MODERN RAILWAY INFRASTRUCTURE ASSET MANAGEMENT

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ABSTRACT

Complexity of today's railway sector imposes high and often conflicting demands for 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 an Asset Management System (AMS) for Railway Infrastructure (RI). Putting together the databases and tools for such an AMS is the major challenge of today's railways. The Paper describes the modern concept of Railway Infrastructure Asset Management System as well as its main sub-systems and the activities they are supposed to handle:

Infrastructure Inventorying

- Defining RI objects
- Defining relevant RI objects' inventory information (attributes)
- Surveying RI objects' location
- Collecting, compiling and maintaining the inventory of all objects constituting RI

Infrastructure Condition Monitoring

- Defining RI objects needing condition monitoring
- Defining relevant RI objects' condition information (measurements)
- Organizing, scheduling and performing condition information collection (measurements)
- Storing RI objects' condition information
- Managing RI objects' condition information (e.g. presenting "raw" data)
- On-line real-time vs. continuous (regular time-based) monitoring

Infrastructure Life Cycle Management

- Managing RI objects condition (degradation modeling)
- Life Cycle Management principles
- Developing and applying cost-effective M&R strategies
- Maintenance vs. Renewal
- Life Cycle Costing
- Managing risks

Keywords: Railway, Infrastructure, Asset Management, Maintenance and Renewal, Resource Allocation, Optimization, Decision Support

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1. INTRODUCTION

In order to provide high-quality decision-support, any RI AMS requires large amount of data to be available. This data is usually contained in various databases and storage systems, which requires careful data-selection and transferring into the RI AMS database to be used for the infrastructure condition-analysis and work-planning purposes. This, in other words, means that the compilation of a RI AMS database practically represented Data Warehousing job for a specific RI AMS User. This work, however, to all those familiar with the Data Warehousing, is known to be a very sensitive one, cause all future analyses and consequent work-planning to be performed in the RI AMS, will be based on this data. Hence, the quality and reliability of the transferred data represent one of the two crucial issues and keys to success of any RI AMS implementation and use. The other crucial issue is the Rule-creation, i.e. the transfer of the User’s knowledge, standards and regulations (comprising in fact his overall Maintenance Policy) into RI AMS Decision Rules.

All of these issues must be faced and mastered during any RI AMS implementation at any railway, as was the case with the implementation of the system called “*RAMSYS*”, and the special version of it called “*InfraManager*” installed at the Italian Rail Infrastructure Provider RFI which will also be explained further on.

2. BASIC DATA NEEDED FOR PREDICTION AND PLANNING

In order to properly manage track maintenance a vast amount of data is needed. Types of data to be collected for computer-based RI AMS are summarized in Figure 1. Specific data are needed for proper monitoring of the various types of track deterioration.

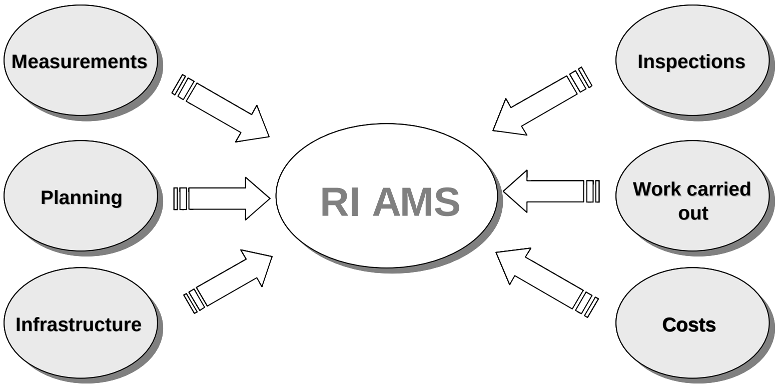

Figure 1. Types of data to be collected for computer- based RI AMS [1].

But before all the above data are collected and stored, in order to reference them properly to the appropriate objects or locations on the track, the actual location of the track objects along/and the accurate track layout must be established.

3. LOCATING RAILROAD ASSETS

With most of the World’s railroads approaching the age of 200 years, during which many reconstructions and corrections of the track layout happened, most of which have not been documented properly, the current track charts and layouts defining locations (e.g. stationages) of various railroad assets are effectively inaccurate, hence unreliable.

