A LOGICAL FRAMEWORK AND INTEGRATED ARCHITECTURE FOR THE RAIL MAINTENANCE AUTOMATION

Cores, F.; Caceres, N.; Benitez, F.G.
Transportation Engineering, Faculty of Engineering, University of Sevilla.
Escriba, S.; Jimenez-Redondo, N.
CEMOSA, Malaga.

1. INTRODUCTION

The maintenance of the railway infrastructure is a complex process that represents a significant percentage of total railway infrastructure costs. The state of infrastructure depends on many factors such as the characteristics and age of the elements, the track geometry, topography and geology, weather conditions and supporting loads. Furthermore, the saturation of the capacity of the track sections as a result of increased load of rail services requires intensified maintenance and the planning and coordination of the rail activities, in order to accommodate maintenance tasks to the availability of time windows needed to guarantee technical regulatory levels. Finally, the maintenance management based on cyclical preventive works and on corrective maintenance entails high costs in both resources reliability and availability of infrastructure. This situation requires the streamlining of the maintenance management based on monitoring the track condition, automating the planning management and especially monitoring the evolution of the parameters that determine the track condition for predictive maintenance and risk analysis. This schema would allow evolving the maintenance management model based on corrective/preventive maintenance into a model based on conditions/predictions, helping those responsible for making decisions to achieve optimal maintenance plans that minimise the maintenance costs, ensure a satisfactory safety margin and prevent quick degradation of track quality.

2. THE ACEM-RAIL PROJECT

ACEM-Rail (ACEM-Rail, 2013) is a project funded by the European VIIFP for the organization and control of the maintenance of railway infrastructure. The project aims the development of new technologies for the automation of the maintenance management with the goal of reducing costs, time and resources required for maintenance activities and, therefore increasing the availability of infrastructure.

ACEM-Rail project is based on five pillars:

- development of several technologies for the automated and cost effective inspection of the track (some of them on-board of commercial trains);
- development of algorithms for assessing the state of the infrastructure and estimating the evolution of defects;
- development of optimization algorithms and techniques for planning and scheduling the maintenance tasks in short, mid and long term;
- development of technologies and tools for monitoring the proper execution of maintenance tasks by the use of mobile devices;
- development of an effective Infrastructure Subsystem Management that supports the decision-making process and is responsible of the management of the railways maintenance;

  This last component is the one presented in this communication.

3. INFRASTRUCTURE SUBSYSTEM MANAGEMENT (ISM)

ISM is designed in order to help managers of railway infrastructures use quality data and make objective judgements in selecting maintenance strategies. The system is intended to be a decision making tool that creates a framework for both long and short-term planning. In particular, it includes and combines all kinds of specialised monitoring, data collection and decision support systems.

As a fundamental objective of the functions assigned to project management system are:

- Automation of maintenance. The system allows the automation of the entire process, from the assessment and prediction of track conditions, planning of maintenance tasks, generation and communication of work orders, and storing the results and incidents of the maintenance operations.
- Integrates condition monitoring, planning and maintenance operations in the same platform. Compatibility problems associated with the use and interpretation of different tools are avoided by providing all the maintenance information in a single tool.
- Enables the generation of statistics, reports and summaries about the different maintenance components. By storing all the historic information about the maintenance, the system provides with reliable statistics and allows making inferences about the different factors that may influence maintenance: materials, machinery, critical areas, operators, execution procedures, etc...
- Provides with specialized interfaces adapted to the user necessities. Tools like GIS, charts, Straightline Chart, etc. facilitates the processing of

information and interaction with the user in a visual, easy and intuitive manner.

3.1 ISM in ACEM-Rail context

ISM is the core of ACEM-Rail project, being the integrator of all relevant information, and the channel through which information is communicated from one to other project components, causing the entire system to work coherent and coordinated. Figure 1 show the basic relationships between the ISM and the different components of ACEM-Rail project.

