Towards automated and cost-efficient track maintenance. Final developments of the ACEM-Rail project

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Abstract

This paper presents the latest developments of the FP7 project ACEM-Rail. It focuses on the development of techniques and tools to automate track maintenance tasks. It covers developments in inspection techniques, systems and tools to manage and organize all the information together with data analysis and decision support tools and definition of Maintenance Performance Indicators to evaluate the sustainability of the maintenance process. The results of the embarked on commercial trains inspection technologies have been very promising as well as the benefits of the comprehensive tool to manage the railway infrastructure maintenance. The combination of the above concepts (inspection, data management and Decision Support Tools) is not reported in previous experiences/research projects.

Keywords: Tracking; maintenance; automated; cost-effective; infrastructure management system; inspection technologies; optimization; mobile tools; ACEM-Rail

Résumé

Cet article présente les derniers développements du projet FP7 ACEM-Rail. Il met l’accent sur le développement des techniques et des outils pour automatiser les tâches de maintenance des voies. Il couvre les développements en matière d’inspection de la voie, des systèmes et des outils pour gérer et organiser toutes les informations ainsi que l’analyse des données et des outils d’aide à la décision et la définition des indicateurs de performance de la maintenance pour évaluer la viabilité du processus de maintenance. Les résultats des technologies d’inspection embarquée sur trains commerciaux ont été très prometteurs ainsi que les avantages de l’outil complet pour gérer l’entretien de l’infrastructure ferroviaire. La combinaison de ces concepts (inspection, gestion des données et des outils d’aide à la décision) n’est pas reporté dans précédent expériences ou projets de recherche

Mots-clé: Voie, maintenance, automatisé, rentable, système de gestion de l’infrastructure, les technologies d’inspection; optimisation, outils mobiles; ACEM-Rail

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1. The scope of ACEM-Rail: track maintenance

Railway infrastructure can be broadly structured into: the track, the power supply system and the signalling/communication. It is a complex infrastructure that requires a high degree of safety and reliability. The maintenance of this system is a complicated and expensive task which represents an important share of total railway infrastructure costs. On the other hand, the maintenance of the track represents around 40% of the total maintenance cost of the railway system.

The state of track 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 and coordination, 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.

The ACEM-Rail Project is an FP7 project funded by the European Commission whose duration is 36 months. It started in December 2010. It focuses on track maintenance. This paper presents its main achievements. The project aims at the development of new technologies oriented towards the automation of the track maintenance and maintenance management with the goal of reducing costs, time and resources for maintenance activities thereby increasing the availability of the infrastructure and the quality of rail services.

2. The state of art/practice in track maintenance and the progress beyond achieved by ACEM-Rail

Track maintenance is still a very little automated process based on rules established a long time ago (preventive maintenance) complemented by the execution of on-call corrective tasks whenever there are faults in the system. Track maintenance is still a very little automated procedure which relies on the skills of specialised human operators. On the other hand, as railway uses increases so does the need for maintenance while the availability of the track for maintenance decreases. As a consequence, the work is mostly carried out outside of daylight conditions and under pressure increasing the risk of staff accidents.

The maintenance of the track requires of inspections on the track. Such inspections are mainly visual performed by operators walking along the track, sometimes after drivers alerts. Small vehicles (often two axles ones) loaded with track geometry evaluation instruments can also run along the track. More sophisticated, complex and expensive track inspection vehicles are also owned by Railway administrators to cover the entire national network. These vehicles perform comprehensive inspection of the track. They run on more important lines and its schedule is planed with enough anticipation as usually there is only one inspection vehicle for the whole country.

Data collected by any of the above means (visual ones or by monitoring equipment) can be reported in paper or in electronic format. Severe faults are reported at once and immediate actions are taken. Other non-urgent defects are delivered to the central/regional office where the defects are evaluated by rather simple algorithms and ranked by severity indexes.

ACEM-Rail aims for the automation of track maintenance. It has tackled the whole process of track maintenance. This is an important feature of the ACEM-Rail with respect to other similar FP7 projects such as: PM’n’IDEA (www.pmniea.eu), which deals with novel sensor technologies and assessment methods of track integrity in urban lines; SUSTRAIL (www.sustrail.eu), which deals with the design of new vehicles and track systems for enhancing freight transport, including a set of predictive maintenance tools; AUTOMAIN
ACEM-Rail is the first project which pursues innovations the whole process of railway maintenance while considering the cost-effective approach in every one of the following subsystems:

- the monitoring and gathering information on the track,
- the evaluation of track condition and the estimation of defect evolution,
- the optimization of maintenance tasks covering from the very short term (today or this week), to the medium term (two months ahead) or long term (12 months ahead),
- and the monitoring of the execution of maintenance and the reporting/feedback of maintenance staff.