Also, with track segments being allowed to behave differently and knowing that the existence of various track objects (e.g. S&C, bridges, level-crossings, culverts, etc.) effects decisively this behavior, it is obvious that the location of such objects must be determined accurately. In fact, it is absolutely crucial that all the measurements and inspections are referenced to the right track location in order to fully and properly define its behavior.

This discrepancy between the actual and required accuracy, having in mind the extremely large extent of the railroad networks, could only be corrected by means of some extremely fast, yet accurate surveying system. Many engineers world-wide facing this problem searched for such systems, and effectively, arguably one of the most promising systems to be found nowadays is the FLI-MAP system, by Fugro Inpark b.v. Providing precisely what was needed, fast, efficient, yet accurate survey, this system was quickly adopted and utilized by many railroads world-wide (Spoornet-South Africa, AMTRAK NEC-U. S., Railtrack Scotland & South-East Zones, DB, SNCF, Romanian and Spanish Railways, etc.

FLI-MAP® (Fast Laser Imaging and Mapping Airborne Platform) (Figure 2) in fact represents a laser altimetry system, which measures points on the earth surface with a scanning laser from a helicopter. The system, which can be attached to several types of helicopters, passes over the area of interest collecting precise GPS, platform attitude, laser ranges, and imagery data. With two lasers' data collection rate of over 22,000 ranges per second, height above ground of 50 to 150 meter, and an aircraft velocity of 50 to 70 km/h, data density can vary between 5 and 25 points per square meter. This data density is required to differentiate objects such as transmission line structures, conductor, distribution poles, lines, rails, mileposts, signals, switches, etc. by recognizing patterns of points with spatial relationships.

FLI-MAP is a (land) corridor-mapping tool, which can provide engineering information to the Railroad, Electric Transmission, Flood Defense, Pipeline and Transportation Industries with numerous applications in many other industries. During the last four years the system has been used successfully in the United States of America, Australia, South Africa and Europe in more than 150 projects.

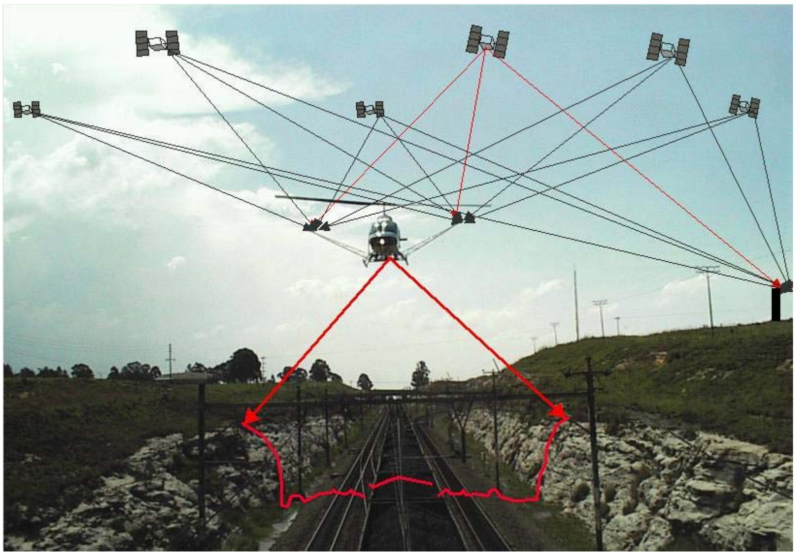

Figure 2. The FLI-MAP system.

For a typical railroad asset inventory project the flight altitude and speed will be set to produce a high data point density of about 15 points per m^2. This high point density makes it possible to map details such as power-line conductors and railroad features including switches, rails, mileposts, etc.

The purpose of deploying FLI-MAP is to define the accurate geographic position and attributes of all fixed assets in order to build an integrated information system to manage and maintain the fixed railway assets. The first step in establishing a RI AMS is to identify where all assets are located.

