MODERN CONDITION-BASED RAILWAY INFRASTRUCTURE ASSET MANAGEMENT

Stasha Jovanovic[1], Arjen Zoeteman[2]
1 MER MEC Group, Italy
2 Delft University of Technology, The Netherlands

Abstract

Complexity of today's railway sector imposes high and often conflicting demands on Rail Infrastructure Managers. The shear vastness of Railway Networks requires advanced tools and methods to aid humans in managing them efficiently. This problem necessitated in the recent years the introduction and application of Railway Infrastructure Asset Management Systems (RI AMS). Knowing that the condition-based approach was undoubtedly by far the most efficient existing approach to maintenance engineering, modern RI AMS are almost entirely based on collecting, processing and utilizing asset-condition data. This clearly made Railway Infrastructure Condition-Monitoring (CM) the single most important building-block of any RI AMS, because the overall managing capabilities of RI AMS will greatly depend on the quality of the available Monitoring systems and data they produce. The purpose of monitoring is usually twofold. The first, immediate reason is obviously the detection of the irregularities that could endanger safety and reliability of the railway traffic. However, in addition to this, if a monitoring technique is continuous and fast enough to allow consecutive monitoring runs to be performed in regular time intervals, an extremely important temporal aspect is obtained which is of essential importance for a successful condition-based asset management. This means, that such monitoring techniques can provide detailed insight into the infrastructure assets' behavior over time, enabling condition-forecasting and consequent planning of maintenance & renewal (M&R) works. This concept effectively represents the ultimate goal of CM as well as that of the Railway Infrastructure Asset Management Systems as a whole.
The paper discusses various CM techniques and their optimal utilization for Asset Management and Life Cycle Costing purposes, as well as the main RI AMS sub-systems and the activities they are supposed to handle.

Keywords: Railway, Infrastructure, Asset Management, Life Cycle Management, Maintenance & Renewal, Decision Support

1 Introduction

Manay different definitions on Asset management are found in the literature. One of the most "elegant" definitions is: "*the process of guiding acquisition, use and disposal of assets to make the most of their service delivery potential and manage the related risks and costs over their entire life*" [1]. Focussing on rail infrastructure managers, the core business may be defined as delivering RAMSHEC or RAMSHED, which stands for:

1. Reliability: the time that the infrastructure is available during agreed hours of operations
2. Availability: the time that the infrastructure is available for operations per calendar period
3. Maintainability: the time it takes to repair or replace components and assets. Its impact materializes in Reliability and Availability.

4 **Safety, riding comfort, Health and Environmental friendliness** (e.g. sustainability, noise and vibrations): crucial factors to be controlled through design, inspection, maintenance and operating procedures;
5 **with minimized Life Cycle Costs / affordability or Durability;** asset management should be aimed for the lowest life cycle costs for the required performance: the realization of an acceptable cost of ownership for the short and long term through controlled asset strategies, focused on maximum return on investment (ROI).

In the development of physical asset strategies it has to be taken into consideration that the asset owner's influence on cost and performance levels is best during planning, design and acquisition. Once installation and commissioning has taken place, corrective actions are needed to restore lacking quality. Costs for such actions multiply, last but not least "*because the house has to stay open during reconstruction*". Over the life of the assets, margins to improve or reduce costs are gradually decreasing: the asset ages. It therefore pays off to invest a lot in initial quality and predictive maintenance in order to avoid capital destruction.

The approach taken in this paper is a pragmatic one, using examples from the management of railway tracks. Section 2 first deals with the theortical concept of Asset management.

2 Asset management

Looking at the processes of Rail Infrastructure Managers to provide infrastructure of a continuous high quality (at an affordable price), a chain from strategic to operational decisions can be recognised. At strategic level, choices are made on fundamental technological directions. *Should we continue 1500V DC or should we migrate to 25 kV DC for traction power supply? Or: Should we start to increase distances between tracks now in order to anticipate future safety legislation?* "Downstream" decisions tend to become less policy based and more planning and project based. Maintenance policies still contain strategic elements. *What initial quality level are we intending to deliver when renewing infrastructure? Which activities do we intend to insource or outcource on the long run?* Actual plans of maintenance and renewal activities clearly have a more tactical character. For instance: *how can we distribute work loads in order to minimise traffic disruption over the coming period?* Finally, close to the operating processes "outside", detailed work schedules and task lists for maintenance personnel are developed and used. This paper focuses on the tactical and operational Asset Management questions, which mostly deal with Maintenance and Renewal (M&R).