With respect to item 1 above, one of the most promising results of the ACEM-Rail project is the development of monitoring technologies to be embarked on commercial trains (freight or passenger). This is the unattended measurement concept which is not new. A large scale experiment on this subject started years ago in the UK (about 30 trains to be equipped). Eventually it failed, probably due to unreliable components and wrong software architecture. Other experiments are known, but none is in commercial operation at this time.

Embarking inspection techniques on commercial trains to automatically inspect the track would significantly save maintenance costs because: i) expensive measurement train wouldn’t be required, ii) cost of performing the operation (crew, traction, etc) would be saved and iii) slots for maintenance operations, difficult to find on busy lines, wouldn’t be required as the track as inspected at the same time that rail services are provided. Therefore, the track availability for service would increase. Moreover, because the train would be on service, normally going up and down the same line everyday, the frequency of the measurements would be high.

Items 2 and 3 above are oriented towards the development of an intelligent maintenance tool. Such tool can be conceived as a comprehensive and holistic asset management tool including the inventory of asset (infrastructure assets with their characteristics and location), human and technical resources (staff and machinery/equipment to perform maintenance tasks), schedule of rail service, etc together with some decisions support algorithms to organize and optimise the planning and execution of maintenance tasks. Such an Intelligent Maintenance tool cannot be found yet in modern railway systems. As already mentioned, coarse algorithms are use to organise the maintenance task by experienced staff.

Summarizing ACEM-Rail has contribute to the progress of the state of the art in cost-effective railway maintenance mainly because of its achievement in the fields of automated inspection techniques embarked on commercial trains and intelligent maintenance tools. Other developments were performed in non-embarked inspection techniques. Besides, mobile tools have been developed to assist the operator infield in the execution of maintenance tasks and to reduce the paper reporting.

3. The ACEM-Rail project: general overview

ACEM-Rail performs a deep analysis of the different fields involved in track maintenance structured in three blocks and seven items.

Block I: Evaluation of track condition

- Inspection techniques and defects detection. Within the project, several instrumentation techniques have been developed for the inspection of the track. Some of them are embarked on commercial trains offering the possibility of very frequent and cost-effective measurements because data are collected while the trains are offering their services on a daily basis avoiding the need of special (and expensive) testing train and reducing the time slots required for track inspection. Besides, fibre optic sensors have been laid along the track.
- Evaluation of track condition. The collection of the measurements gathered frequently (on a daily basis) by different inspection techniques allows a precise characterization of the track. Mechanical and geometrical defects are identified and classified in first phase. Meanwhile the analysis of forces and accelerations on passengers requires the simulation in a Multibody code software.
Block II: Infrastructure System Management and Decision Support Tools

- **Development of an Infrastructure Subsystem Management tool.** This tool compiles, gathers and organises all the information on railway infrastructure and services. It is a platform at the core of the ACEM-Rail project. It receives quality data on current track condition, evaluates defects degradation paths through integrated algorithms, defines warnings that are send to optimization of maintenance tasks algorithms, collects optimal allocation of maintenance tasks, sends the list of maintenance tasks to the operator in field and receive feedback and results from visual inspection from the operator in fields, etc. Therefore the ISM tool is a platform to help decision making.

- **Estimation of track degradation.** Predictive algorithms have been developed to estimate the evolution of defects. Such algorithms take into account the type and severity of the defect, the characteristics of the infrastructure, the characteristics of the trains running along the track and the characteristics and frequency of rail services.

- **Optimal planning of maintenance tasks.** These algorithms allocate the maintenance tasks in the medium (up to 9-12 months) and short term (time horizon in between 1 week and 2 months). The goal is to minimize cost and disruption of rail service while keeping the track in a safety level and comfort conditions for passenger.

- **Development of mobile tools to assist the operator in field** in the execution of maintenance tasks and visual inspection.

Block III: Impact analysis

- **Definition of a set of Maintenance Performance Indicators (MPI)** suitable for the quantification of the objectives of the project and the evaluation of the impact of ACEM-Rail achievements.