4. TRACK CONDITION MONITORING

The second crucial step in establishing a RI AMS is to measure regularly and accurately as many as possible of the relevant condition aspects of various infrastructure objects. Herewith several such systems dedicated to the measurement of various condition aspects of different railway infrastructure objects will be provided, along with their application for the Infrastructure Maintenance Management purpose and integration with RI AMS.

In Italy railway maintenance is undergoing a substantial change. The infrastructure operator RFI has recently added to its fleet of measuring cars an innovative diagnostic train-set, named "*ARCHIMEDE Diagnostic Train*", fully dedicated to the high speed monitoring of railway infrastructure, Figure 3. Basic facts on this train are given in Table 1.

The Italian company MER MEC S.p. A. has been responsible for the development and the integration of a complete set of measuring systems on board of ARCHIMEDE. Such train is aimed at profoundly modifying the management of infrastructure maintenance planning, by making available several measurements and information about both track and overhead line to enable an optimized planning of the Maintenance and Renewal works.

Table 1. Some basic facts on "ARCHIMEDE – Roger 2000" project.

Composed by 1 locomotive + 4 coaches + 1 driving coach	number of sensors: 157
Length of the train 150 m	number of video-cameras: 15
Traction Electrical - dual voltage (3 KV cc, 25 KV ac)	number of acquisition and processing boards: 350
Measuring Speed 0 ÷ 220 km/h (Self-propelled)	number of processing units: 50
2 millions of source code rows	number of monitors: 41
100.000 hours for design and development	number of instrumented pantographs: 4
90 engineers and technicians involved in design, development, test and calibration	length of optical fiber: 4 km
duration of the Roger 2000 project 2000-2003	network throughput: 30 Gbit/sec
	1 multimedia conference room and different meeting rooms
	1 room for visual inspection of overhead line

Figure 3. Archimede diagnostic train.

The monitoring systems integrated on board are able to carry out measurement regarding several aspects of the railway infrastructure, Table 2. The major advantage is that measurements and information concerning different aspects of the railway infrastructure such as track geometry, overhead line geometry and ride quality can be correlated and analyzed in an integrated way, this lead to a real and effective implementation of:

- *"condition-based" maintenance*, i.e. planning a work only when and where it is required.
- *Predictive Maintenance*, that is carrying out appropriate simulations based on the acquired data in order to potentially foresee the future behavior of the infrastructure.

Table 2. Parameters measured per some systems.

	Track Measurement
Track Geometry	Left/right longitudinal levels Left/right alignments Curvature Gauge Cant Twist (2m, 9m or user selected base)
Rail Profile	Vertical wear Horizontal wear Wear 45°
	Overhead line measurement
Overhead Line Geometry	Stagger (static/dynamic) Height (static/dynamic) Gradient of the contact wire Outside temperature
Contact Wire Wear	Wire thickness (up to 8 wires)
Pantograph Interaction	Contact strip vertical speed Pantograph / Overhead Line forces Contact strip accelerations Contact strips height Contact strips temperature Space domain frequency analysis Hard points
	Overhead line measurement
Arcing Measurement	Duration of each arc Number of all arcs Sum of all arcs duration Largest arc duration Percentage of arcing Arc location (Kilometric position)
Electric Parameters	Overhead Line voltage DC voltage up to 4.5 kV AC voltage up to 30 kV (50 Hz) Overhead Line drained current DC current up to 4 kA AC current up to 400 A (50 Hz) Time domain frequency analysis

	Other measuring systems
Telecommunications Monitoring	Field strength RxLevel RxQual Layer 3 parameters
Signaling Monitoring	FFT of common mode signal FFT of differential mode signal RMS of common mode signal RMS of differential mode signal Carriers Frequency Carriers Intensity Code Duty Cycle (traction current) RMS common mode signal (traction current) RMS differential mode signal De-codification codes Comparison codes with on board codes
	Track Measurement
Rail Corrugation	Rail corrugation in several wavebands in the range [20, 3000] mm
Surface Defects	Rail breakage Abrasion from skidding Shelling Flaw Corrugation Welding anomalies Rubble imprints Absence of fastener Cracks in the sleepers Integrity of sleepers fasteners
	Ride quality
Wheel-Rail Interaction Forces Measuring System	Real time Y & Q force monitoring Real time Y/Q ratio monitoring Bogie lateral acceleration correlation
Vehicle Accelerations	Comfort and RMS value index calculation, statistical analysis according to UIC 518
Wheel-Rail Contact Geometry	Angles of contact and equivalent conicity at several values of sigma

These measurements can be analyzed at two different levels:

- *Level 1*: analyzes the single parameter (e.g. gauge).
- *Level 2*: analyzes more than one parameter concerning one or more aspects of the railway infrastructure (e.g. track geometry + ride quality).