Asset management can be placed at the planning-based level, including both strategic and tactical decisions. It focuses on realising optimum performance of the installed base (i.e. given the technological state of the art). Examples of asset management questions are: *What initial quality level are we intending te deliver when renewing infrastructure? How can we distribute work loads in order to minimise traffic disruption over the coming period? What is the expected return on investment (ROI) in terms of benefits for transport operators and society for extra Euros put into technical subsystems and maintenance technologies?*

European railway management is in general not rooted in a firm "asset management" history, in contrast to for instance the North-American heavy haul railways. Implicit decision-making and informal networks made the railways function, under the umbrella of nationally integrated companies. However, with the separation of Infrastructure and operations due to European policy into separate processes, Service Level Agreements (SLA) and the need to work in a much more business-like manner have become a necessity. Stakehodlers need to know from each other to which level they will be producing / delivering performance and quality. Performance must be demonstrated in an explicit manner, using a set of Key Performance Indicators (KPIs). Pressure is also increasing with respect to the financing of infrastructure, which need clear justifications based on actual maintenance needs.

Asset management uses as much as possible quantitative, business administration methods (e.g. net present value and real option analysis) and requires therefore the following ingredients:

- Up to date asset registers with accessible and combinable data tables related to the specific assets and asset data (location, age, physical condition, maintenance history and so on);
- Maintenance concepts based on risk analysis and knowledge of infrastructure behavior (failure and degradation patterns). Such concepts should also (be able to) match specific transport requirements for specific corridors. It provides the ability to offer different products for different markets (for example, light rail, combined traffic or dedicated freight traffic);
- Life cycle cost optimization from the asset planning and design phase on, including costs and revenue losses incurred by operators due to insufficient infrastructure performance.
- A Product Management/Quality control system to guarantee quality of assets to be installed and maintenance performed. In such a system, minimum quality specifications are prescribed and compliance with the standards is audited.

3 Condition-based methods: basic data needs

A vast amount of data is needed to feed railway infrastructure asset management decisions, as the infrastructure is build up by many different components that need to have both a structural quality and a geometrical quality. The infrastructure stretched over a long distance and has to meet quality requirements to allow traffic at a certain speed and axle load to pass over it. Basic examples of data needs are listed in the Table 1 below:

Table 1 Basic data needed for prediction and planning

Geometry measurements · alignment, · vertical, · twist, · crosslevel, · gauge, · quality indices, · number of faults per fault-category, · other user-specific parameters	**Inspections and other measurements** · General condition · Ballast condition (% surface soiling, % pumping, % weedy ballast) · Fastening condition (% ineffectual fastenings, % loose fastenings) · Sleeper condition (% bad sleepers, % medium sleepers, sleeper condition, clustering of bad sleepers) · Rail failures (number of failures, number of failures outside welding zones, % of defective rails) · Rail wear (vertical wear of rail-head, lateral wear of rail head, chamfered angle of rail-head) · Corrugation (amplitude of corrugation, vertical acceleration)
Layout and operating · Curves (start and end km, curve hand, radius, etc.) · Loads (annual load [MGT], maximum axle load [tons]) · Speeds (speed of freight trains and passenger trains) · Gradients (start, end, value)	**Superstructure and infrastructure** · Subgrade (geological condition, various monitored parameters, GPR data, cone-penetrometer data, etc.) · Ballast (ballast type, date of installation, thickness, etc.) · Sleepers (sleeper type, were sleepers new when laid, cumulative tonnage on sleepers when laid, sleeper spacing, type of fastening, date of installation) · Rails (rail type, jointed track or continuously welded, weld type, date of installation, were rails new when installed, cumulative tonnage on rails when installed) · Structures (type of structure, start and end km, code, name) · Switches and Crossings (type of a switch, code, name, start and end km)
Work history · Renewals, grinding and tamping work history (trackID, start+end km, type, cost) · Speed restriction history (start/end date of temporary speed restriction, reduced speed value, cost) · Spot maintenance history (trackID, start+end km, type, date, cost) · Inspection history (trackID, start+end km, type date, cost)	