Summarizing, Block I gathers data on track condition and processes and analyses them. Block II manages all the information on track state and rail services and provides a tool to support decision making helping in the optimal allocation of maintenance tasks and assisting operator in field and receiving his feedback on maintenance tasks and visual inspection. Finally, Block III provides the system to quantify the benefits of ACEM-Rail.

4. Inspection techniques

The development of instrumentation technologies to inspect the track is one of the basic pillars of the ACEM-Rail project. Six inspection technologies has been analysed by this project:

- **Inspection technologies laid along the track**
  1. Fibre optic sensors laid along the track and other infrastructure elements (such as bridges) (Minardo et al., 2013)

- **Inspection technologies embarked on commercial trains**
  2. Hollow-shaft integrated acoustic sensor system (Schubert et al, 2013)
  3. Rail monitoring sensor combining eddy current distance measurement with acceleration data
  4. Laser profiler and inertial pack to monitor the track geometry

- **Inspection technologies embarked on special testing trains**
  5. Ultrasonic non-destructive fuzzy inspection techniques
  6. Non-contact thermography system for rail surface monitoring

The first four techniques above are the most promising because they allow the Railway Infrastructure Manager keeping updated information on a daily basis on the track state in a very cost-effective way. Technologies 2, 3 and 4 above are embarked on commercial trains. The developments achieved by ACEM-Rail projects using inspection technologies 2, 3 and 4 above allow an automated and unattended measurement system embarked on commercial trains. This is a step forward in track inspection technologies which will reduce the need for expensive instrumentation trains inspecting the infrastructure during the night when there are not rail services and will increase the capacity of the rail transport. Moreover, the availability of frequent and quality data on the track condition makes possible the condition-based maintenance on the basis of daily updated measurements.

At current state of development, technologies 5 and 6 above can only be run on trains at low speed which make them unsuitable for commercial trains.
Figure 1 illustrates the first two steps of ACEM-Rail which are inspecting the track and managing the measurements. In particular, only those instrumentation techniques that have been validated in the Railway Infrastructure of Ferrovie de Gargano (Section 6) in Italy are represented in it. Other instrumentation techniques, such as items 5 and 6 above, can easily be integrated in the ACEM-Rail system (Figures 1 and 2).

As shown in Figure 1, the data gathered by different technologies are uploaded into a commercial cloud storage which also allows for filtering, data analysis and correlation among different sources of data and with historical information. The analysis of the data stored in the cloud permits the identification of defects together with a severity level. This together with the information on the characteristics of the trains running in the track and the frequency of their services allows for the estimation of track degradation. The list of defects and the estimation of track degradation are converted into warnings with severity level into the ISM system described in Section 5.1. Such warnings are processed by the optimization algorithms described in Section 5.4.

5. Infrastructure subsystems management (ISM)

5.1. ISM. Overview

An intelligent system to manage and automate track maintenance lies at the heart of ACEM-Rail (Cores, 2013), 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 in a coherent and coordinated way. The ISM is designed for being a decision making tool to help managers of railway infrastructures use quality data and make objective judgments in selecting maintenance strategies.

The ISM has a modular architecture built on subsystems (algorithms and data) under the shelter of software tool specialized in assets maintenance management. To meet these objectives, the system incorporates a number of internal tools (programmed on the system) that communicate with external tools, developed in other blocks (see Figure 2).

The most important component of ISM is the Computerized Maintenance Management System (CMMS), mounted on top of IBM Maximo 2012, which provides with many of the modules required for the maintenance management like: assets, inventory, resources, work orders, warning management, etc. Other ISM components have been developed, tailored and integrated into IBM Maximo by overriding and extending the application functionalities. In particular, it includes and combines the management of measurements collected by sensors,
the algorithms for evaluation and prediction of track condition, the communication with peripheral devices and the communication with algorithms for optimization of maintenance planning.

![Fig. 2. Main blocks of the ISM and external connections.](image)

5.2. Evaluation of track condition

The track condition is characterized through a set of “quality parameters”, each one relative to a specific defect typology presents on the track (Bosso et al., 2012). Some of these parameters are obtained by a simple analysis of the post-processed data coming from sensors, as they depend on geometric and/or mechanical characteristics of the track that can be directly compared with the allowable limits. However, other kind of quality parameters must be obtained using numerical models where not only the track geometry is taken into account, but also the traffic characteristics and the passenger perception of comfort/discomfort.

