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1.1 Executive summary

Automated and Cost-Effective Maintenance for Railway (ACEM-Rail) is a collaborative research project funded by the Seventh Framework Programme (FP7) of the European Union. The goal of the project is to develop the technologies and systems to increase the automation level of railway infrastructure maintenance and to improve the cost-effectiveness of the maintenance process while enhancing the quality, the reliability and the competitiveness of railway services.

The project focuses on the track including also track bed, subgrade and engineering structures (such as bridges, tunnels or retaining walls). It tackles the problem of track maintenance from a comprehensive perspective including the whole sequence of processes involved in it: since the monitoring of infrastructure (by means of automated technologies) up to the final execution of maintenance tasks and going through the evaluation of track condition and analysis of defects' degradation, optimization of maintenance scheduling (including preventive, predictive and corrective tasks) and assistance to the operator in field in the execution of maintenance tasks.

All these processes can be structured in three blocks. In all of them, ACEM-Rail has achieved promising results and has improved the state of the art.

- Block 1: Processes oriented towards the automated inspection of the track and evaluation of its condition. ACEM-Rail has developed six inspection technologies for the automated inspection of track condition. One of them is based on fibre optic sensors laid along the track while three of them are embarked on commercial trains. The most promising ones are those that allow frequent and cost-effective measures (based on fibre optic sensors laid along the track and embarked on commercial trains).

- Block 2: Processes oriented towards the development of a system for the management of the huge amount of information gathered by the afore mentioned the inspection technologies, the automation of the maintenance process, the development of Decision Support Tools such as those for the evaluation of infrastructure condition, the estimation of track degradation and the optimization and scheduling of maintenance tasks (taking into account human/technical resources and rail services) and the assistance to the operators in field in the execution of maintenance tasks and automatic reporting to the office.

- Block 3: Evaluation of the sustainability of the maintenance process in terms of economic impact (cost), social impact (safety and quality of service, user perception and safety conditions for maintenance crew) and environmental impact (CO_2 emissions). A set of Maintenance Performance Indicators (MPI) is proposed since there is not consensus among Infrastructure Managers

ACEM-Rail has successfully met all the technical goals in the three blocks above. The results of the project were validated in the *SIEMENS Test and Validation centre in Wegberg-Wildenrath* (Germany), in the railway infrastructure provided by Ferrovie de Gargano (Italy) and in simulated scenarios based on real railway infrastructure systems. The project has proved to achieve important benefits in terms of cost, safety, quality and sustainability of railway service. It has also enlarged the capacity of railway infrastructure.

1.2 Summary description of project context and objectives

Railway Infrastructure can be broadly structured into: the track, the power supply system and the signalling/communication. It is a complex infrastructure that requires of a high degree of safety and reliability. The maintenance of this system is a complicated and expensive task which represent and important share of total railway infrastructure costs. The maintenance of the track, which decisively affects both the train safety and passenger comfort, represents around 40% of the total maintenance cost of the railway system. Therefore, these costs should be kept as low as possible while ensuring, for a specific train speed, that safety and passenger comfort remain acceptable at all times. An optimum solution should be sought so as to ensure a satisfactory safety margin and prevent quick degradation of track quality.

ACEM-Rail is a collaborative Seventh Framework Programme (FP7) project under SST.2010.5.2-1 ‘Automated and cost effective railway infrastructure maintenance’, funded by the European Commission comprising 10 partners from five European countries: CEMOSA (Project Coordinator, Spain), University of Seville (Scientific Coordinator, Spain), Fraunhofer (Germany), Politecnico di Torino (Italy), Second University of Naples (Italy), OPTIM-AL (Bulgaria), DMA (Italy), Tecnomatica (Italy), SIEMENS (Germany) and ScanMaster (Israel). The project duration was 36 months. It started in December 2010. It focuses on track maintenance.

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 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 traditional 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. This is the goal pursued by the ACEM-Rail project.

ACEM-Rail faces track maintenance from a holistic perspective. It pursues a high degree of integration of the subsystems affecting the maintenance tasks with the goal of significantly increasing the automation of track maintenance. The project covers the whole maintenance process since the monitoring of the infrastructure to the execution of maintenance tasks and the reporting of the office and including the automation and optimization of the scheduling.

The technologies developed within ACEM-Rail allow maintenance operations to be performed in an effective way: track inspection will be performed in an unattended and automatic way by commercial trains (conventional and high speed) and fibre optic sensors laid along the track, maintenance will be based on condition/prediction, maintenance tasks will be optimally allocated minimizing track occupancy and maintenance crew will be better assisted and the reporting to the office will be automated. As a consequence, the cost for maintenance will be reduced and the availability of the track will significantly increase. The latter will motivate an increase of freight transport competitiveness with respect to other means of freight transport such as road.

Besides, because of the better maintained tracks, rail transport will be a safer, more reliable and more environment friendly mean of transport after ACEM-Rail. Furthermore, the work conditions for maintenance crew will be safer (better assistance online while the operator is infield and fewer operations at night time).

ACEM-Rail has also proposed a selection of a suitable set of Maintenance Performance Indicators (MPIs) to evaluate the economic, social and environmental impact of the proposed maintenance technologies. This set of MPI was proposed since there is no consensus in MPI's for Railway Infrastructure Managers.

ACEM-Rail aims to improve the automation degree of railway maintenance in order to reduce the cost and improve the safety and quality of rail services. It also improves the safety of maintenance crew which will work under better and more controlled conditions. To achieve this purpose, the project has focused on the following goals:

- The development of innovative solutions for automated monitoring of railway infrastructure and for the analysis of infrastructure condition.
- The development of algorithms for the evaluation of track degradation taking into account track condition, rolling –stock characteristics and rail services.
- The development of algorithms and tools for an automated planning and scheduling of maintenance task.
- The development of mobile tools to assist the operator in field and to facilitate reporting to the office.
- The development of an intelligent Infrastructure Subsystem Management (ISM) system which is at the core of the ACEM-Rail concept which integrates and centralizes all the relevant information (condition, planning and operations) in the same platform and allows for the automation of maintenance management. Such platform is also the shell to allocate the Decision Support Tools developed within the project (such as those for optimization of task scheduling or estimation of track degradation).
- The definition of a set of Maintenance Performance Indicators to evaluate and quantify the economic, social and environmental impact of a better maintenance on rail services.

The above goals have been properly met. As a consequence, the most relevant achievement of the project can be structured in three fields:

- Development of six inspection technologies for the automated and unattended monitoring of infrastructure condition. One of them is based on fibre optic laid along the track (which allows for automatic continuous monitoring). Three on them are embarked on commercial trains. Therefore, very frequent measures (on a daily basis) are possible (as frequent as rail services on the trains hosting the instrumentation). This is an important achievement because no time slot for special testing train is required and the frequent measures allows for a close watching on track condition which facilitates the evolution from the classical preventive /corrective scheme to a more cost effective maintenance policy based on condition/prediction.

- Development of an intelligent Infrastructure Subsystem Management (ISM) tool which integrates and manage all data and provides Decision Support Tools (especially those in charge of the estimation of track degradation and of the optimization of maintenance scheduling) to help Infrastructure Managers achieve a cost-effective maintenance keeping the quality and the reliability of rail services.

- Definition of a set of Maintenance Performance Indicators to evaluate the sustainability of the rail maintenance.

- The demonstration of the technologies developed in real and simulated scenarios.

The expected benefits of the project for the Infrastructure Managers and the Society in general are:

- reduction of cost in maintenance services,

- reduction of impact on rail services,

- increase in safety, quality and reliability of the service,

- improvement in the working conditions of maintenance crews and reduction of work accidents,

- increase in the capacity of the track and, as a consequence, increase of track availability for freight transport,

- reduction in CO2 emissions because of more efficient and better organised trips of the maintenance crew and because of the increase in rail freight transport with respect to road freight transport.

1.3 Description of the main S&T results/foreground

1.3.1 The ACEM-Rail approach and main results

ACEM-Rail focuses on the maintenance of the track including the subgrade and structures (track, track bed and engineering structures such as bridges). It covers the whole process of track maintenance including the automatic monitoring and inspection of the infrastructure, the analysis of the track condition and the estimation of defect degradation, the optimization of maintenance tasks, the generation of work orders and the crew assistance and monitoring of execution of maintenance tasks and the automatic reporting to the office.

The project has fostered the technologies to facilitate and improve the automation of railway infrastructure maintenance, including:

- The development of inspection technologies for the monitoring of the railway infrastructure. These technologies included fibre optic laid along the track and structures and inspection technologies embarked on trains. Among the latter, the most promising are those embarked on commercial trains. Using the results of fibre optic and of embarked on commercial trains inspection technologies, allows a very frequency monitoring and supervision of track state facilitating the implementation of a maintenance policy based on condition/predictions.

- The integration and centralization of all relevant information (asset condition, maintenance planning and operations) in the same platform: Such platform facilitates the automation of railway maintenance. It is the shell in which some Decision Support Tools have been allocated.

The main steps (and features) of the ACEM-Rail system are listed below:

1. Monitoring technologies inspect the track and structures. Each technology performs its own data processing and analysis.

2. All measurements are compiled by a web-based platform for data acquisition, management, analysis and report (VisioStack).

3. After the different sensor technologies data analysis, a list of defects (and, of course, location) together with a severity index is automatically generated by the evaluation tools. A list of warning is also automatically produced.

4. Furthermore, with the help of prediction algorithms, the evolution of the identified defects taking into account their severity and the characteristics of the traffic and the trains running on the lines is estimated.

5. The information on identified defects and estimation of evolution is transferred to the Computerized Maintenance Management System (CMMS) which is the core of The ISM.

6. The CMMS provides all the modules that are required for automated maintenance management. In ACEM-Rail a commercial solution is adopted (IBM Maximo) on top of which some especially tailored modules have been developed. One of the most important modules of the ACEM-Rail ISM is the one devoted for Warning Management and production of Work Orders.

7. Warnings are sent to the Maintenance Planning module (ACEM-Rail Optimization tool) which produces as output a maintenance schedule.