One of the most important groups of data is the condition-monitoring data group. Table 2 includes some of the main categories of measurement (diagnostic) systems available on the market for measuring/acquiring condition-data:

Table 2 Diagnostic Systems

Track measurements · Track Geometry · Rail Profile · Rail Corrugation · Ballast Profile	**Overhead line measurements** · Overhead Line Geometry · Contact Wire Wear · Pantograph Interaction · Arc Detection · Overhead Line Electric Parameters
Vehicle dynamics measurements · Ride Quality · Body, bogie and axle boxes accelerations · Wheel-Rail Interaction Forces · Wheel-Rail Contact **Vision systems** · Automatic Rail Surface Defects detection · Automatic Overhead Line Defects detection	**Other monitoring** · Signaling · Telecommunication Quality · Environmental Temperature · Tunnel Ceiling status detection · Railway infrastructure kinematic envelope/gauge · Tunnel detection system · Positioning System · Monitoring of Signaling systems · Time Radio-Synchronization system
Video inspection · Railway Section and Surroundings · Track Surface · Overhead Line	· Platforms · Way Side

Obviously, complex analyses utilizing such a vast amount of data could never be performed manually. Computer-based Railway Infrastructure Asset Management Systems (RI-AMS) are needed with sufficient power and flexibility to handle multitude of data, situations and their variations.

4 Analysis and planning

The planning phase for Asset Management decisions can be realized by building the appropriate historical knowledge-base supported by further software tools for easy data access/correlation (e.g. work history data), processing and decision-making. ICT Methods and tools have been developed to collect and process the monitoring data in as much an automated manner as possible. This section will use the RI-AMS system developed by MerMec Group named RAMSYS (a Decision Support System for railway Infrastructure Maintenance & Renewal Management) to explain the way these systems operate [2, 3].

RAMSYS represents a dedicated system for Railway Infrastructure Maintenance Management designed to help Railway Infrastructure Managers to handle complex multidisciplinary and multidimensional process of infrastructure degradation by integrating all necessary information through advanced visualization, Figure 1, and analytical capabilities necessary for optimal planning of M&R works and permanent control of assets condition, Figure 2 & Figure 3.

RAMSYS system, being extremely complex, requires lot of space for proper description, thus in this paper only the basics will be provided. The main idea however is that it puts full focus on utilizing condition data for work planning. All condition data coming from various Diagnostic Systems are utilized simultaneously, together with the complete history to capture/define the "behavior" of each and every asset and then to use this "historic-perspective" to generate the "forecasted behavior", with the use of sophisticated deterioration models. Only based on the forecasted behavior and comparison to the required quality and incurred costs, the optimal combination of activities (M&R works, as well as inspections, etc.) can be defined and proposed for execution. Thus, RAMSYS has the ability to balance Maintenance versus Renewal

works, as well as quality versus costs, in order to define the optimal scenario, i.e. the M&R policy/strategy. Decision Support that RAMSYS provides is catered through the various data-analysis functionalities, typically divided into two Levels – **Low Level Analyses** and **High Level Analyses**. The session (typically Planning or Viewing) starts by selecting a piece of railway network to be analyzed. The selection is extremely simple – from the Tree View Structure on the left-hand side of the screen, the Lines/Tracks to be analyzed are simply selected into the Work Space area, starting and ending stationages defined and the Work Space saved (if necessary). Immediately upon that any kind of analysis (low or high level) can be initiated.
Low level Analysis – i.e. the deep analysis of any of the condition parameters, independently or in cross-examination with any number of other given parameters (see Figure 1). Data analysis at this level is easy and intuitive. Data can be arranged in any preferred way, overlaid and combined in any order allowing, in the first step, excellent overview of the situation and noticing of anomalies, e.g. threshold exceedences, local clustering of defects, etc. The user can quickly obtain trend plots, including the well-known "saw-tooth line" due to Maintenance & Renewal actions. The user specifies which works are to be included (those works that influence the displayed parameter) or specify a Threshold and calculate the time when it will be reached.