5.3. Prediction of track degradation

One of the most powerful tools of the ISM are the algorithms for the prediction of track degradation. There are a lot of degradation models in the literature. Paris et al. (1963), for example, proposes an exponential formula for propagation of cracks in rails that has been supported by the UIC Code 725R (2007). This kind of theoretical law depends only on the accumulated gross tonnes running on the track. However, there are other important factors influencing track degradation process, such as the track layout, the asset features or the characteristics of trains services, that are not usually taken into account (Kumar, 2006).

![Fig. 3. The daily updated measurements allow successive approximations to the real evolution law of track defects, leading to more accurate predictions.](image)
The ISM developed in ACEM-Rail enables the integration of these additional factors in the estimation of evolution curves, which leads to a more accurate prediction of maintenance necessities. Moreover, the frequency at which data on infrastructure condition are stored in ACEM-Rail (daily) allows updating degradation curves. The degradation curves are confirmed or corrected in each train measurement run. This is an important characteristic of ACEM-Rail predictive algorithms: it benefits significantly from the daily measurement collected in an automated and unattended way each time the train runs its service. The results of the predictive algorithms are fed into the optimization algorithms so that the optimal allocation of maintenance tasks is achieved. Figure 3 above illustrates how the predicted degradation curves can be updated in each measurement. This permits a more cost-effective maintenance keeping safety and comfort conditions.

5.4. Optimization of maintenance planning

The current track condition, the predicted degradation of rail defects, the available resources and the train services are inputs for the algorithms for the optimization of maintenance planning. In order to optimize preventive, predictive and corrective maintenance, two subtasks are defined within ACEM-Rail (Figure 4):

- **Tactical planning** which deals with the selection, combination and allocation of maintenance tasks to time slots and considers a time horizon of up to 9 to 12 months.
- **Operational planning** which performs the detailed scheduling of resources and maintenance tasks over time and focuses on a time horizon of in between 1 week to 2 months.

The tactical level (Heinicke, 2012; Heinicke, 2013) aims at the planning of predictive maintenance tasks, together with the preventive and corrective ones in a medium-term planning horizon. Thereby a coarse maintenance plan is determined that defines which tasks are combined together to form greater tasks as well as what time intervals are allocated for the execution of the selected tasks. This tactical plan serves as the base for booking future track possessions and for scheduling the maintenance tasks in detail (operational level).

The second level of the ACEM-Rail maintenance optimization deals with the operational level (Figure 4). In this case, the current infrastructure condition is the basis for short-term maintenance planning. No deterioration of track condition is considered in operational planning. On the other hand, unforeseen events are scheduled in this kind of dynamic planning. The solution reacts to uncertainties by continuous re-planning in a rolling process. The detailed schedule of train services is also taken into account for track possession booking of specific maintenance tasks in operation al planning. The optimization algorithms consider both direct and indirect costs of maintenance, leading to an accurate and cost-effective utilization of resources and time windows.

As shown in Figure 4, the detailed maintenance planning delivered by the operational planning algorithms for the following week is sent to the ISM system which produces the daily/weekly works orders for the execution of maintenance tasks by different maintenance crews. Of course, the system is able to include at any time the unexpected severe faults that may arise and need to be handled at once.
5.5. Tools to assist operator in field

ACEM-Rail includes some tools to assist the operator in field. The Operators crew receives the list of maintenance tasks using these mobile tools. Maintenance tasks are converted into a pack of simple but detailed work orders which includes all the steps, work plan, itinerary, technical information and resources necessary to perform the repair in an optimal way. These work orders reside in a “Maintenance Master” application, which is an external tool of the CMMS with two versions: office and mobile application.

- The office application is used by the maintenance manager and its main function is to assign the work orders to specific maintenance teams and to monitor the progress of the execution of works.
- The mobile application is synchronized with the office application. By the use of these mobile devices, the field operator can read in-situ the work instructions and report the progress of work.

On the other hand, operators can report to the office and send the results of visual inspection using the same mobile tools.

6. Analysis of the impact: definition of a set of Maintenance Performance Indicators

In order to measure the effectiveness and efficiency of ACEM-Rail system in a quantitative way, a set of 24 Maintenance Performance Indicators (MPIs) has been defined (Jimenez-Redondo, 2013). These indicators have been classified in an architecture similar to the one proposed in the standard UNE-EN 15341:2007 (CEN, 2007). This standard distinguishes among three types of indicators: economical, technical and operational. ACEM-Rail has defined a set of MPI structured in five groups, adding two new groups in order to measure/evaluate other external factors to the railway system itself but still important such as the social and environmental perception of railway maintenance.