8. The maintenance schedule produced by the optimization tool is converted into Work Orders in the CMMS. Work orders include detailed instructions of the maintenance tasks to be performed together with the human and technical resources and timing. Work orders are sent from the central office to the infield peripheral devices.

9. The maintenance crew infield report to the central office so that the CMMS validates the execution of maintenance tasks and receives pictures and results of the visual inspection by the qualified staff.

Moreover, the ISM platform developed within ACEM-Rail generates statistics, reports and summaries about different factors that may influence the maintenance process and which provide relevant information for decision makers. Therefore, in the long run, once the system has long enough data based on historical information, ACEM-Rail will be able to re-evaluate the convenience of preventive tasks in favour of a condition/prediction based maintenance system.

Figure 1 illustrates the ACEM-Rail concept.

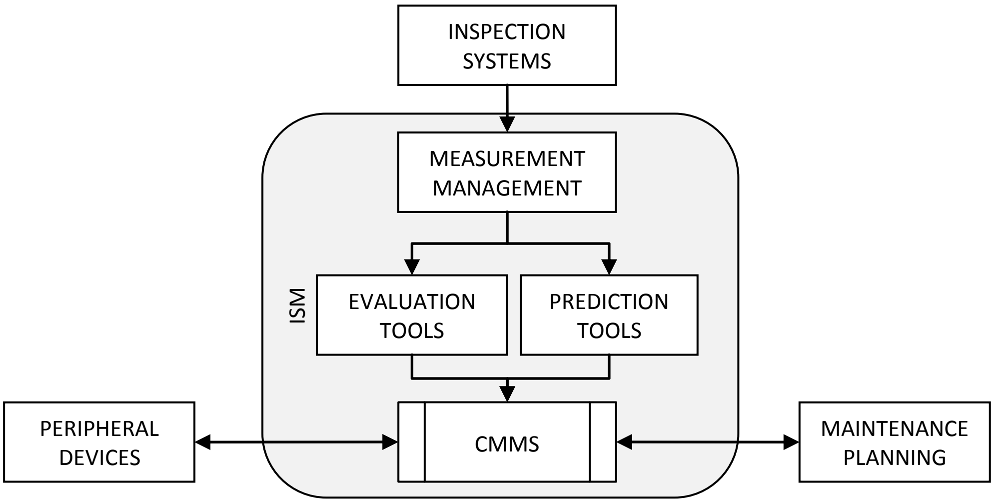

Figure 1. Block diagram showing the ISM modules and external subsystems

Besides, in order to be able to evaluate the impact of the maintenance procedures and since there is no consensus regarding Maintenance Performance Indicators within Railway Administrators, ACEM-Rail also includes the definition of a set of MPIs specially tailored to evaluate the economic, social and environmental impact of rail maintenance.

The Research and Innovation developments of the ACEM Rail project can be structured in the following 3 blocks:

- *Block 1: Development of innovative technologies for the inspection of the track*. Six technologies were included in the project. Three of them are suitable to be embarked on commercial trains and have produced promising results: one of them (Laser Profiler and

Inertial Pack) is ready for market exploitation while the other two (Hollow Shaft Acoustic Sensor and Eddy Current and acceleration sensor system) need still some more developments to be ready for the market. Two of the inspection technologies are only suitable to be embarked on special testing trains at very low speed and are still far from market exploitation (Thermographic testing system and Ultrasonic Fuzzy Logic inspection). Finally, Brillouin Fibre Optic laid along the track and structures was also use to the monitor the structural health of such assets and train operation. This technology is also close to market exploitation.

The work developed within *Block 1* included also the unique (for all technologies) system to assign locations to the different measurements (based on odometers) and the use of a web-based platform to collect all the measurements. Such platform sends the data to the Data Management System developed within Block 2 below.

- *Block 2: Development of an Infrastructure Management System (IMS).* This block included all the work related to the development of an intelligent system able to manage all the data of the system (including information on the railway infrastructure and its state, rail services and traffic information, train characteristics, technical equipment and machinery available and human resources) and the Decision Supports Tools for an optimal performance of the maintenance systems. Such DST's comprise those related to the evaluation of defects and prediction of defect degradation taking into account the severity of the defect and the characteristics of the traffic and trains and those related to the optimization of maintenance tasks with a time horizon from one year ahead to the very next future (from next week to 1 or 2 days ahead). *Block 2* also includes some mobile tools to support the operator in field for the execution of maintenance tasks and reporting to the office (including visual inspections).
- *Block 3: Evaluation of the impact of the developed maintenance techniques and definition of a set of Maintenance Performance Indicators to quantify it.* In order to analyze the economic, social and environmental impact and sustainability of the maintenance technologies developed within ACEM-Rail and since there is no consensus among Railway Infrastructure Managers, a set of Maintenance Performance Indicators (MPIs) was proposed and used to quantified the result of the project.

On the other hand, the technologies developed were validated in two demonstrators: the test and validation centre in Wegberg-Widenrath (Germany, Figure 2) were all the technologies under the care of SIEMENS (Eddy Current and acceleration sensor system) and FhG – IZFP (hollow-shaft acoustic sensor and thermographic testing system) were validated.

All the technologies developed but the thermographic and the ultrasonic testing were validated in Ferrovie de Gargano (Italy, Figure 3) embarked on a commercial train and, in the case of fibre optic, laid along a stretch of the track and a structure. Thermographic and ultrasonic weren't tested in Ferrovie de Gargano because of the technical constraints (low speed).

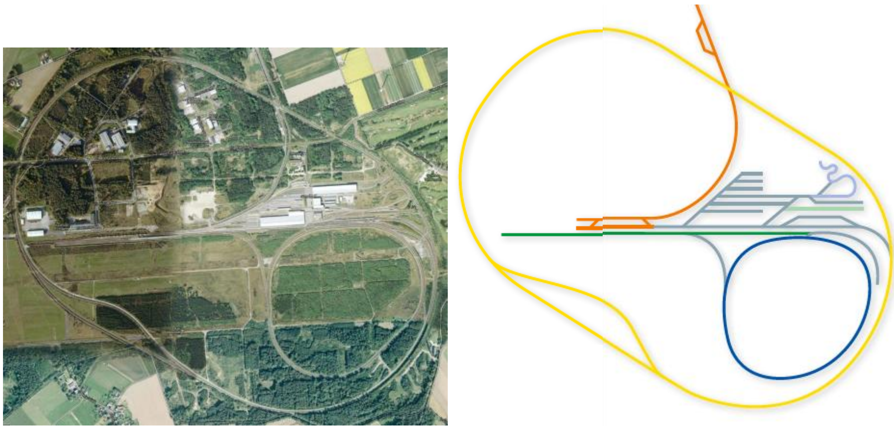

Figure 2. Aerial picture and scheme of the demo site 1: The railway test track in Wegberg-Wildenrath (Germany)

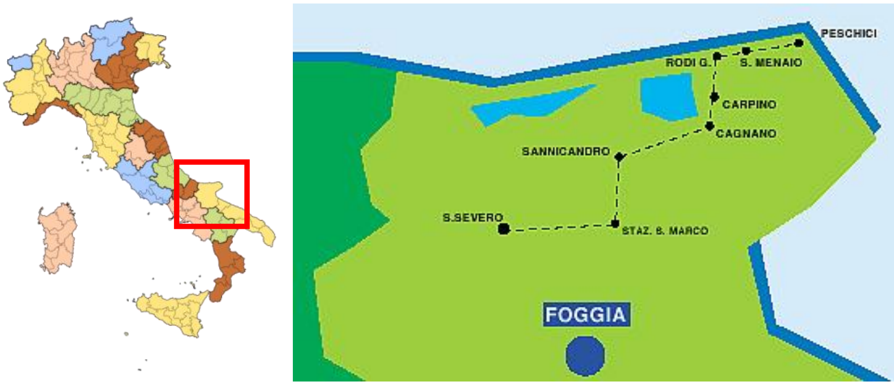

Figure 3 Location and schematic view of the demo site 2: The railway line San Severo- Peschici (Italy)

Figure 4 below illustrates the structure of the project.

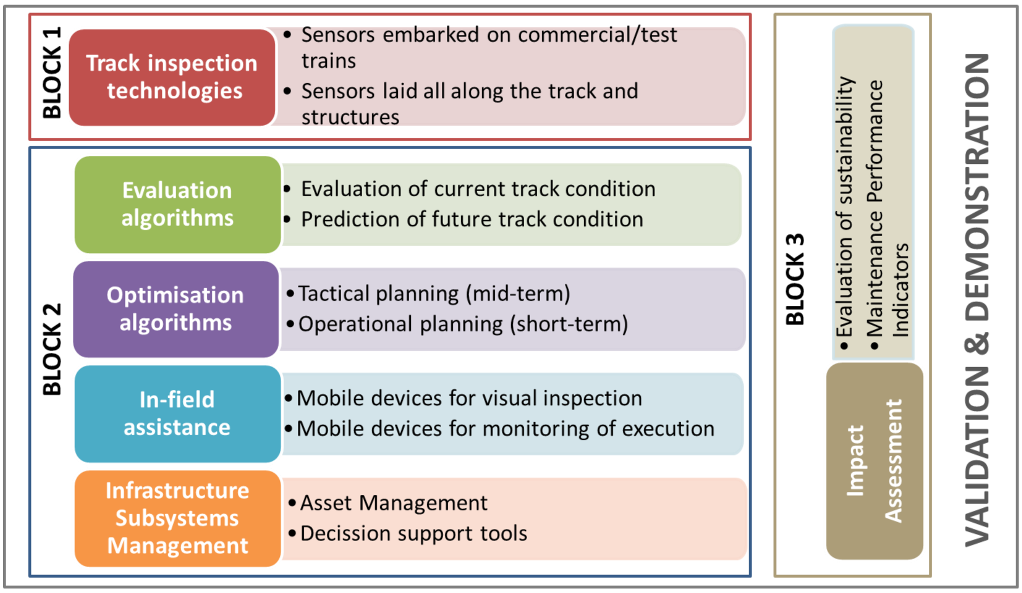

Figure 4. Structure of the ACEM-Rail project

Summarizing, the main results of the ACEM-Rail project are:

1. The development of a set of instrumentation technologies to evaluate track condition
    - Eddy Current and acceleration sensor system (embarked on commercial trains)
    - Hollow shaft acoustic sensor (embarked on commercial trains)
    - Thermographic testing system (embarked on special testing trains)
    - Laser Profiler and Inertial Pack (embarked on commercial trains)
    - Fuzzy ultrasonic testing system (embarked on special testing trains)
    - Brillouin Fiber optics (laid along the track)
2. The development of a comprehensive tool able to compile all the information of the system and provide the shell to allocate Decision Support Tools to help railway infrastructure managers. This is a very promising result of the ACEM-Rail which still needs some development before its exploitation in the market but which it is not very far from it.
3. The development of algorithms and tools able to schedule maintenance tasks in an optimal and robust to uncertainties way. It is made up of nested optimization algorithms for the long/medium term (from 2 months to 12 months ahead) and short term (from one week to 2 months ahead).
4. The development of tools based on mobile computers to bring the office to the field and assist operators in the execution of maintenance tasks.
5. The definition of a set of 24 MPIs to evaluate the economic, social and environmental impact of the maintenance process.
6. The demonstration of the technologies in two real and simulated scenarios. The real environments were the Wegberg-Wildenrath Test and Validation Center (Germany), owned by SIEMENS, and the railway line San Severo – Peschici (Italy), owned by Ferrovie del Gargano (FdG). Simulated scenarios were developed on top of FdG layout or using some other railway systems in those cases where the degree of implementation in FdG was not completed or FdG layout was too simple to prove ACEM-Rail capabilities. In any case, the suitability and applicability of ACEM-Rail developments to real railway system is demonstrated.

1.3.2 Description of the instrumentation system

This section describes the main outcomes of Block 1 on the instrumentation technologies.

1.3.2.1 Eddy Current and acceleration sensor system

This inspection system combines two measurement principles: distance sensors based on Eddy Currents and acceleration sensors. The measurement system combines these two different sensors channels into a common data set: The distance sensors provide the relative position of the sensor to the rail while the acceleration data provide the absolute position. The combination of both values yields the difference of the actual rail from the ideal line on a length scale of up to several meters allowing for the evaluation of geometrical defects. Figure 5 below illustrates the basis of the system.

Additionally, the acceleration data by itself can be used to detect small range defects such as gaps, dents or corrugation can be detected on a smaller scale in the order of centimeters.

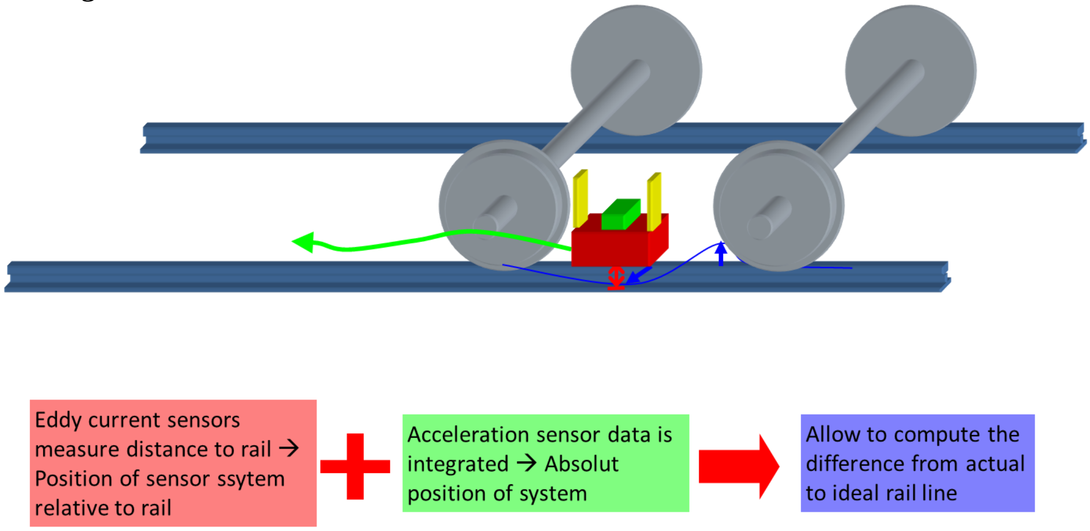

Figure 5 Measurement principle of the Eddy Current system.

As the working distance is about 30 mm by design, the system can be mounted directly to the bogie of a commercial train. Figure 6 shows the different sensor units for short range and long range rail contour inspection.

Figure 6 Accelerometer mounted on the wheel bearing (left picture) for short range rail measurement and Eddy Current sensor + accelerometer (right picture) for long range contour inspection

Figure 7 shows results from the field tests for the Wildenrath test track. Major impacts (blue line) above the background noise (red and green line for different averaging settings) can easily be recognized and in some cases could be attributed to infrastructure elements like insulated rail joints. A visual inspection of the remaining indications revealed several defects of the rail that were previously unknown to the owner of the test track and were first detected using this method (Figure 8). This was a remarkable result of the validation of this technology in the Wegberg-Wildenrath Test and Validation Center.

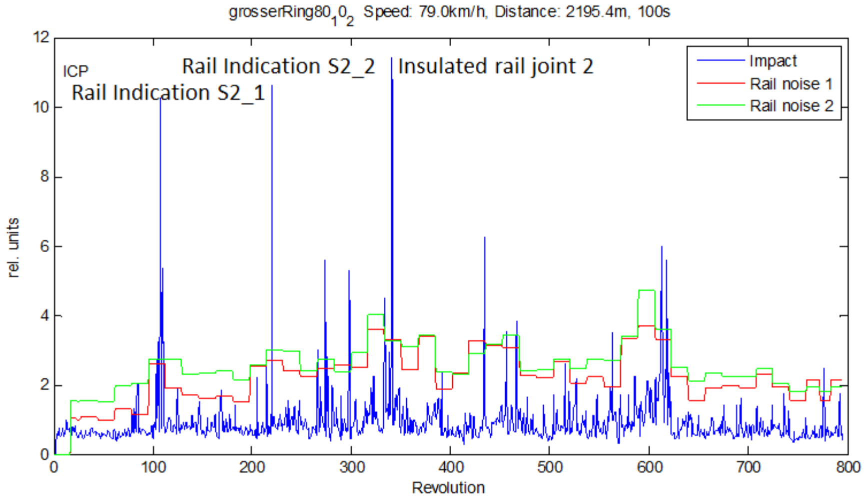

Figure 7 Wildenrath results along the large test ring obtained at a train speed of 79 km/h. The displayed number of wheel revolutions corresponds to a track length of 2195.4 m and a duration of 100 s.

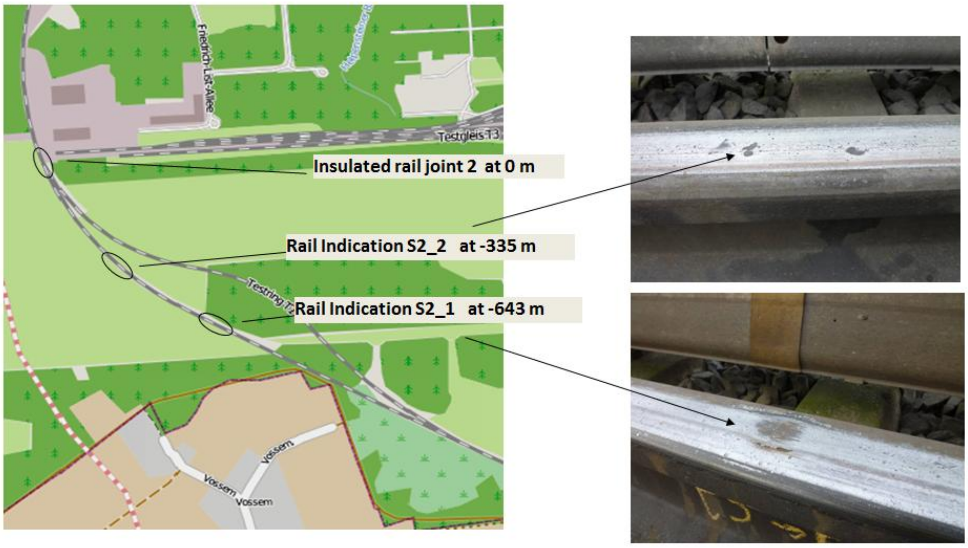

Figure 8 Identification and validation of the three main rail indications shown in Figure 7

This technology was also validated in the railway system of Ferrovie de Gargano (Italy). Several test runs were performed during the last year of the project. By comparing different test runs, also in different directions of train movement, it could be demonstrated that the obtained indications were reproducible and, therefore, the instrumentation system was working properly.

The analysis of the measurements in Ferrovie de Gargano also yielded a number of defects in the tested line between San Severo and Peschici, such as corrugation, flats and joint gaps.

As a summary, it can be concluded that the combined eddy-current and acceleration sensor set-up in the ACEM-Rail project is very promising because it has been demonstrated its capability to reveal major rail defects at a possibly minimal equipment cost. Smaller range defects on the order of centimeters are also directly detectable using only the acceleration data. A comparison with previous measurements or known infrastructure elements is necessary and also visual inspection may still be needed to differentiate between different types of defects. However, for rail deviations over several meters the eddy-current based rail sensor can provide data directly in millimeters which can be fed into a maintenance concept without need of visual inspection.

During the field tests the system could be demonstrated up to a speed of 140 km/h due to the constraints of the test track. Previous experiments on a laboratory set-up showed that the system could also work for speeds up to 300 km/h.

1.3.2.2 Hollow shaft acoustic sensor

The hollow shaft acoustic sensor system was designed within the ACEM-Rail project for monitoring both the rail track and the subbase. The system analyses signals produced by the rail-wheel contact. It includes a combination of acoustic sensors (for high frequency signals detection), 3-D acceleration sensors (for low frequency signals detection) and optionally temperature sensors. It can be fully integrated in the hollow shaft of a high-speed in-service train (Figure 9 and Figure 10).