In addition to the above measurements equally important are the *Ultrasonic Rail inspections* providing invaluable insights into the existence and development of the internal rail defects. Timely detection of these defects is of vital importance for the railway operations cause some of them, under specific circumstances, could grow rapidly leading towards rail breakages. Visual inspections with/and various hand-held measurements are also of significant importance for integrated condition analysis.

5. VISUALIZATION

Considering the fact that the highly-sophisticated systems like all those presented in the text till here produce mountains of data (for example, ARCHIMEDE produces about one Terabyte of data every month), it is obviously impractical or arguably impossible to handle in the alphanumerical form. Instead, most of this data must be properly visualized in order for Users to gain insight into the actual behavior of the objects in question. Hence the utter need for high-quality visualization when it comes to infrastructure management. This is because, sometimes, even looking at the data if displayed in the proper and smart way can help infrastructure manager derive invaluable insights.

Figure 4 shows some of the visualization capabilities of the “RAMSYS” system (**R**ailway **A**sset **M**anagement **SYS**tem) developed by MERMEC. Important thing here is the complete freedom of the user in terms of defining Views and customizing them to his/her own needs and liking, as well as freedom in combining various data types in any user-defined way in order to gain better insight into mutual dependencies between the data, correlations in order to search for the root cause of the problems.

However, even the best visualization can take us only so far. Therefore, especially for larger-scale considerations and processing, alternative solutions must be sought.

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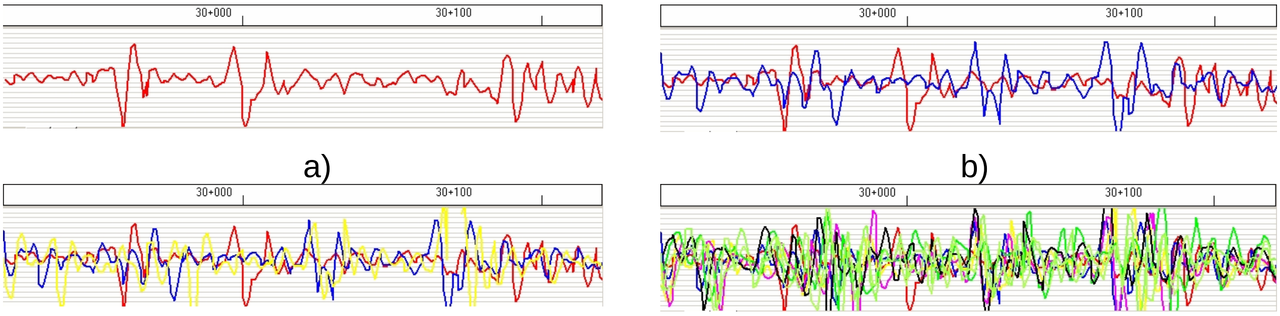
Figure 4. Some of the visualization functionalities of the RAMSYS system.

The Visualization limitations can best be realized on the Figure 5. Having one single measurement in a view allows very good insight into actual condition as it is changing along the track, a). Adding one more measurement (b) allows very clear determination of the temporal changes in the condition, either in terms of deterioration as a consequence of traffic loads and other detrimental influences, or restoration (improvement) as a consequence of M&R activities. However, already with adding the third measurement (c) brings difficulties in determining what exactly is happening with the condition over time; where was it deteriorating, where was it improving, where was it first deteriorating and later improving after M&R and how well was it improving, where was it not improving after M&R as we expected, etc. Finally, having more than 3 measurements at the same view (d) (in this particular case 9) creates a complete mess leaving the user with no capability whatsoever of determining how exactly was the condition changing.



a) b)

c) d)

Figure 5. Visualization limitations.

