 15 railways. It resulted in a stepwise process for generating an M&R work plan (see Fig. 2).

Input are track measurements, M&R work histories

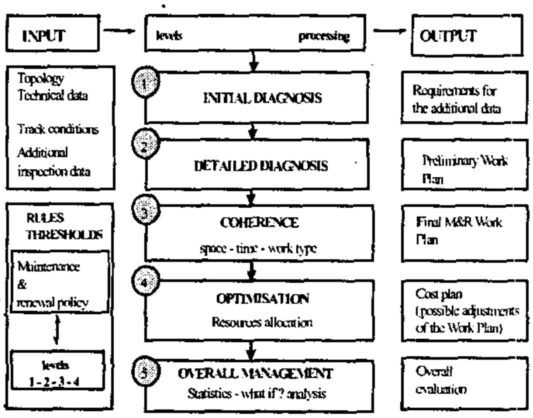

Figure 2: ECOTRACK - the calculation process for composing M&R plans [7]

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 M&R needs are calculated, while the system points the user at desirable, additional data for more detailed diagnosis (e.g. data on the percentage of fines in the ballast bed). In the detailed diagnosis the work plan for each track component is refined. Linear degradation forecasts are developed. Finally, the preliminary work program is improved in terms of clustering renewal works, which are "close" in time and space. The fifth level provides, finally, a number of statistics, such as overall network costs, expected for the coming 10 years. Although the rule-base contains default rules, the experience from feasibility studies, held in the last years, is that modifications in the data- and rule-base need intensive support from EcoTrack specialists. At the moment, EcoTrack is not yet seriously being used for the planning of maintenance and renewal in any railway. After 1997, there has been no further development and improvement, but in 2004 EcoTrack has been transferred to the engineering company Arcadis, which has plans to invest in the program.

TRIS, developed by Volker Stevin, is a system worth mentioning because of its approach to improve the planning of particularly smaller routine maintenance [8]. TRIS's aim is to develop condition-based maintenance strategies for tracks, switches, and the civil structures. Where ECOTRACK focuses much more on a few quality degradation patterns, needed for planning heavy M&R work, TRIS can handle a variety of maintenance tasks in a flexible manner. It needs expert judgments and data from both patrol inspections and track recording cars; checklists have been developed, which can be used during global and detailed surveys by the patrol teams. The user can add its own, linear or non-linear, models to describe the behavior of a specific degradation mode under the effect of loading. The user defines in advance the possible types of M&R and the intervention levels to keep track components within desired condition limits. TRIS can deal with qualitative judgments, such as 'beginning', 'intermediate' and 'advanced deterioration'. Calculated strategies are ranked on the basis of the net present value for the first 20 years (Fig. 3 presents the stepwise calculation process). A disadvantage of TRIS may be that much data is needed for an accurate prediction.

The lacking availability of empirical data has perhaps been one of the reasons why CMMSs research and implementation of such systems has not yet been more far-reaching and widespread. Relatively more attention has been given to the development of DSSs for Life Cycle Costing. The model of Zoeteman, LifeCycleCostPlan, is presented later in this IEEE Session, but other models are already discussed here.

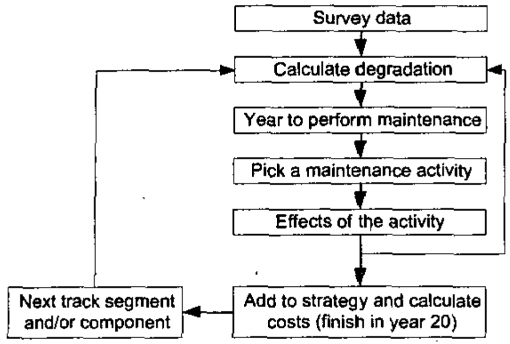

Figure 3: TRIS process for composing strategies [8]

A first LCC example from Europe comes from Veit [9], who calculated internal rates of return for different maintenance strategies. Applications include an analysis of track maintenance cost impacts from different locomotives and a revision of existing track M&R practices. The network of the Austrian railways (OBB) was categorized in standard track categories during this last project, using criteria such as traffic density, curve radius, and subsoil conditions [9]. Typical 'activity profiles' were developed for each of these categories, using expectations from knowledgeable track maintenance planners and data on historical M&R volumes. These profiles describe the necessary M&R during an average track life span (see Figure 2.14 for an example). Having such activity profiles available, it is possible to compare life cycle costs of different maintenance practices, operating and subsoil conditions, including costs of line closures and temporary speed restrictions.

YEAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Track (re)-Laying	1																							1
Levelling-Lining-Tamping	1		1		1		1				1	1		1	1			1		1	1		1	1
LLT including switch									1								1							
Change of layer						1					1					1					1			
Rail Grinding						1					1					1					1			
Rail Changing													0,3											
Others																								

Characteristics: >70 KGT per day, UIC60 rails, concrete sleepers, good subsoil, radii: 400 to 600 m. Unit of measurement: the cells contain the amount of track (in km's) to be maintained.

Figure 1. Life cycle activity profile for a standard kilometer Westbahn [9]

The French Railways Authority (RFF) developed a tool named MOVE. MOVE generates a theoretical M&R Work Plan for the tracks on the entire French network for a period of 50 years with a minimal amount of input [10]. Life expectancies are calculated as functions of the cumulative and annual traffic loads (tonnage). Next, MOVE selects automatically an applicable strategy from a predefined set of about ten M&R strategies, which also includes the clustering of renewals on adjacent track sections. Finally, life cycle costs are calculated for the entire network under an interest rate of 4%; costs of traffic disruption are not included. Parameters are calibrated by the use of an SNCF database containing detailed data on annual renewal quantities and costs. MOVE is used for presenting the long-range impacts of different M&R policies, such as a postponement of the renewal of tracks with timber sleepers, as well as for the comparison of specific renewal proposals of the SNCF Maintenance Regions to national averages.