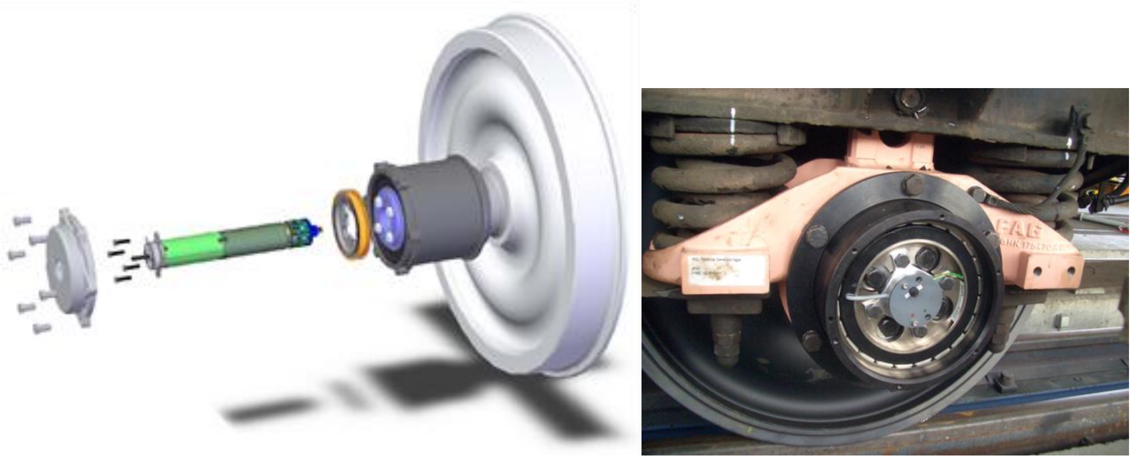

Figure 9 Mounting of hollow shaft sensor system

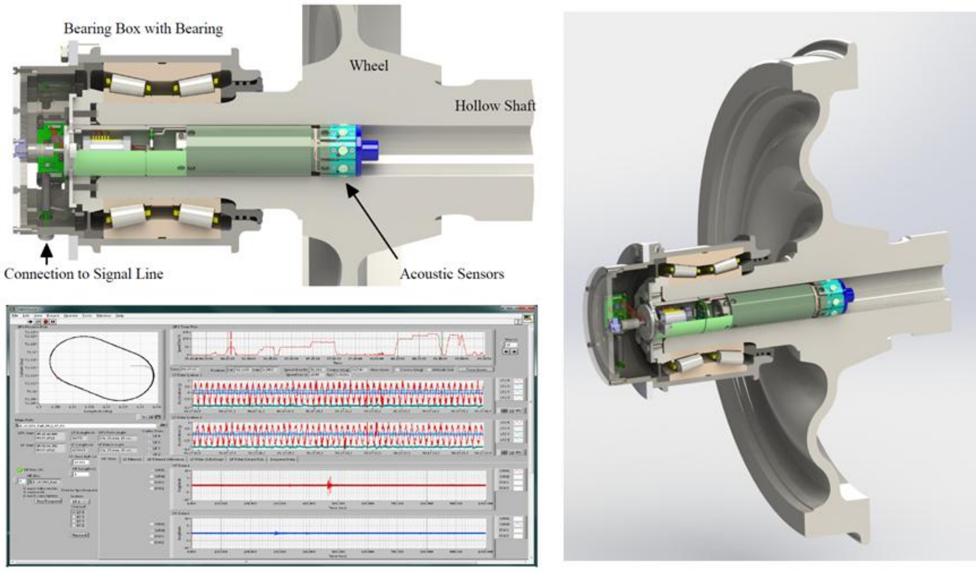

Figure 10 Detailed view of integrated hollow shaft sensor system and software GUI for data acquisition and evaluation (bottom left).

After the first successful laboratory tests in the facilities of the institute Fraunhofer IZFP-D in Dresden, the acoustic hollow shaft system was installed and tested at the Siemens test track in Wegberg-Wildenrath in Germany. The rail car which was used for the field measurements was equiped with two hollow shaft systems on a bogie on one side of the rail car (i.e. in series). The sensor systems in both axles (distance = 2.5 m) were identical so that the data acquisition could be checked for redundancy and reproducibility, respectively. Furthermore, the continuous position was recorded via GPS receiver. As the system was only on one of the rails, only that rail was inspected.

In this context, the acoustic sensor system in the hollow shafts worked properly and reliably. Several individual events along the tracks could be identified: rail joints on straight parts, bends with and without rim friction, turnouts, etc.

Further field tests were performed at Ferrovie de Gargano along the track between San Severo and Peschici. In this case, there was one hollow-shaft system in each side of the bogie so that both rails were inspected. During the measurements several defects could be found along the track (red circles in Figure 11 top).

Figure 11. Gargano track (top) and field installation of monitoring system (bottom).

The post processing of the data provided by the hollow-shaft acoustic sensors system produces the following output:

1. Presence of a defect (yes/no)
2. Position of the defect along the rail (by GPS, internal wheel rotation and external odometer)
3. Horizontal dimension of the defect zone (calculated by the duration of the indications)
4. Kind of defect (calculated by HMM (Hidden Markov Models) classification software)
5. Severity index (calculated by the maximum amplitude and the kind of defect)

The software of this measurement system includes classification routines for data analysis based on time-frequency representations (spectrograms) of the measured signals which are used as acoustic fingerprints of the track (Figure 12). Further developments within this technology are required in the post processing of the data gathered in order to bring it closer to the market.

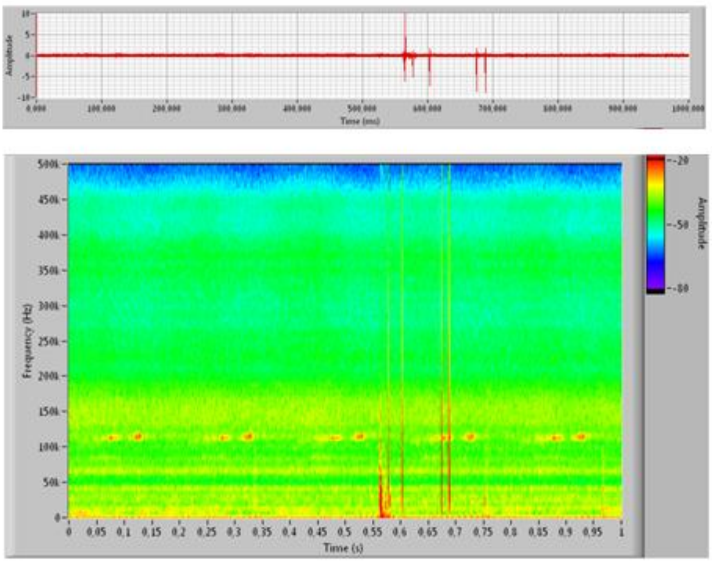

Figure 12 Spectrograms are used as acoustic fingerprints for the HMM classification software

1.3.2.3 Thermographic testing system

This system is based on the principle of induction thermography. Induced Eddy Currents are affected by cracks (Figure 13). Increased current densities cause an additional local heating that can be analyzed by an infrared camera mounted at the train (Figure 14).

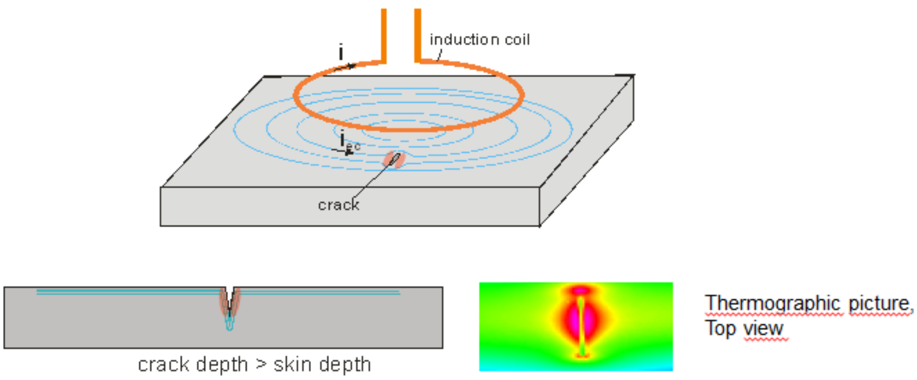

Figure 13 Principle of induction thermography

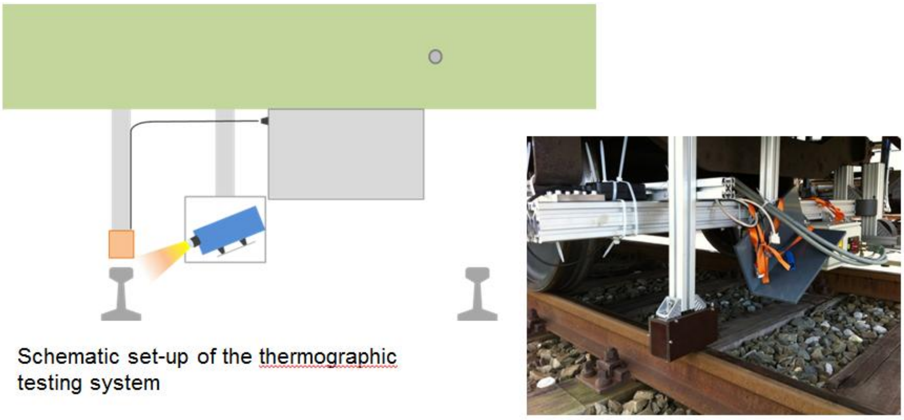

Figure 14 Position of induction unit and infrared camera at the train

This system was tested at the Siemens test & validation centre in Wegberg-Wildenrath (Germany). During the measurements, performed along the small inner and the larger outer oval, it was found that surface cracks are detectable with good signal-to-noise ratio. A detailed analysis showed that the defect amplitude drops down significantly as a function of train speed *v* (Figure 15). However the signal decrease is slower than 1/*v*. This technology can only be applied for rail defect identification embarked on special testing trains because of speed constraints. The degree of development prevented its demonstration in Ferrovie de Gargano (speed constraints).