This is why for the more complex elaborations we need to resort to the utilization of segments, which is the only way of truly mastering the time prospective of the change in condition. Namely, the basic idea behind the Segmentation process is to divide (chop up) the infrastructure (e.g. track) elements into segments, of certain (possibly varying) lengths (the lengths will depend on the segmentation concept). Basically, all infrastructure elements characteristics can be labeled either “*defining*” or “*non-defining*”. The defining properties influence the segmentation in terms of segments’ starts and ends, whereas the non-defining ones do not. Basically, at the locations where any of the defining properties changes, a new segment is created and old one is finished. All the information, both defining and non-defining, are then assigned to so-created segments, including all properties and condition measurements aggregated down in terms of condition indices like standard deviations, averages, maximums, minimums, etc.

Now, if we take one such segment, and display for example standard deviation values calculated for several consecutive measurements, and display them in time, we could get the situation as on the Figure 6.

Now, in order to use the measured data to see whether the particular track segment was improving over time or deteriorating, and/or how was it deteriorating (i.e. to capture the behavior of the given track segment), we could attempt to calculate the trend line for the measured values over time. However, as can be seen on the slide (blue, dashed line), this may indicate that the track was improving over time (downward trend indicating decrease in measured values, indicating improvement), which, although wishful, seldom happens in practice. This again is suggesting that we were either misinterpreting the available data, or, which is more likely, were still missing some important piece information on it – most probably the Work History.

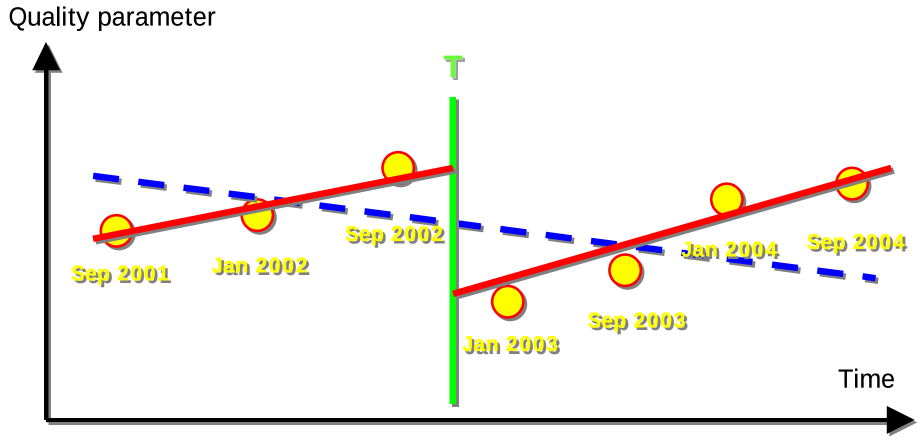


Figure 6. Temporal change of a condition parameter.

If we now, for example added information on the work history pertaining to this segment, e.g. adding the Tamping work at the moment when it occurred, we are suddenly obtaining a completely different picture (red solid lines), which is suggesting a completely different behavior, and which is much closer to the reality

But, even now, can we really say if this segment was performing well or badly? Well, we can attempt to judge by the slope of the trend lines indicating the "*speed/rate of deterioration*". But, the same slope (e.g. relatively high) could represent good behavior (or understandable, thus acceptable) for the "old" track that has seen a lot of traffic, and at the same time this slope could represent (very) bad behavior if the newly laid track was in question.

Therefore, it is obvious that in order to say whether the measured values are indicating that the track segment in question is good or bad, we need to know the age of that track segment, or/and the accumulated tonnage, but also most probably operating speed on that segment, possible presence of a switch, or level crossing, or bridge on that segment, perhaps also existence and intensity of the rail corrugation, presence of a curve(s), transition(s), slopes, etc.

This simple example illustrates the importance of having complete information and moreover, consistently complete and accurate information. Only in that case the information becomes reliable and usable. This is because, if there is one thing that is worse than having no data, it is having unreliable (let alone inaccurate) data. This is again because, if we had no data, we would know that, and try to make best engineering judgment as possible. On the other hand, if we did have the data, but this data was unreliable (or let alone inaccurate or wrong), which we did not know of, we are most likely going to base our decisions on it, and thus, all our decisions would also unavoidably be unreliable or wrong, which could have much more far-reaching consequences.