Danzer [11] developed LCCRailTrack, which estimates life cycle costs for tracks and switches, depending on an operating environment defined by the user. The model also includes deterioration functions, based on a Markov multi-state model. The possible states of a 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. Danzer uses fuzzy logic to deal with the uncertainties involved in the estimation. The model is developed in co-operation with Deutsche Bahn (DB). Another model in use by DB is a model for assessing the life cycle costs of ballasted and slab tracks, depending on given soil and operating conditions; life cycle costs, including the costs for civil substructure, are estimated on the basis of the given geographic terrain [12].

ProRail developed several models. Firstly, a general-purpose "LCM Calculation Tool" is used, in which staff can put their assumptions and estimate life cycle cost levels for solutions, devised by them. Further, a tool called Optimizer Plus is used at a central level to analyze maintenance concepts for entire line sections, in order to "optimize" them in terms of life cycle costs and reliability risks. The Optimizer Plus uses data from maintenance concepts of individual assets.[1] With this approach, it should, in the end, be possible to plan the line performance. Problems to overcome are, however, unavailable empirical data, technical staff experiencing the concepts as a threat, and existing regulations for planning M&R [13].

[1] An asset maintenance concept contains all key data of a particular asset type, needed to develop maintenance strategies for assets of that type in relation to the entire rail infrastructure on a line (average life span, M&R activities and frequencies, mean time between failures, mean time to repair, unit maintenance costs, and so on.

The QM4C Model is a third model, used in ProRail for strategic studies and cost control in the OPC maintenance contracts. QM4C estimates (life cycle) costs on the basis of general characteristics of the line (section) under consideration [14]. QM4C is not based on degradation models, but on historic cost and performance data from existing railway networks, which have been aggregated for different types of assets. The model is based on a couple of reference cost and availability templates, which contain data of more than 100 infrastructure components (e.g. switches and track systems) from the Dutch rail network. Data relate, for instance, to population numbers, unit costs for construction and M&R, average economic service lifetimes, and average downtimes. About 400 cost norms explain ProRail's annual M&R costs of about 400 million euros. Because these templates reflect the particular Dutch situation in terms of train intensities, reliability standards, possession regimes and wages, a cost index model is used to extrapolate the data to changed operating environments or even entire new lines, such as the HSL South. This index model was derived from the international UIC InfraCost study.

Researchers from a range of European countries, including [15], [16, [17], [18] and [19], recently reported the development of tools for LCC aspects for their national IM. In a couple of these tools, it is tried to use statistical analysis on the basis of historic M&R work logs [cf. 15], and most attempt to include, in more or less detail, estimates of traffic disruption costs, caused by the infrastructure.

Estimation and minimization of traffic disruption can be considered as a special area of LCC research, requiring special tools, such as mathematical algorithms and simulation models. Studies that have been undertaken in the last years include attempts to develop:

- Optimal maintenance execution plans, i.e., scheduling consecutive M&R machine runs optimally in time in order to minimize integrated costs of track works and possessions [20];
- Optimal possession allocations over the network for mainly small M&R works, which are performed during the train timetable, in order to minimize disruption [21];
- Optimal clustering and timing of small M&R works into regular, mostly nightly, maintenance slots [22];
- Objective review procedures for track layouts [23]: in this study, life cycle costing and mathematical algorithms were combined in order to review the necessity of disruption switches in track layouts.

4 Observations and conclusions

The mentioned railway reforms and the examples of R&D work done at several European infrastructure managers show the growing interest and, perhaps, need to apply 'systems engineering' principles in railway design and maintenance, in order to demonstrate and optimize impacts on life cycle costs and RAMS (reliability, availability, maintainability and safety).

Yet, despite the desire to come to a higher quality of decision making, the maintenance management process at the "work floor" of the infrastructure manager showed still to be in an early phase. This is underlined by the state of the art in maintenance management systems, which are practically not used anywhere in Europe to plan M&R in a structured manner, based on empirical data. The LCC models and studies mentioned in Section 3 are a first, useful and necessary, step towards more professional management, but this does not take away the need to improve the quality of underlying data. It would be best, if LCC models can function within, or on top of, CMMSs as a kind of what-if analysis modules.

A significant problem is that information is still mainly collected for the purpose of accountancy (e.g. of labor hours and budgets) only, and hardly for maintenance management and engineering. Estimation of life-cycle impacts of design and maintenance decisions is therefore often a difficult issue. Moreover, current asset information systems are often based on inaccessible, unreliable or incomplete data systems [24].

Probably, this situation can only gradually change, if infrastructure managers are more challenged through performance-based costing regimes and audits. The European Standard 50126, which prescribes the testing, commissioning, monitoring and auditing of railway systems and maintenance services, could serve as an important vehicle. Furthermore, research institutes and academics could assist infrastructure managers through the development of harmonized M&R planning approaches and (prototype) systems.

All in all, it can be, cautiously, concluded that railway maintenance is slowly moving from a 'craftsmanship' phase, in which maintainers follow historic, rigid work instructions and (subjective) experience, to an 'engineering' phase, in which quantitative assessments play a key role. Yet, much R&D remains to be done, while many obstacles do not make it an easy road. Co-operation of researchers at a European level is therefore highly desirable, and this may be achieved through a forum for maintenance engineers in the European railways.

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