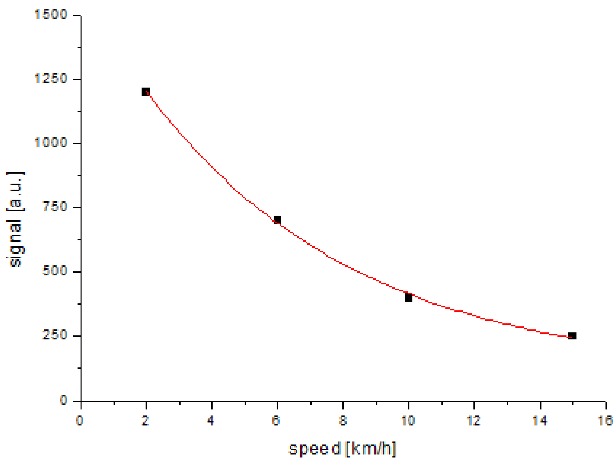

Figure 15 Defect amplitude as a function of train speed.

1.3.2.4 Laser Profiler and Inertial Pack

Track geometry is probably the fastest deteriorating component of the railways infrastructure. Moreover, “bad” geometry immediately affects the trains running quality, in terms of safety and passenger comfort and wheel-rail forces, thus starting a positive amplification loop. This is the reason why, among the different measurements composing the infrastructure monitoring, the track geometry has been selected for pushing the automation at the maximum achievable levels. Automatic measurements can be done frequently. High frequency and accurate measurements are necessary to compute the deterioration trends that are the base data on which the maintenance planning can be optimized.

The inspection technology described in this section is devoted for monitoring the track geometry. It consists of an inertial pack for creating the reference straight line (or reference curve) and the optical instruments for giving the deviation of the actual rail shape from the reference one. Figure 16 shows the instrument mounted on a bogie.

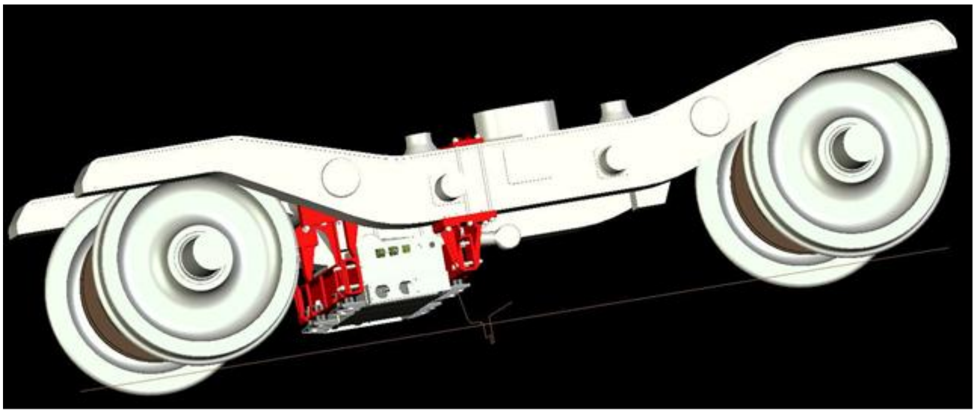

Figure 16. Track geometry monitoring instrument mounted on a bogie

The inertial pack consists of 3 gyros and 3 accelerometers (Figure 17). The 3 gyros measure the rotation on the 3 axis. Integrating the rotations, the attitude angles at any time t are obtained, relative to a reference position at time t_0, when the process is initiated. This way, the direction of the accelerations and speed vectors are known at any time t_n. These directions are fed to the module integrating the 3 accelerations. The double integration of the accelerations gives the position. Spatial position and 3 attitude coordinates provide the information needed to place the two rails in the dimensional space (3D). Thus the inertial pack gives the instrument trajectory in the 3D space (all 6 degrees of freedom), which is equivalent to having the reference straight line.

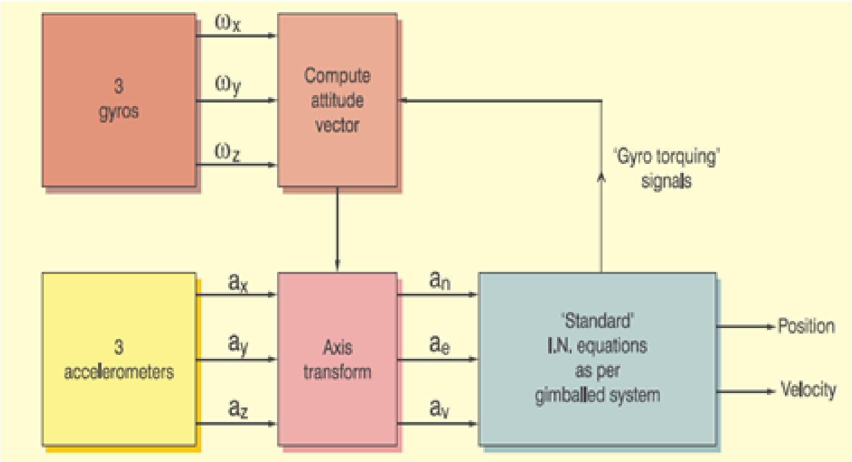

Figure 17 Composition of the inertial pack

After having the reference line, the optical instruments measure the distance of the actual rail from it. The optical instruments are based on the triangulation method, shown in Figure 18.

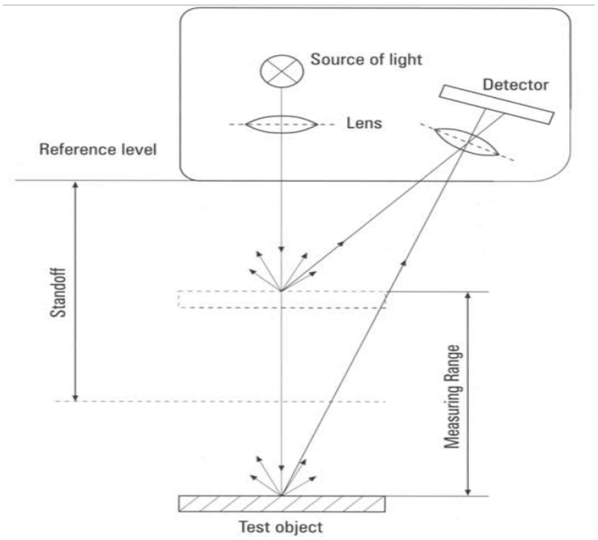

Figure 18. Triangulation method based optical instrument

Figure 18 above shows a device measuring just one point. Stacking many of these devices, a whole profile can be measured (that is, the rails profile is measured). Actually, rather than stacking many separate devices, a digital camera is used. This can be thought of as a stack of independent line detectors.

Good algorithms for reading the reflected light improve the measurement accuracy and reduce the sensitivity to the environmental conditions. Linearization algorithms are necessary as the transfer function is intrinsically non linear.

This inspection system was successfully proved on the railway line San Severo-Peschici. Figure 19 (left) shows the installation on a passenger coach. The test runs performed along more than a year allowed to test the accuracy and repeatability of the measurements. Geometric defects such as gauge deviation, wear or spalling were properly identified. Figure 19 (right) shows an output of the software used for the data analysis. The differences between two consecutive measurements, red and blue lines, show the effect of tamping in this particular stretch. This technology is already ready to be applied in the market.

Figure 19 On left side, laser profiler and inertial pack mounted in the coach (Ferrovie del Gargano, Italy). On right side, output of the GUI software. Gauge, cant and curvature in section between KP 65.5 to 66.8. It shows evident track refurbishments.

1.3.2.5 Ultrasonic testing system

ACEM-Rail included some developments for data processing and defect identification on measurements provided by ultrasonic inspection system embarked on special testing trains as those shown in Figure 20.

Figure 20 Slow speed rail inspector for in-service detection and evaluation of flaws.

A typical configuration of an ultrasonic system is shown in Figure 21. It contains various ultrasonic probes for different kinds of defects and defect orientations.

#	Probe angle	Objectives
1	0º	- Measuring rail-height. - Detecting horizontal defects, some star cracks and volumetric defects in the central portion of the head or in the web. - Corrosion on the foot cased by the “sleeper” (tie).
2	+35º -35º	Detecting horizontal and volumetric defects as well as some star cracks and back-surface defects in the head, the web and the foot.
3	+70º -70º	Detecting vertical traverse horizontal and volumetric defects in the central portion of the head.
4	+ 70º skew - 70º skew	Detecting vertical traverse horizontal and volumetric defects in the gauge side portion of the head, as well as surface cracks on the head.
5	+70º Shift - 70º Shift	Detecting transverse cracks of the section of the weld progressive transverse cracks in the rail head (alternative to 70 skew).
6	+55º - 55º	Detecting vertical split head / piped rail on the head.

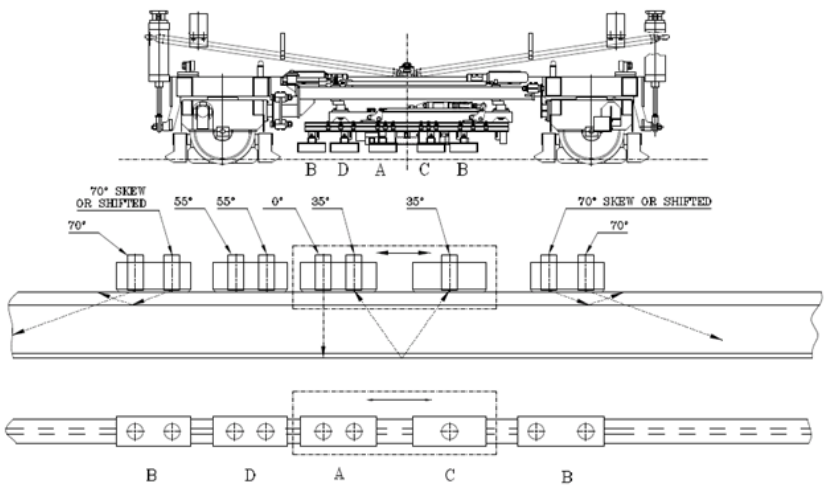

Figure 21 Typical configuration of an ultrasonic rail inspection system

Typical results of the ultrasonic inspection system are shown in Figure 22. Several problems complicate the data evaluation procedure:

- Not reliable data – noise, missed indications
- Ambiguous defect definition
- Slow Reaction time of “conventional” algorithms
- Over detection as result of above

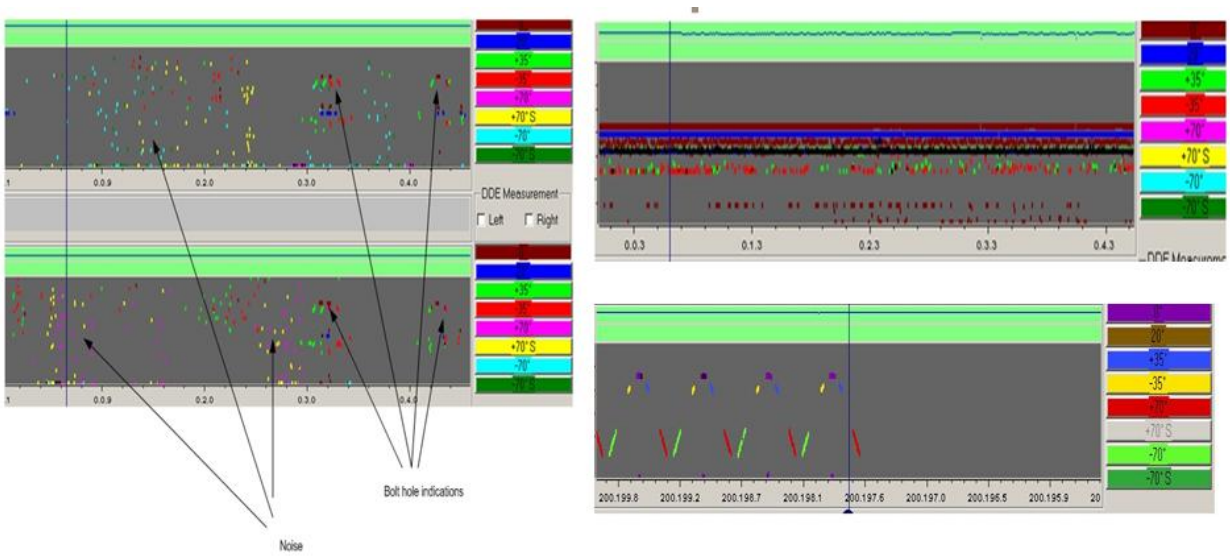

Figure 22 Typical results of an ultrasonic rail inspection system

From experience in the field, it is known that trained operators are always able to recognize defects even within partial and inconsistent data. Therefore, fuzzy logic algorithms promise to provide good results. They allow minimizing the amount of parameters used for the measurement configuration.

In the ACEM-Rail project such fuzzy logic algorithms were implemented and tested with already existing data for defect recognition. . However, this technology wasn't validated in any of the two systems (Wildenrath or FdG) used for the validation of the instrumentation techniques. It wasn't either validated in the Israeli Railway System as was originally foreseen. Scan Master that was the partner in charge of this technology used only to validate their algorithms some benchmark data publicly available from DB.

1.3.2.6 Brillouin Fiber optics

Distributed optical fibre sensors based on Brillouin scattering represent a promising technology to monitor the structural integrity of the rail tracks, as they allow a spatially-continuous monitoring over distances that can reach tens of kilometers with the spatial resolution of one meter.

The main advantage of this technique is that a single optical fibre can be used as a sensor over distances of tens of kilometers. Hence, the distributed fibre sensor can contribute significantly to increasing rail safety, permitting to quickly identify anomalies or interruptions of the rail tracks

A portable Brillouin optical time-domain analysis (BOTDA) measurement central unit was developed in ACEM-Rail project, to be employed for structural health monitoring of railway infrastructures. A sketch of the newly realized BOTDA central unit is shown in Figure 23 (left), while Figure 23 (right) shows a photograph of the prototype.

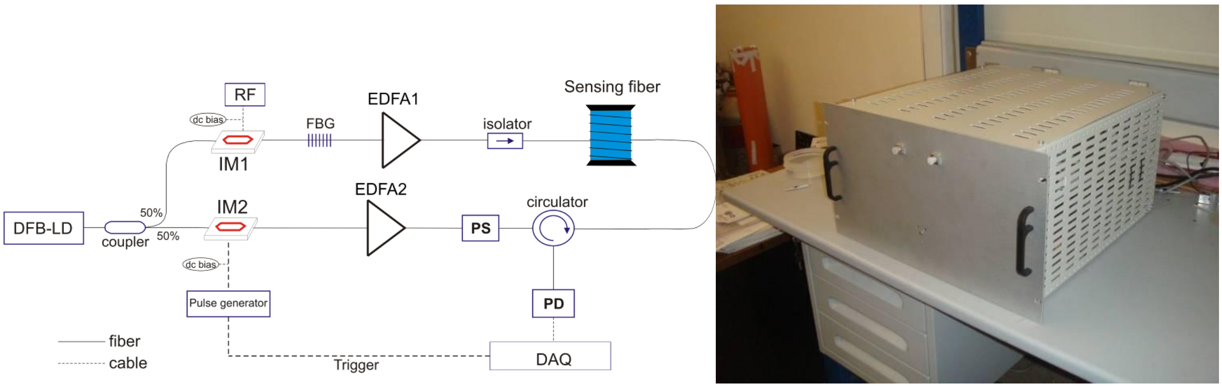

Figure 23 On the left side, sketch of the optoelectronic unit. On the right side, picture of the realized prototype

The whole acquisition process is fully automated. The measurement takes place by running a MATLAB® script, by which it is also possible to set the measurement parameters. Another MATLAB® script processes the acquired data, thus providing the temperature or strain profile along the sensing fibre.

After laboratory tests, the fiber optic inspection system was placed in a rail bridge of the San Severo-Peschici line (Figure 24). This 3m-long stone bridge presented some cracks near the keystone in the seaside. It was detected an abnormal dynamic behaviour of the bridge close to this cracks during the passing of trains.

Figure 24 Rail bridge at San Severo-Peschici railway line, near San Menaio Station. It shows cracks at the seaside keystone of the bridge.

Moreover, as well as the above developments for infrastructure monitoring, this technology was also used for train monitoring. This wasn't originally planned for the project but was found to be an extra development which enriches the system. In this case, a standard single-mode optical fiber was attached along a 60m-long rail by using an epoxy-based adhesive (Figure 25). The optical fiber was protected by a tight-buffer PVC jacket with a diameter of 900 µm. The fibre was deployed as a loop with the return path not bonded to the rail and employed for measuring the temperature in proximity of the rail.

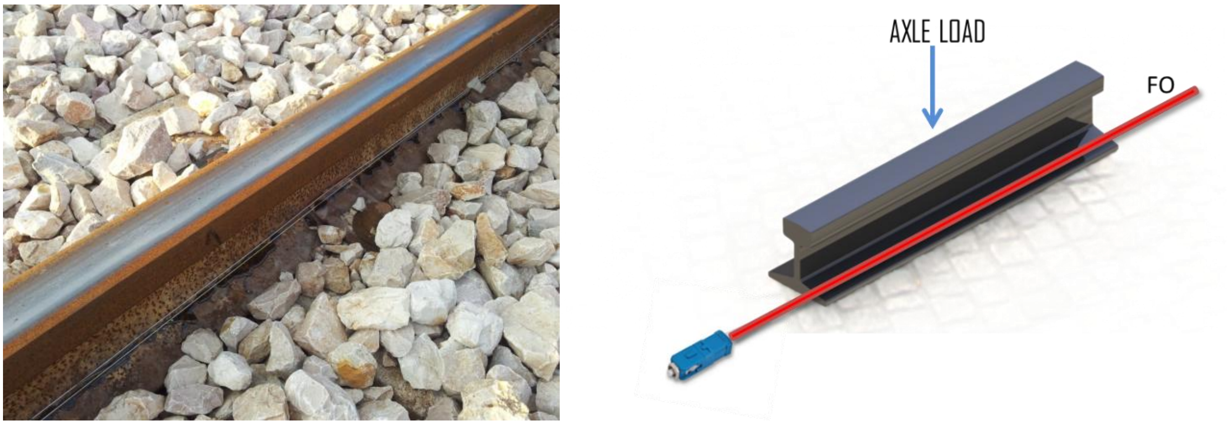

Figure 25. Fiber optic sensor glued to the rail foot at the railway line San Severo-Peschici (Italy)

The measurements were made in different dates, allowing assessing the influence of different factors such as temperature and humidity, as well as performing useful measurements for train operation. Measuring axel loads (static and dynamic), axles number and distance (identification of the train), direction and train speed (constant or accelerating) was possible using this method. Figure shows the output of a dynamic strain acquisition during a train passage.

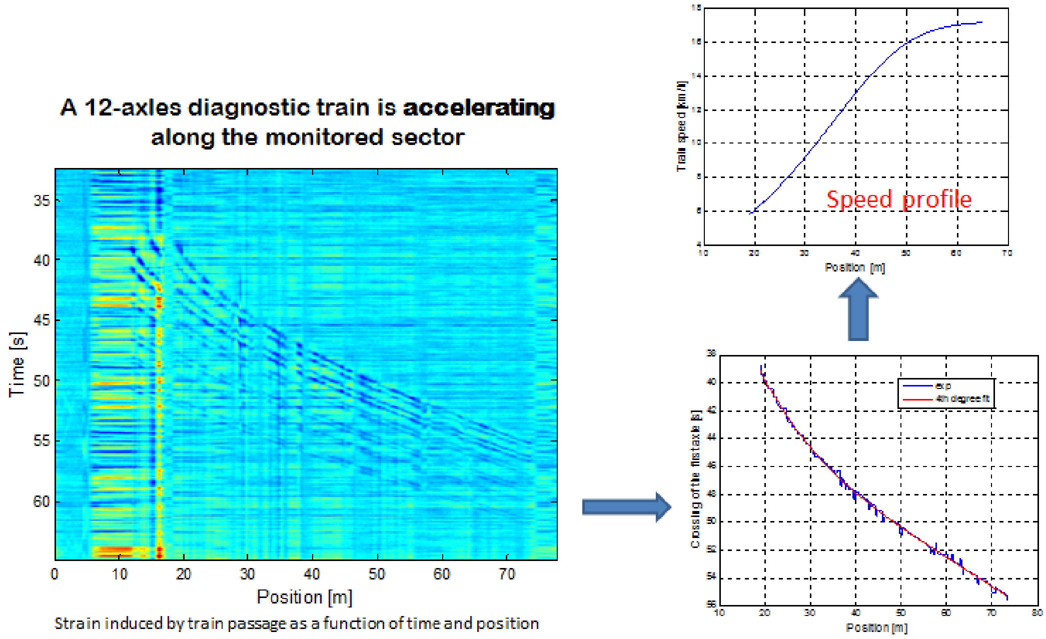

Figure 26. Distributed dynamic strain acquisition during train passage. The 12-axles diagnostic train is acceleration along the monitored section.