Representing condition data in time perspective and generating trends in fact brings us to yet another important issue and the implementation step in Asset Management, and that is Deterioration Modeling.

6. DETERIORATION MODELING

Deterioration modeling will be explained on the basis of the functionality embedded in the RAMSYS system. Track condition is defined by the condition of its components and its geometry. These two groups of elements are closely interrelated within the complex process of track deterioration and restoration; if one is in poor condition this will contribute to the deterioration of the other, and if the components are in poor condition it will not be possible to correct the geometry efficiently. Since it is known that different track sections tend to behave differently under the effects of loading, RAMSYS divides the track into segments as. Each of the segments is treated as a separate “organism” or object, which is allowed to have distinctly different behavior. This behavior, of each and every segment, is monitored throughout the (known) history (e.g. over the last several years), using various measurements (e.g. track geometry, rail-profile, ultrasonic, etc.) and various condition inspections (e.g. visual inspections) and thus “captured”. This means that by analyzing the history of the behavior of every segment, the pattern how this particular segment was behaving (deteriorating under traffic and other influences, as well as improving after the performance of maintenance and renewal works) is defined. Based on the so defined behavior, and knowing the allowable limits (thresholds) for various condition parameters, the moment when these limits will be reached in future is calculated/forecasted, and the appropriate M&R activity is determined. By doing so over the entire railway network (or a part of it) M&R plans are created and the associated costs calculated.

These costs can be further optimized using Cost Optimization tools, balancing the costs against the resulting quality, thus defining the final M&R Plan. These Plans can be viewed or further printed out, either in graphical or tabular form to be forwarded to the maintenance gangs or Contractors to be performed when scheduled.

The global idea of RAMSYS is to analyze the condition of the track elements (rails, sleepers, fastenings, ballast, etc.) from as many aspects as possible. This is why a track condition database should be quite extensive as explained earlier. The goal is to enable the track manager to see the "total picture", i.e. to simultaneously display all kinds of information that can influence the condition of the track, in order to search for the real cause of certain track problems and reach decisions about the best possible remedial actions, which is exactly what makes RAMSYS a *“Track Manager’s Desktop”.* This decision-making can be performed either *manually,* displaying and overlaying simultaneously all sorts of information, or *automatically* using the decision rules defined by the User.

6.1 The Basics of the Analysis Principle [3]

General explanation of the diagnostic principle could be seen on the Figure 7. The basic idea of the diagnosis principle is that the behavior of track geometry of a certain segment, expressed via certain geometry parameter, is being monitored in time and thus captured.

The thick green line shows the hypothetical deterioration of the track geometry if the track was let to deteriorate without any maintenance input. On this line we can also distinguish three phases: the first one, often referred also as “youth”, which occurs immediately upon a (re)construction or completion of certain major renewal work and which characterizes rapid and substantial deterioration due to the initial settlements of the track (Figure 7, the part of the curved green line marked with “a”). This period is also highly unpredictable and differs considerably from one track section to another and thus very hard to model. This is why this period is usually disregarded by discarding any geometry measurements performed within this period from any analyses. The length of this period is fortunately quite short, which diminishes the consequences of its omitting.