The initial evaluation of MPIs was carried out at the beginning of the demonstration phase in the railway network provided by Ferrovie de Gargano (FdG) in Italy. Using the data provided by FdG for the period 2009-2012, the trend for 2013 was estimated and considered as the Reference Value (see Table 1 below) to assess the improvements after ACEM-Rail. Expected Values in Table 1 below represent the original targets pursued by ACEM-Rail since the beginning of the project. At the end of the project, after one year of measurements, a second evaluation of these indicators was performed. These Final Values were compared both with the Reference and Expected values (with ACEM-Rail implementation). Some of the most relevant indicators are shown in Table 1. All ACEM-Rail objectives were extensively fulfilled.

<table>
<thead>
<tr>
<th>Groups of factors</th>
<th>Relevant indicator</th>
<th>Reference value (without ACEM-Rail)</th>
<th>Expected value (with ACEM-Rail)</th>
<th>Final value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economical</td>
<td>$\text{MPI}_{\text{E5}} = \frac{\text{Total Inceptive Cost}}{\text{Total Maintenance Cost}} \cdot 100$</td>
<td>15%</td>
<td>11%</td>
<td>6%</td>
</tr>
<tr>
<td>Technical</td>
<td>$\text{MPI}_{\text{T2}} = \frac{\text{Corrective Maintenance Cost}}{\text{Total Maintenance Cost}} \cdot 100$</td>
<td>63%</td>
<td>48%</td>
<td>42%</td>
</tr>
<tr>
<td>Operational</td>
<td>$\text{MPI}_{\text{O4}} = \frac{\text{Time spent to transfer}}{\text{Total working time}} \cdot 100$</td>
<td>15%</td>
<td>13%</td>
<td>12%</td>
</tr>
<tr>
<td>Environmental</td>
<td>$\text{MPI}_{\text{E2}} = \text{CO}_2$ emissions from maintenance activities</td>
<td>105.4 ton/year</td>
<td>89.6 ton/year</td>
<td>27.4 ton/year</td>
</tr>
</tbody>
</table>

Due to the incomplete integration of the ACEM-Rail system in the Ferrovie del Gargano facilities, in particular the ISM and maintenance planning tools, the social impact (related to punctuality, customers satisfaction, etc)
could not be assessed. In any case, it would be a positive impact although not as large as others MPI as according to FdG surveys, customers are already very much satisfied in FdG.

7. Validation and demonstration

The validation of ACEM-Rail technologies has been accomplished as follows. Inspection technologies have been validated in two locations: the Wegberg-Wildenrath Test and Validation Centre (Germany) where the instrumentation technologies developed by SIEMENS (eddy current) and Fraunhofer (hollow shaft and thermography) have been validated in a first stage and the facilities of Ferrovie de Gargano (Italy) where all inspection technologies but the thermography and the ultrasonic non-destructive fuzzy inspection were validated.

The ISM system (including evaluation and prediction tools and work order management) and the maintenance planning where tested on simulated scenarios on the real layout of Ferrovie de Gargano facilities. This was the only procedure to evaluate and validate the results due to the incomplete implementation of the system in Ferrovie de Gargano’s organisational structure.

The tools developed to assist the operator in field were, on the one hand, validated on simulated scenarios to test the communication with the ISM system but, the system developed was also tested on the Ferrovie de Gargano were the maintenance crew used such tools to perform visual inspections and report ‘on-line’ to the central office.

The results of the validation of the Infrastructure Subsystems Management (ISM) and the optimisation of maintenance planning on simulated scenarios are summarized below:

- The Hollow-Shaft Acoustic Sensor was successfully proved in FdG facilities. It was able to detect the presence of defects, the precise position along the rail and the horizontal dimension of the defect zone. However, additional development needs to be done in order to be able to clearly identify defects’ types and to assess the severity index. Besides, the huge amount of data gathered in each run should be filtered and pre-processed at the acquisition system. ACEM-Rail project hasn’t cover the filter and pre-process required for a commercial exploitation of the technology. This is a future line of research.

- The Eddy Current and Acceleration system was able to identify several defects over the whole distance covered in FdG line. The system showed a good reproducibility. The signals from different drives were aligned and the same defects were displayed. The automation of the system was also proved. The equipment was able to operate in a stand-alone mode and start automatically the measures when powering on the system.