1.3.3 Description of main results of the Infrastructure Subsystems Management (ISM) and Decision Support Tools (DST) allocated in it

At the core of the ACEM-Rail approach there is a comprehensive system that organize and manage all the relevant information and provides the shell to allocate several decision support tools to assist infrastructure managers. Some of these Decision Support Tool have been developed in an external module that communicates with the core of the ISM system (such as those for the optimization of the planning and scheduling of maintenance tasks) while others were directly developed into the ISM system (such as those for warning management or work orders generation).

1.3.3.1 General description of the ISM

The Infrastructure Subsystems Management (ISM) manages and integrates all relevant information and tools that are required for the automation, control, monitoring, planning, optimizing and tracking the maintenance management process. The ISM is also the channel through which information is communicated from one to another ACEM-Rail system, making the whole project working in a coherent and coordinated manner, as shown in Figure 27. It has been implemented over a commercial tool (IBM MAXIMO Spatial and Linear Assets).

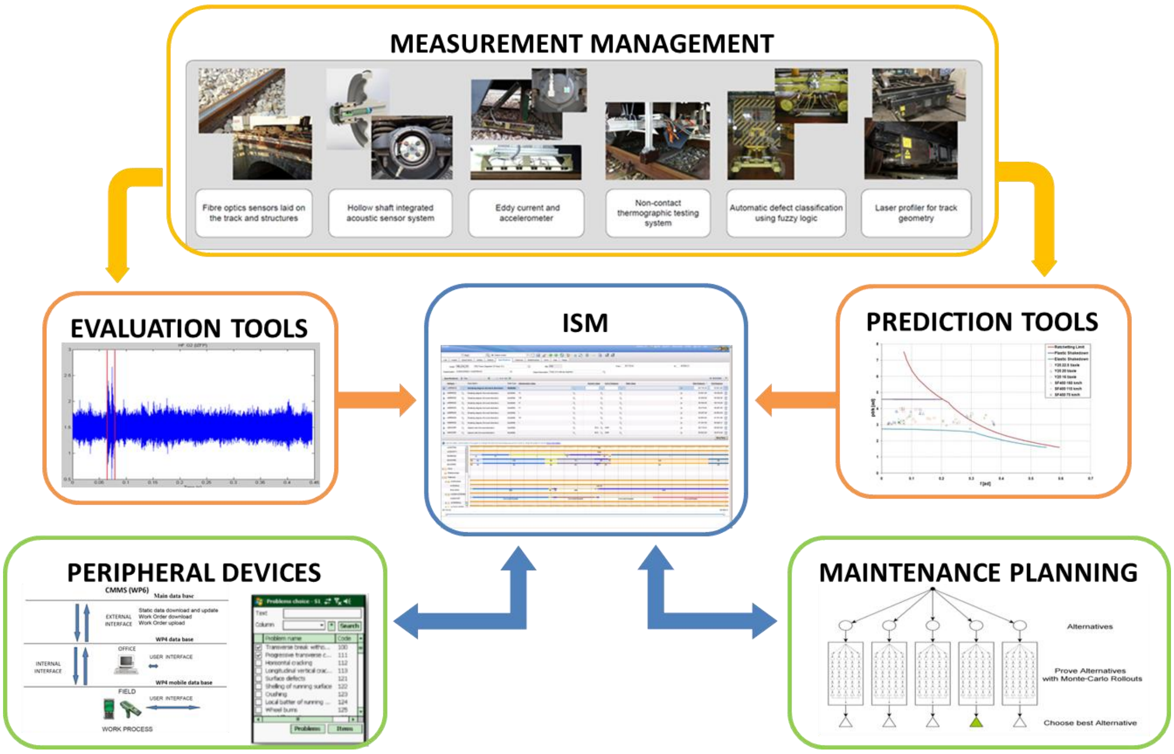

Figure 27. Integration of the ISM with other subsystems of ACEM-Rail

The Warning Management module developed into the ISM is the basis for the maintenance automation system developed in ACEM-Rail. This module makes use of some of the advance features already included in IBM MAXIMO together with additional logic specially tailored in ACEM-Rail.

Warnings correspond with defects, degradations or abnormal conditions of the infrastructure that require control, monitoring and eventually correction. This ISM's Warnings management module manages the life cycle of the warning from the entry point (notification of a new defect) to the end point (the warning is cancelled or the defect is corrected). There are two main phases on the warning management workflow:

1. Analysis & planning phase: In this phase, warnings are managed automatically to determine when and how a maintenance action has to be performed.

2. Work order phase: In this phase, the warning is converted into a work order or a set of work orders. Work orders are scheduled and assigned to specific time slots and maintenance crew. Once the work order is accomplished, the system receives feedback form the crew about the execution procedure and the state of the infrastructure.

Figure 28 shows the life of a warning. Blue colored cells correspond to the processes in Phase 1, while orange ones correspond to Phase 2 processes.

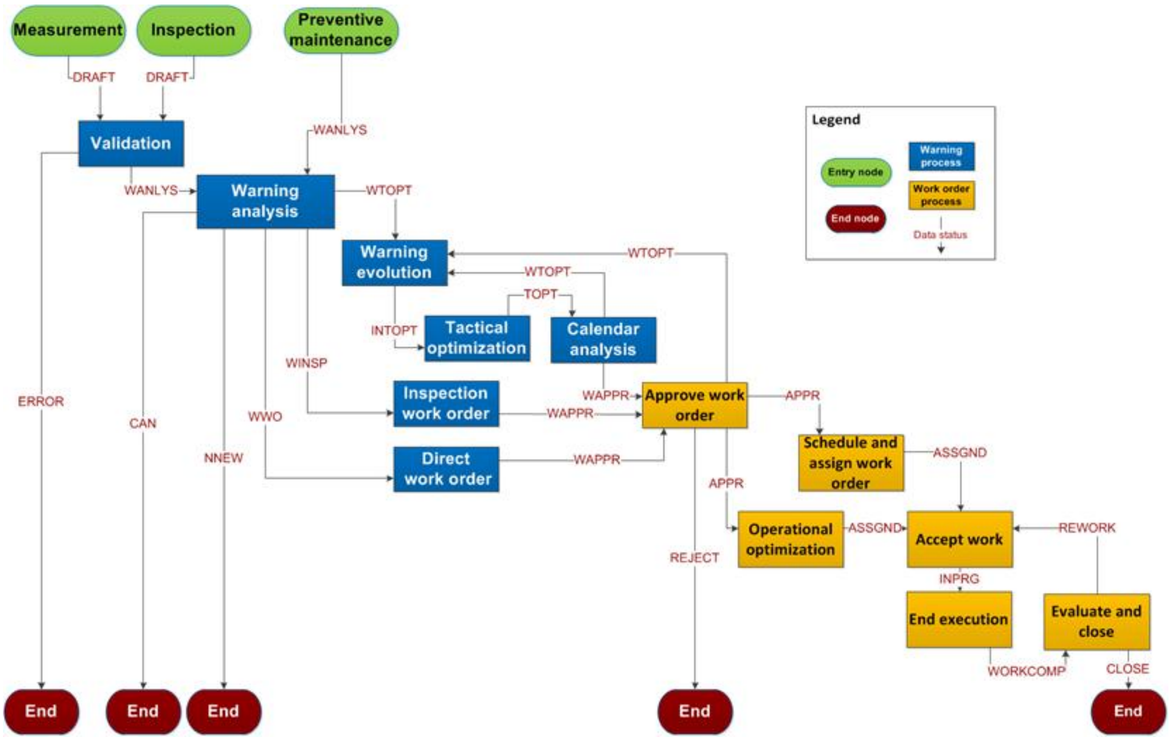

Figure 28. Warning management workflow

Phase 1 starts with the warning generation. A warning can be generated after:

- Evaluation Tools: as a result of the analysis of the measurements.
- Visual inspections/maintenance executions: during in field operations while performing maintenance operations (including visual inspections).
- Preventive maintenance master plan.

After a preliminary validation of incoming warnings, the system determines whether a warning corresponds to a new defect/warning or to a previous reported warning. For previous warnings, the process estimates the current state of the defect as a function of the reliability of the sensor and the acquisition date. Depending on the reliability of data and the associated risk, the process can select different workflow paths: i) visual inspection for poor reliability; ii) tactical planning loop for high confidence and low risk; or iii) corrective maintenance for high reliability and high risk.

One of the main tasks developed within Phase 2 is the integration and communication with the systems and tools based on mobile systems for the in-field execution and monitoring of maintenance works.

1.3.3.2 Optimization

Mathematical optimisation of maintenance planning plays a crucial role and fills a gap existing in classical railway maintenance approaches which schedule maintenance tasks using only experience and some simple rule based algorithms. The final goal behind ACEM-Rail is to achieve the (partial) automation of the overall maintenance process. ACEM-Rail system performs very frequent measures of the infrastructure state. Huge amount of previously unavailable data will be collected and pre-processed by sensor systems for automated inspection. This information will be stored and manage to improve the maintenance of the infrastructure.

In order to optimally make use of this information, software tools for maintenance planning are indispensable, and the optimisation of resource allocation, scheduling of tasks and on similar objectives will be enabled. Only with this step the full benefit of automatizing the maintenance process will take effect.

Within the ACEM-Rail project, solutions for two different levels of maintenance planning (tactical and operational) have been developed. They are consecutive and have to be coordinated in practice: the tactical and the operational planning.