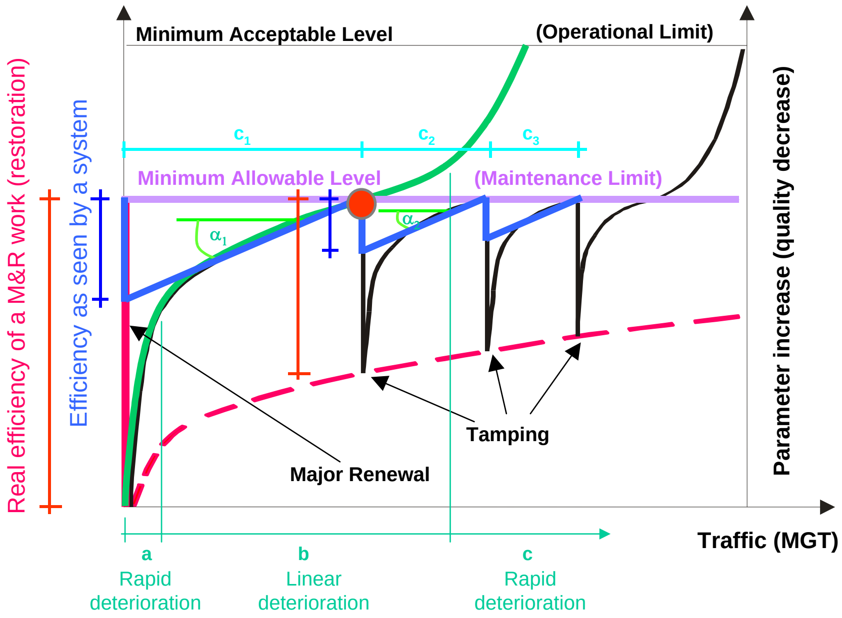


Figure 7. [3] Analysis principle applied on a hypothetical track geometry deterioration.

The second phase, which occurs once the track has been sufficiently stabilized, shows more or less linear deterioration pattern. This kind of behavior is present during the most of the track lifetime and this is exactly the period on which the most of the analyses are based (Figure 7, the part of the curved green line marked with “b”).

The third period occurs in the latter part of the track lifetime and is characterized by more and more rapid deterioration, which eventually takes up even exponential-like form (Figure 7, marked with “c”). Normally, this is the situation which should never be allowed to happen at any circumstances, cause it could effect the safety of traffic as well. This is avoided by applying certain appropriate M&R works at a much earlier stage, i.e. there is always a pre-set maintenance threshold value (horizontal purple line), which when reached triggers certain M&R activity.

Based on this concept, measurement data within the normal (linear) part of the track behavior are being analyzed. This way the track geometry behavior is being “captured” by calculating the trend line through the measured points and extrapolating it. Then, provided that the maintenance threshold had been set (purple horizontal line), the moment (or the tonnage) when this extrapolated line will reach the threshold is being calculated, marking the moment when certain M&R activity, e.g. tamping should be performed.

Furthermore, after tamping has been performed, the parameter value abruptly drops, i.e. the quality increases again. On a Figure 7 this is represented by the vertical distance marked with red (real parameter drops), or blue vertical distance and vertical drops in the thick blue saw-tooth-like line (simulated parameter drops). After the quality has been improved by tamping, deterioration process will start again. However, over the time, as the track grows older, several things change. The first thing that changes is the efficiency of tamping, e.g. the intensity of the “vertical drop”. This can be observed both at the line showing “real behavior” of the track (red vertical dimensioning line) or the simulated linear one (thick blue saw-tooth-like line), or even better from the dashed red line showing this change over time. Other thing that changes is the “deterioration rate”, i.e. the slope of the line defined by measured points (represented with green angle marked with α_1 & α_2). Finally, both of these two events have their impact on the required tamping frequency, which becomes higher and higher, i.e. the time period between two tamping works (tamping cycle) becomes shorter and shorter. Eventually, tamping frequency becomes so high, that tamping becomes inefficient, but rather there is something else needed to be done, i.e. some other M&R activity, like for example ballast renewal. This kind of logic has also been adopted in the RAMSYS system to search for the optimal work to be done on a certain track section, i.e. for the decision-making process incorporated in RAMSYS.

7. CONCLUSIONS

It is obvious that due to the great expenditures made on railway infrastructure M&R every year, even marginal improvements in the M&R Management RI AMS will most certainly bring could yield significant absolute savings. RI AMS have proven to be very capable, providing solutions to the difficult problems of maintaining infrastructure at the required quality levels helping resolve delicate trade-offs between maintenance and renewal as well as costs and quality. Extensive database and powerful decision-rules ensured thorough yet quick track condition-analysis, enabling track managers to investigate different scenarios in order to arrive at the optimal M&R Plans. RI AMS have also paved the path towards replacing the prescriptive M&R with the condition-based preventive one. This all meant that using RI AMS, M&R can finally be scheduled only if really needed, only where really needed and only when really needed, thus considerably minimizing the costs, while improving the quality and efficiency of the railway infrastructure.

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