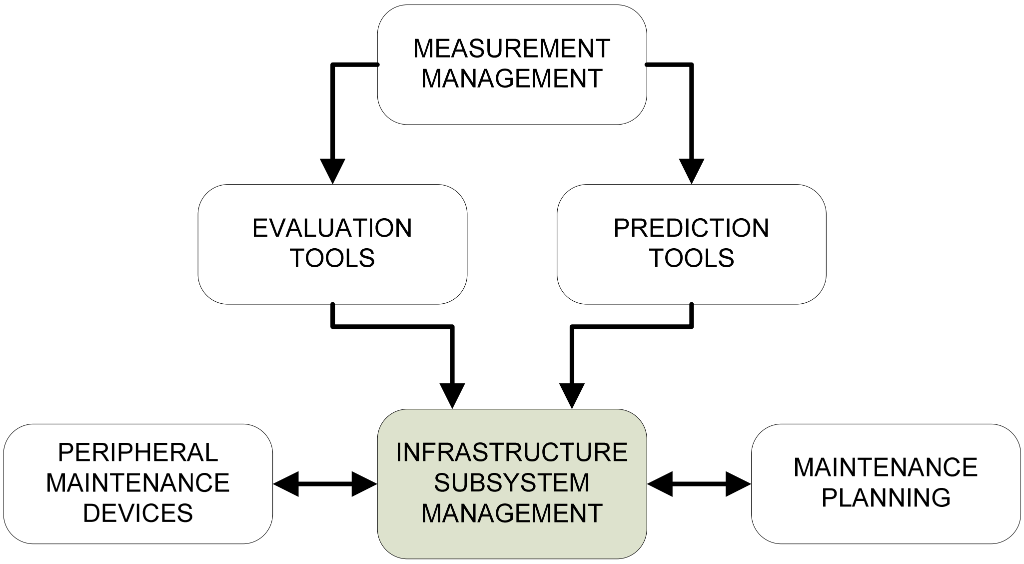

Figure 1: ISM in ACEM-Rail context

The other components of ACEM-Rail project that interacts with ISM are:

- **Measurement Management** is the platform for the collection and transmission of measured data captured by on board sensors. The platform provides with a database for the storage of all historical measurement, but it also includes specific algorithms for the correction and alignment of the data obtained in different inspection runs.
- **Evaluation Tools** is the condition monitoring component. These tools analyse sensor measurements in order to asses the infrastructure state providing with quality indexes based on different track parameters and with warnings about possible detected problems. These tools are built specifically for each sensoring instrument.
- **Prediction tools** block estimates the degradation of the infrastructure and the propagation of defects. These algorithms simulate the interaction between the vehicle wheels and the rails to quantify the loads and stresses that are generated on the track. With the results of this interaction the component

estimates the deterioration of the track by applying theoretical models for each type of defect. The results are calculated for each homogeneous segment of the track in terms of geometry, composition and supporting loads.

- **Maintenance Planning** algorithms are developed for the optimal schedule of maintenance tasks in order to minimize costs, use of resources and impact on rail services and traffic. Maintenance planning is divided into Tactical Planning and Operational Planning. **Tactical Planning** is designed for mid and long term optimization. This tool analyses the data coming from the evaluation and prediction of the infrastructure condition in order to make decisions on the necessary maintenance tasks to be performed in the future. **Operational Planning** is specialized in short term optimization. It focuses on planning the tasks and the allocation of resources for the next days and weeks.
- **Peripheral maintenance devices** system provides the maintenance operators with mobile devices that allow the management and reporting of work orders off-line. With these peripherals, the Maintenance Team is informed with the work orders assigned and they can report the evolution of the maintenance operation, incidents and information captured during on-field inspection. As a result, this information is available at any time at the office and on the field.

3.2 ISM architecture

The ISM has a modular architecture built on subsystems (algorithms and data) under the shelter of software specialized in assets maintenance management. To meet these objectives, the system incorporates a number of internal tools (programmed on the system) that communicate with the same external tools, developed in other blocks. The most important components of ISM are:

- **CMMS** is the main component of ISM. The solution adopted for the project is IBM Maximo (IBM, 2012a) that provides with most of the modules required for the maintenance management like: asset, inventory, resources, and preventive maintenance, work orders, etc. Figure 2 shows the main modules of CMMS. IBM Maximo includes an extension for Linear Asset Management (LAM). This extension provides with functionalities for the *dynamic segmentation* of the line, allowing specifying attributes and features along the railway lines and also facilitates defining *linear relationships* between linear assets like intersections, parallel, grade crossing, etc.