- The Laser Profiler and Inertial Pack showed the highest level of maturity. The exploitation of this technology in the market is straight forward and will be performed by the technology developer (the Italian company DMA). The measurement campaign for this sensor consisted of 5 runs spaced during a whole year. The reproducibility and accuracy of the system was proved. A high number of track geometry defects were detected and later analysed by evaluation and prediction tools.

- The Fibre Optic sensor was also successfully employed in Gargano for static and dynamic distributed strain measurements along a rail and a bridge and also during the train circulation. The fibre installed along the rail was able to identify the number of axles, the speed and the load per axle of trains. The weak-points of the bridge, such as cracks near the keystone, were also identified through the fibre installed on this structure. Aspects to be improved are the spatial resolution and accuracy of the sensor as well as the process of fibre installation.

The tool for tactical planning was tested on a simulated benchmark consisting of 1986 warnings generated from the uploaded real infrastructure data and combined with maintenance statistics obtained from railway expertise. It is important to take into consideration the probabilistic information derived from historical maintenance data and degradation models for infrastructure elements. By doing so, it is possible to estimate the future degradation process as well as the costs incurred by future maintenance interventions. This enables operators and dispatchers to make decisions on scheduling of maintenance operations based on well-founded calculations.

- The tool for operational planning was tested on a large set of benchmarks with varying specifications. It was focussed on a specific sub-task that has high influences on overall costs and resource consumption: the ballast
tamping. It has been demonstrated the solvability of a complex planning task using an appropriate optimisation model and implementing an efficient local search procedure (Simulated Annealing). The results showed a high potential for cost reductions to be achieved in comparison with traditional planning and optimisation methods.

The tools developed to assist the operator in field based on mobile technologies were tested in Ferrovie del Gargano. Several field tests were performed dealing with the inspection activities defined as a part of the preventive maintenance. Several aspects were successfully proved, such as the data transmission via wireless, the capturing of pictures, the in-field measuring and the reporting to the office.

Finally, the Performance Measurement System has shown to be appropriate to assess the economic, technical, organizational, social and environmental impact of any maintenance process and in particular of ACEM-Rail.

8. Conclusions

The ACEM-Rail project deals with the whole process of track maintenance since the monitoring/inspection of the track up to the delivery of work orders and the execution of maintenance task, including intelligent tools for the cost-effective organization, automation and optimization of the process.

ACEM-Rail includes an automated and unattended inspection system embarked on commercial trains which allows a very precise knowledge of the state of the track updated on a daily basis. Besides, the logical of the ACEM-Rail Infrastructure Management System enables a cost-efficient maintenance planning which reduce costs, resources, time and impact on rail services due to maintenance activities. Furthermore, the safety and reliability of the system increases because of better maintained tracks and the probability of accidents can be reduced thanks to better conditions of maintenance crew. Infrastructure managers, railway operators, maintenance companies and users of rail services for both passengers and freights transport will benefit from the innovative solutions targeted within this project.

The sustainability of ACEM-Rail in terms of cost (economic impact), quality of rail services (social impact), CO2 emissions and natural resources maintenance (environmental impact) has been evaluated and quantified in a real infrastructure system in Italy through the use of a set of Maintenance Performance Indicators defined specifically for this purpose into ACEM-Rail.

In spite of the promising results, some more developments are still to be made before the possible commercial exploitation of most of ACEM-Rail’s results. The following lines of future research are envisaged:

- In some of the inspection techniques embarked on train, more research is required in the field of data processing, machine learning and defects identification. Due to the project duration no enough data were taken and therefore such data processing research hasn’t been possible.
- The communication of the platform collecting measures and the ISM is performed manually.
- Performing measures on the long term will allow improving the degradation algorithms.

In summary, ACEM-Rail has meant an important step forward in the automation of track maintenance because of its developments in the field of automated monitoring techniques and intelligent maintenance system able to gather all the information of the system and support decision making, in particular that related to the optimization of maintenance planning. Moreover, the ability of the system to gather very frequent measures and to define and upgrade degradation paths together with the statistical data analysis tools included in the ISM system will allow in the long term the substitution of preventive tasks by predictive ones reducing the cost of the whole process while keeping or improving the safety and reliability of rail services. Concluding, ACEM-Rail is an important step for the evolution from rail maintenance based on preventive/corrective tasks to a maintenance based on conditions/predictions.

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