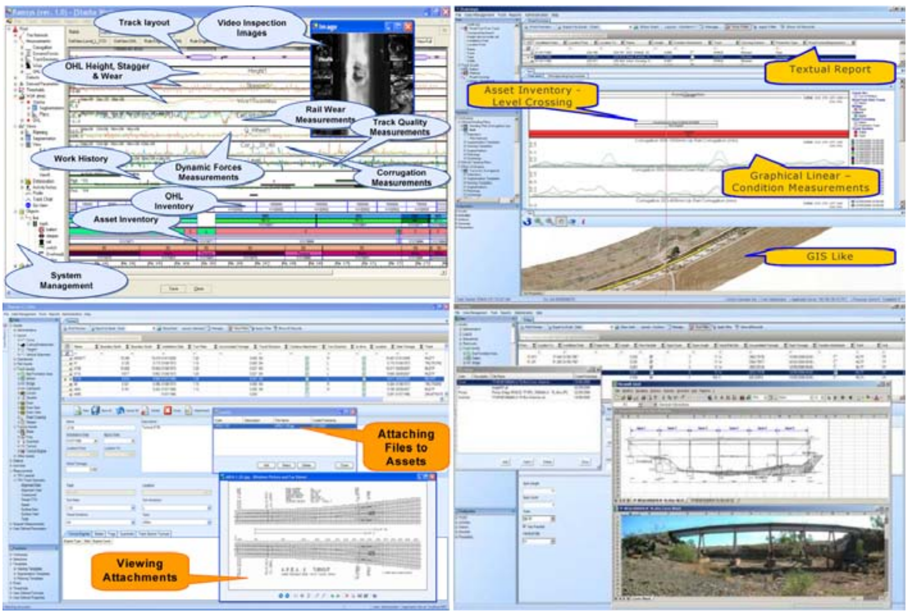

Figure 1 Visualization of various kinds of railway infrastructure assets and their related information

However, the above represents only a "quick", first hand, analysis. Deeper analysis of the deterioration trends of various parameters is provided within a specialized Deterioration View. In this view, depending on the Parameter settings (e.g. types of curves – linear, non-linear, polynomial, logarithmic, etc.) the time progression of the parameter is shown, as well as projected into the future based on the sophisticated Deterioration Models (see Figure 2).
High Level Analysis represents the automatic analysis of any part of a network on a short, middle and/or long term basis, based on the User-defined set of Decision Rules and Threshold, powered by the Deterioration Models. High-level analysis is performed on Segments. Segments in turn are the product of the Segmentation process, where the infrastructure (track, but also overhead-line (OHL), or any other structure that is feely definable in the system) is divided into Segments based on User pre-defined Criteria. The segmentation process is com-

pletely flexible and free of any constraints – segments can be within any length-span (e.g. between 10 and 200m, or any other) and its borders can be determined by the user.

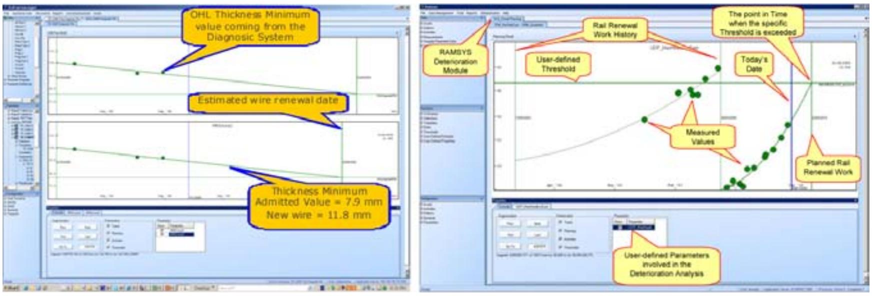

Figure 2 Linear and Non-linear Deterioration trends applied on different condition-parameters (Overhead Line Wire Thickness and Track Geometry Vertical Level, respectively) and visualized within RAMSYS Deterioration View

Based on such segments the automatic analyses are performed, based on User-defined set of Decision Rules and Thresholds, powered by Deterioration Models. Namely, within this analysis, for each and every segment, Decision Rules (differentiated by their relative importance) are run. Normally, the structure of a Decision Rule is such that it first checks if the segment satisfies certain conditions (e.g. if it holds certain type of rail, if it is main line or secondary) and then checks certain condition parameters against their respective thresholds and/or calculates when those thresholds would be reached, Figure 3 a).