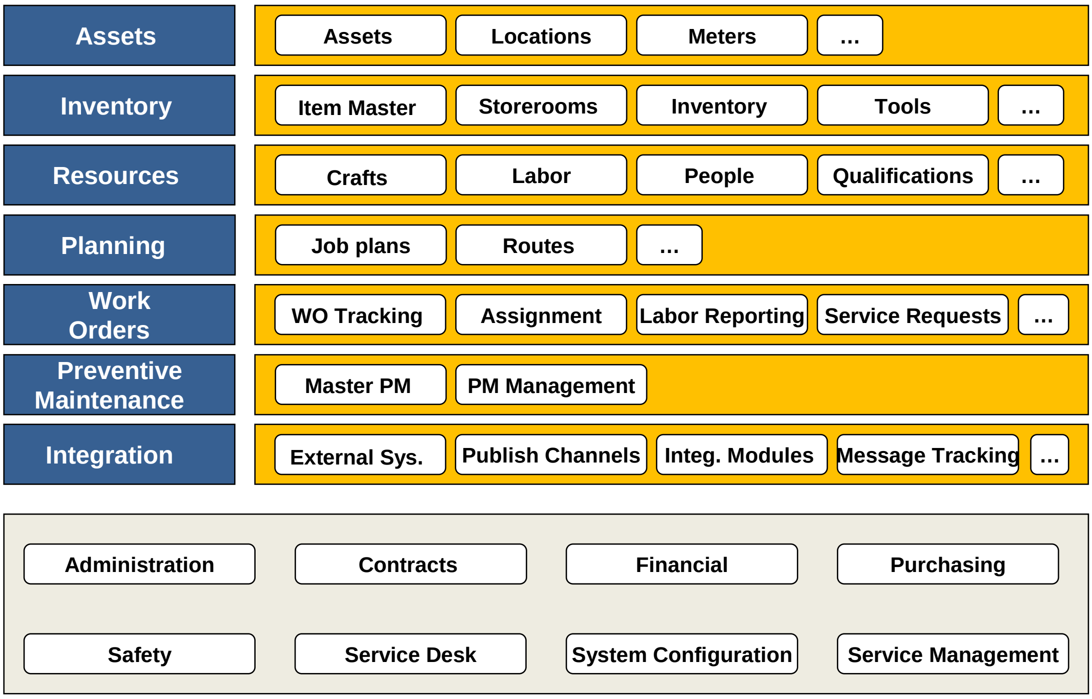

Figure 2: Overview of CMMS applications

The selected CMMS is an advanced, flexible and highly customizable solution. The other ISM components have been developed and integrated into IBM Maximo by overriding and extending the application functionalities.

- The **Railway services** module provides with summarised information about the circulation of trains over the railway infrastructure. The information is simplified by the generation of service patterns that represent the circulation of trains in specific days. Service patterns are associated to assets by a full calendar that specifies the circulating load each day. This information is used to estimate the infrastructure degradation caused by the interaction of train wheels and rails, and also it provides with costs of the track possession caused by the disruption of the railway services during maintenance operations.
- **Defect catalog** module is responsible for the definition and specification of railway defects that are considered. Defects have different severity levels or risks regarding on the level of degradation of the track, the dimensions of the defect and the location along the track segment. Each defect has associated the list of maintenance procedures that can be applied to correct the problem at each degradation level. With this information the system can estimate the cost, time and resources that are necessary to perform the work.
- **Track condition** module is the component that manages and integrates, into the ISM, the historical data about the infrastructure quality indexes provided by the Evaluation Tools. Evaluation tools translate sensor signals captured

during inspections into track quality parameters that represent the state of particular characteristics of the infrastructure. With this transformation, evaluation tools simplify the complexity in interpreting the sensor signals by generating a friendly understandable indicator about the track state. The quality parameters defined in the project are classified into: track alignment (lateral and vertical rail alignment, gauge deviation, etc.), shape (rail profile shape, rail profile roll error), comfort (vibration level, noise level, track flexibility, etc.), crack (crack on top, on side, on web, etc.), safety (derailment safety ratio, wheel unloading safety ratio) and stability (stability index). This information can be used to have an overview of the state of the track, to determine the most critical areas, to identify the most frequent problems and how the track state have evolved with time.

- **Predictive maintenance** estimates the probabilities of degradation in the deterioration process of the known defects. The algorithm applied to estimate transition probabilities is based in time-dependant stochastic process. This algorithm considers that the degradation of a defect in a time interval has a probability distribution function with a predefined shape. The scale coefficient of the density function is calculated for each time interval in order to adjust the mean of the cumulative distribution with the degradation curve of the defect. The degradation curve and the density function are specific for each type of defect and track segment and correspond to the estimates generated by prediction tools. When two or more track segments are affected by the same defect, the algorithm calculates the transition probabilities for each segment and returns the most critical degradation path. Figure 3 shows the evolution of defect degradation probabilities with the time.

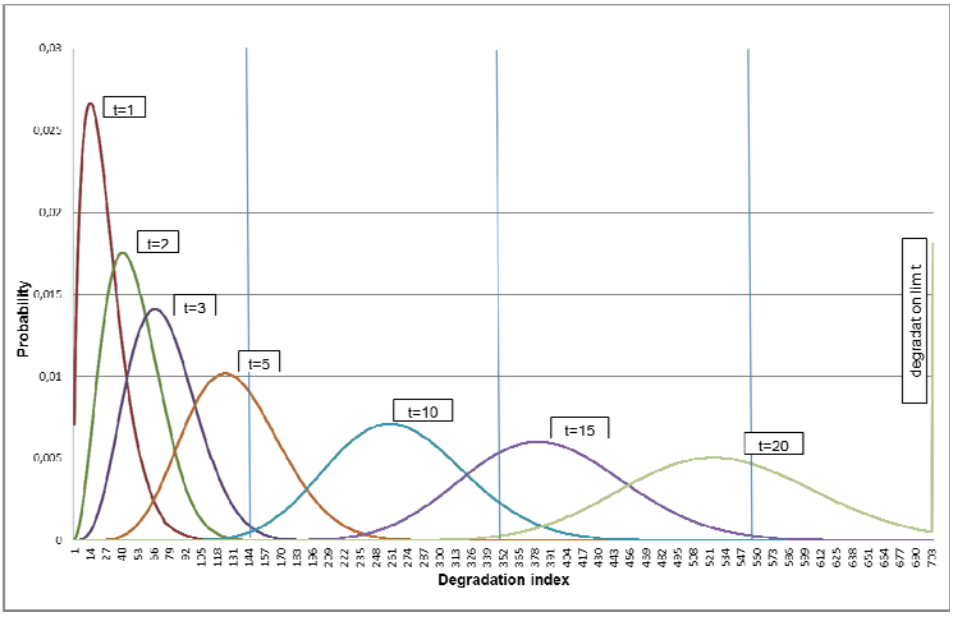

Figure 3: Deterioration process for the calculation of transition probabilities

- **Operation management** module is the ISM component responsible of the communications and synchronizations between CMMS and Peripheral Devices Server. The component consists in a bidirectional communication interface that transmits the work orders that are assigned and planned for the next days to the Peripheral Devices Server, and receives the progress, results and incidents detected during the job.
- **Warning management** module is the core of maintenance management of ISM. Warnings correspond with defects, degradations of the track or abnormal conditions of the infrastructure that require control, monitoring and finally correction. This component manages the maintenance life cycle of the warning from the entry point (notification of a defect) to the end point (the warning is cancelled or the defect is corrected).

3.3 Warning management workflow

Warning management implements a generic workflow to allow the processing of warnings. This workflow is represented in Figure 4.