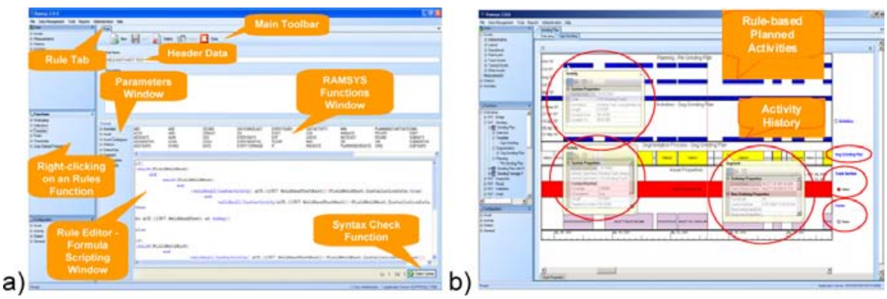

Figure 3 a) RAMSYS Decision-Rule Editor; b) M&R Work-Plan

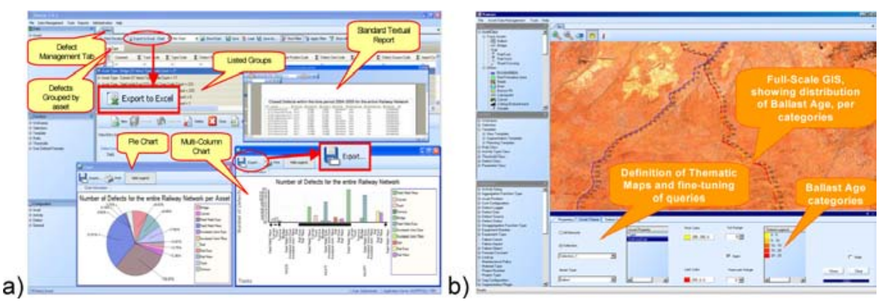

Figure 4 a) Reporting, Statistics and Exporting tools; b) GIS functionality

In order to calculate when these thresholds would be reached the Deterioration Models are used. Namely, in short, for every given condition parameter a “Deterioration Model” is assigned – typically, that would mean what type of curves (linear, non-linear, polynomial, exponential, logarithmic, etc.) and which are the “influencing M&R works”. Once this is described (pre-defined by the User), the system calculates, for every single segment, based on the Actual data (e.g. measurements and Work History) the Actual Curves that fit the behavior of this particular Segment. Based on this “captured behavior”, the system calculates the future behavior (e.g. deterioration, response to various works – i.e. their efficiency, etc.) and forecasts / proposes the Maintenance & Renewal plan including Inspections (see Figure 3 b). Obviously, results must be fully reportable, including full-battery of post-processing statistical tools, as well as exports into standard 3rd party software tools, Figure 4 a), as well as manageable through GIS functionality, Figure 4 b).

5 Conclusions

The described diagnostic systems and consequently the use of the acquired data, play fundamental role for any railway infrastructure manager and operator:

1. Infrastructure in poor condition and with poor performance compromises the railway network operations and safety and can cause high-cost consequences such as corrective maintenance and traffic hindrance.
2. Maintenance and renewal of assets represent the largest part of railways’ expenditures as well as requires significant resources (i.e. people, material, machines and/or line interruptions / possessions), so even the marginal improvements could yield significant absolute savings.

Diagnostic systems and described in this paper provide a comprehensive solution including proper set of measuring, inspection and analysis tools for supporting not only the diagnostics of the railway infrastructure, but also the planning of M&R works and improving the assertive power in taking M&R decisions. Main benefits of the described systems include:

- Reliable and fast data collection
- All measurements are in the digital format and as such they can directly be used to build a historical knowledge base to be used for advanced analysis
- Earlier/timely identification and correction of critical defects and mitigation of risks of critical defect occurrence
- Efficient usage of track access times, thus increasing track availability for the revenue traffic as well as freeing scarce time for engineering works
- Data related to different infrastructure subsystems can be correlated
- Transition from corrective to condition-based and predictive maintenance
- Choosing optimized M&R plans based on true infrastructure conditions

These possibilities will help to achieve the ultimate goal of increasing infrastructure safety and availability at minimum Life Cycle Costs and justify the investments and efforts made to develop and implement Asset Management systems. Because of the historic setting and recent restructuring, the adoption of Asset management involves a big change in methods, techniques and culture. It also means that much effort is needed to bring quality of input, such as asset registers, to a sufficient level. Implementation will often not be straightforward and requires openness to change at the side of Infrastructure Manager’s staff.

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