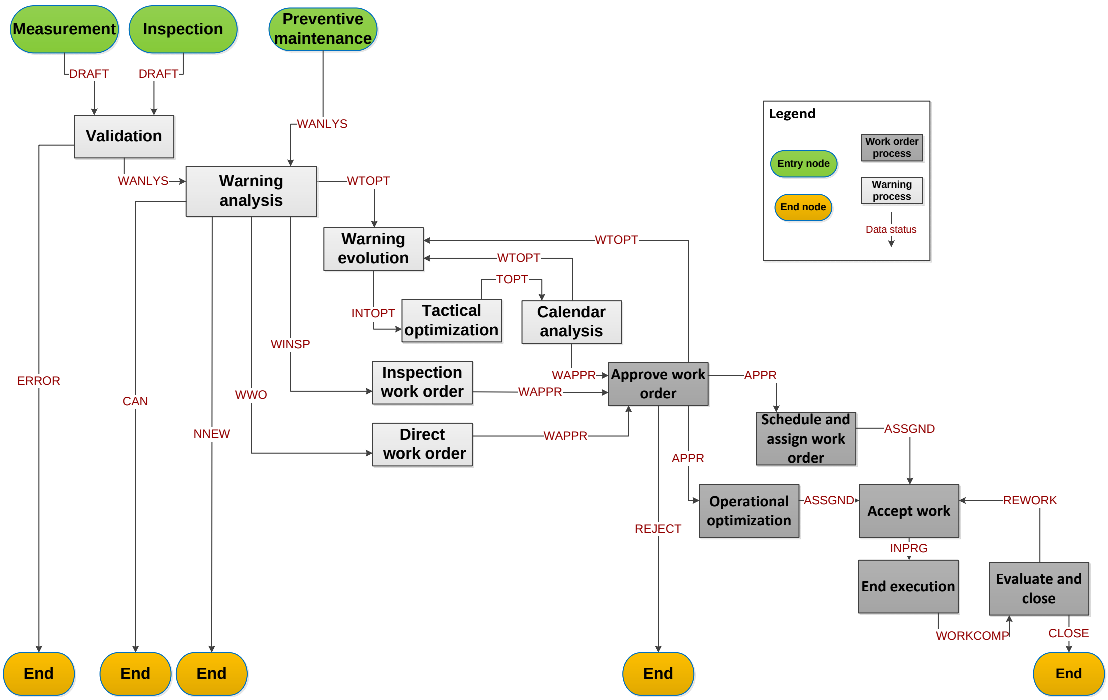

Figure 4: Warning management workflow

- **Entry points:** The management cycle starts with the notification of new warnings to the system. The warnings come from either i) Evaluation Tools, after the analysis of the auscultations in the last inspection run; or/and ii) inspectors and maintenance operators during a visual inspection or the execution of a work order. These warnings are registered with the status of *DRAFT*, being necessary to validate the information.

Preventive maintenance is also treated as warnings with the objective of considering all maintenance operations when performing planning optimizations. In this way, optimization algorithms make decisions in delaying the execution of a preventive maintenance operation in order to prioritise other operations with higher risk or high transition cost when degrading. Preventive warnings are registered with the status of *WANLYS* (waiting analysis).

- **Validation:** Validation is a simple process that checks the information provided by the warning verifying that is complete and coherent. The status of correct warnings is set to *WANLYS* while the status of wrong warnings is set to *ERROR*.
- **Warning analysis:** The same defect can be detected multiple times. Inspection trains are equipped with different sensors, each one with its own capability and reliability in detecting specific defects. In the other hand, the same defect will be detected in the periodic inspections until the end of its maintenance cycle. This process analyses each warning in order to evaluate the probability and consistency of the warning, and to determine whether the warning corresponds to a known problem or is a new one. When a previous warning exists, the process estimates the current status of the defect as a function of the age of the data and the precision in detecting the problem in each measurement.

  With the new information, the process must decide the next action in the management of the defect. For warnings with pour reliability, the warning status is set to *WINSP* (waiting for visual inspection); when the warning is precise and the risk and priority associated to the severity of the defect is high, the warning status is set to *WWO* (waiting work order). In other cases the warning status is set to *WTOPT* (waiting tactical optimization).

- **Inspection work order:** The process generates a new inspection work order for the revision of the defect. The warning status is set to *WAPPR* (waiting approval) and warning management delegates the maintenance management of the defect to the CMMS Work Order.
- **Direct work order:** For high risk warnings, the system generates a new corrective maintenance work order with the execution procedure that corresponds to the severity level of the defect. The warning status is set to *WAPPR* (waiting approval) and warning management delegates the maintenance management of the defect to the CMMS Work Order.
- **Warning evolution:** This process estimates the degradation of the defect and generates the Markovian transition matrix that is required for optimizing the

maintenance plan. The warning status is set to *INTOPT* (in tactical optimization).

- **Tactical optimization:** Tactical planning algorithm is responsible for the optimization of the global maintenance plan in mid and long term. The optimization algorithm schedules the maintenance operation of known problems (corrective and preventive warnings) and determines the execution procedure that must be applied to each problem. The optimization objective is to minimize the global maintenance cost by ensuring the reliability and security of the railway infrastructure. This process is responsible for preparing the data required for tactical planning such as:
  - Known problems to be tactically planned: This information includes the corrective and preventive warnings in the further months and years, their degradation trend, possible execution procedures for each problem and the maintenance costs and time for each alternative.
  - Maintenance capacity: List of maintenance resources with their corresponding capacity in terms of the number of hours available each month.
  - Statistical information about the maintenance procedures: This data consists in the listing of the different maintenance procedures with their information about the historical frequency, costs, requirement of resources and the degradation when no action is taken.
- **Calendar analysis:** Tactical Planning generates the optimal maintenance plan with a horizon of two to three years. During this period, new defects will be detected, not guarantying that the plan remains optimal for mid and long term. This process selects the warnings which maintenance is planned for the next weeks and generates the corresponding work order for the corrective operations. The status of these warnings is set to *WAPPR* (waiting approval) and warning management delegates the maintenance management of the defect to the CMMS Work Order. The rest of warnings are reintroduced into the planning loop by setting their status to *WTOPT* (waiting tactical optimization).
- **Approve work order:** Before a work order is generated, all the life cycle of the warning has to be processed automatically. In this step, the system delegates the decision to the maintenance manager. The manager can reject the work order proposed by the system, finalizing the maintenance cycle of the warning (status set to REJECT). Another option is to delay the maintenance operation by returning the warning to the planning loop (the work order is eliminated and the warning status is set to *WTOPT*). Finally, the manager can approve the work order setting the status to *APPR*.

- **Operational optimization:** Operational planning algorithm performs the short term optimization of very specific maintenance operations that are characterized for being very costly, resource consuming and with high disruption on railway services. The optimization minimizes the global maintenance costs by ensuring that all the operations have been performed in the available maintenance time window. The algorithm is focused in two different variables: Cost and time for displacing the resources from one operation to others; the cost of delaying the maintenance of each problem.

  This process extracts and prepares the information required by Operational planning algorithm. When the optimal plan is generated, the process updates the schedule of the work orders and assigns the resources required to perform the job. Finally, the work order status is set to *ASSGND* (scheduled and assigned).

- **Schedule and assign work order:** The maintenance operations that are not considered in the operational optimization require that the maintenance manager defines the dates to perform the job and assigns the resources. The work order status is set to *ASSGND.*
- **Accept work:** The maintenance operator must accept the work order assigner in order to start the execution of the operation. The work order status is set to *INPRG* (in progress).
- **End execution:** The maintenance operations have been performed and the execution is finished. The work order status is set to *WORKCOMP* (work completed).
- **Evaluation and close:** An organization inspector evaluates the maintenance results, formalizes the paper work and closes the incident setting the status to *CLOSE* (finished and closed). In case the result is not satisfactory, the status of the work order is set to *REWORK*.

BIBLIOGRAPHY

ACEM-Rail (2013). *D6.1 Report and prototype on the system for management of infrastructure subsystem*. ACEM-Rail: Automated and cost effective maintenance for railway. EU FP7. European Commission. Research Directorate General. FP7-SST-2010-RTD-1. http://www.acem-rail.eu.

IBM (2012) Maximo Asset Management. https://www.ibm.com/developerworks/wikis/display/tivolidoccentral/IBM+Maximo+Asset+Management.