The tactical planning focuses on a medium term time horizon (1 year). It is based on predictive information. It is in charge of the selection and temporal allocation of warnings into time slots. The resulting selected jobs (warnings) together with their track position (time slots) for the short-term (next few days or weeks) are the input for the 2nd optimization tool which is the operational planning.

Within the operational planning, a detailed scheduling of human and technical resources is performed in order to perform the maintenance jobs. The operational planning is based on real-time data (execution time, availability, etc).

Figure 29 below shows the relationship between tactical and operational planning and very short term work order plan sent to the maintenance crew.

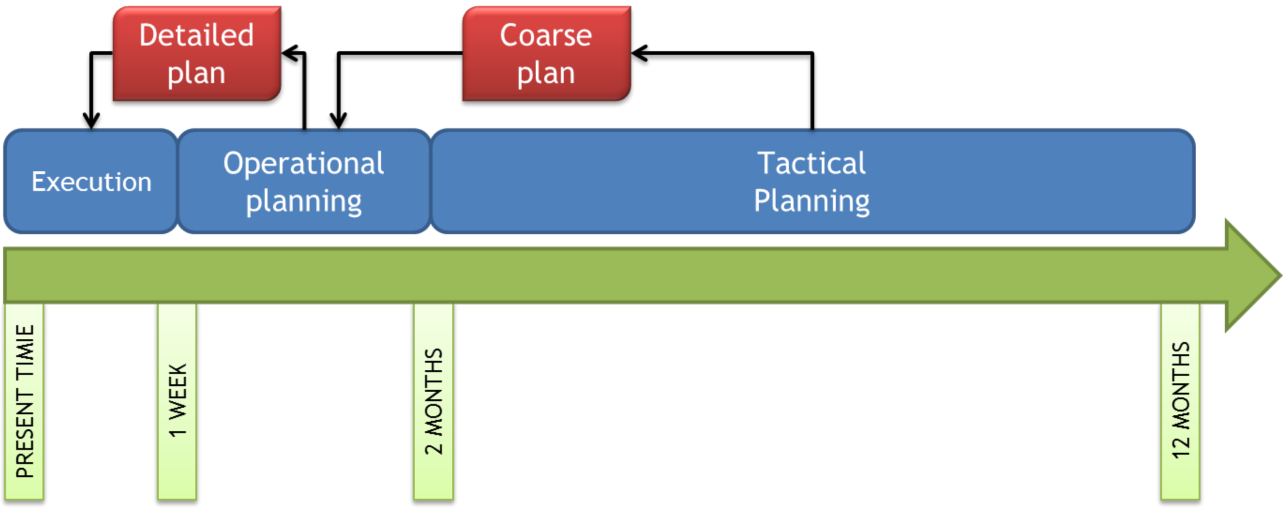

Figure 29. Optimization

For the tactical planning, it has been shown that 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.

As a solution methodology for tactical planning it is proposed the Monte-Carlo Rollout method, which has been modified and adapted within ACEM-Rail to the specific characterisations of the stochastic optimisation problem at hand. The comprehensive computational experiments made using real-world data can be concluded as follows:

- The improvement in the feasibility of maintenance schedules is the main advantage of the Monte-Carlo Rollout method. The occurrence of all three kinds of infeasibilities (due to safety restrictions, track possession booking, and resource availability) could be reduced drastically by looking at future scenarios.

- The evolution of cost values in future scenarios is very robust against uncertain developments. Other than using classical deterministic approaches, where costs are dealt as constant e.g. by using expected values, the Monte-Carlo Rollout method is able to estimate future increases in costs and to provide schedules that select warnings according to a robustness criterion.

Considering the operational planning level, the investigations carried out in ACEM-Rail have shown that there exists a very high diversity in planning processes and tasks applied to different railway companies and maintenance operators. Due to this fact, it is not possible to design a general model of an operational planning problem, as it is the case for the tactical planning. Rather the developments have focused on specific sub-tasks that have high influences on overall costs and resource consumption, where the planning of maintenance tasks is a complex procedure and the use of optimisation tools can have a significant effect.

An example for such a sub-task is the problem of ballast tamping for a rail network system. Within ACEM-Rail it has been demonstrated the solvability of such 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 modelling was made in such a way that the developed ICT tool is easily adoptable to similar tasks in operational planning. Therefore, despite focusing on the ballast tamping problem the planning tools have demonstrated their usefulness based on mathematical optimisation for a whole class of operational planning problems.

The demonstration of the optimisation tools was based on simulated scenarios due to the incomplete implementation of the ISM in the Ferrovie de Gargano’s organisational structure and the unavailability of historical data for feeding the optimisation algorithms.

The tactical planning tool was tested on a benchmark consisting of real infrastructure data from the real line San Severo-Peschici extended with complementary information from other Infrastructure Managers, such as maintenance procedures, performance and strategies, which were adapted to the features of the FdG’s facilites. A list of simulated warnings on this real infrastructure was the input for the optimisation algorithms.

On the other hand, the operational planning tool required a more complex infrastructure network for demonstration. In this case, the simulated scenario consisted of a multimode network where the track condition for each stretch was chosen at random. Figure 30 shows the simulated railway network with indication of the daily costs for traffic interruption at each stretch.

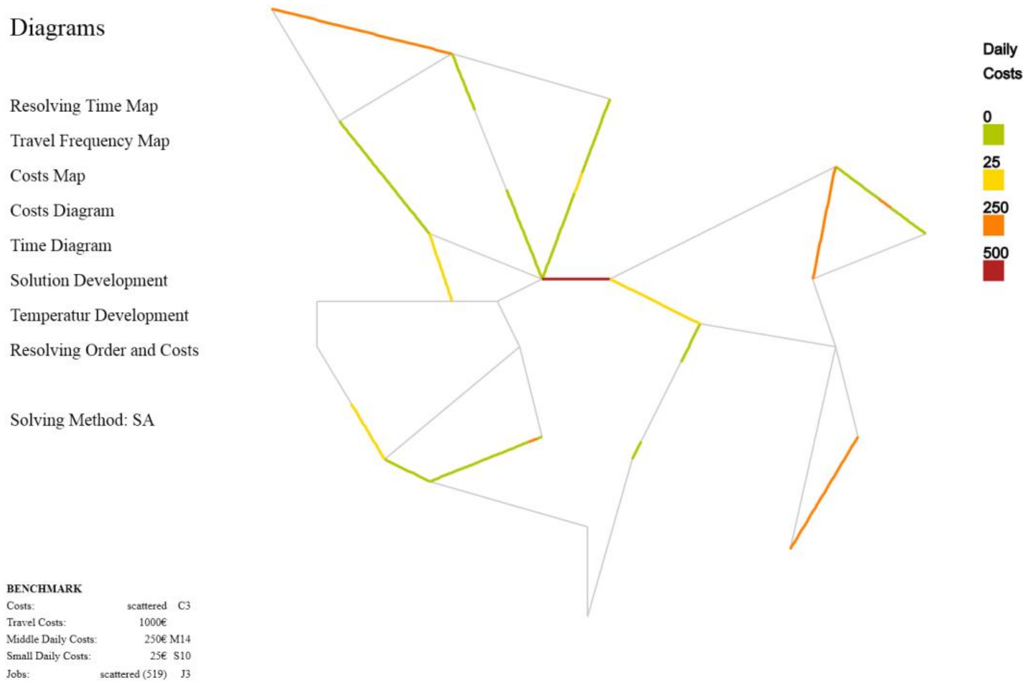

Figure 30 Cost map. Simulated scenario for demonstration of operational planning tool

The results showed the applicability of a complex planning task using appropriate optimization models It can be concluded a high potential for cost reductions to be achieved by the proposed optimization methods in comparison with the traditional planning tools and systems.

1.3.3.3 Prediction tools

ACEM-Rail includes not only the development of tools to evaluate the track condition but also those to estimate the defect evolution taking into account a number of aspect such as the type and severity of the defect, the layout and characteristics of the stretch (such as straight, curve, slope, etc) where the defect is, the traffic (frequency of the trips) and the features of the train running on the track (load, speed, acceleration, …).

In order to evaluate the track condition, different aspects must be considered (geometry, profile conditions, ballast, subgrade, vehicle behaviour, etc). These aspects have been aggregated in a certain number of scalar “Quality Parameters (QP)” chosen in order to allow:

1. calculating the QP from the measures;
2. and estimating the evolution of the QP on the basis of statistical/physical considerations.

Moreover, the selected QP do not mismatch the safety/availability criteria defined by the recently developed EU TSI.

The track condition evolution depends on the factors mentioned above (defects and their severity index, type of stretch, traffic and train characteristics, etc). In order to evaluate the track condition, it is divided into stretches with uniform track types. QP’s are calculated for the different stretches making up the line under consideration

QP’s, which are linked to certain locations or stretches, can be used to identify defects types and to assign a severity index (as defect and quality indexes are complementary to one another). Defects on a track can be generally divided into those related to the geometry of the track (such as gauge deviation, track twist or incorrect curve radius) and those linked to the mechanical efforts (such as cracking, shelling, or crushings).

In order to estimate the evolution of the QP's (or conversely, the evolution of the defects), two methodologies have been used:

1. The evolution of the QPs dealing with geometric defects was performed using multibody simulations to consider the effect of an specific number and type of trains running on the track.
2. The evolution of the QPs dealing with mechanical defects was carried out using theoretical degradation laws (exponential, potential, logarithmics or linear paths) which only depend on the cumulated gross tones and not on the vehicle-track interaction forces. A more sophisticated evolution of mechanical defects including wheel/rail interaction is a further line of development of the project.

Both, the information on the type and severity index of the defect and the information on the defect degradation or evolution is sent to the ISM (CMMS) in order to generate the warnings required by the optimization algorithms developed in the project.

1.3.3.4 Mobile tools to assist maintenance crew in field.

ACEM-Rail includes some tools to assist the operator in field. The maintenance 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 ISM with two versions: one for the central office (office application in Figure 31 below) and another one for crew mobile devices (mobile application in Figure 31 below).

- 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. Using of theses 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.

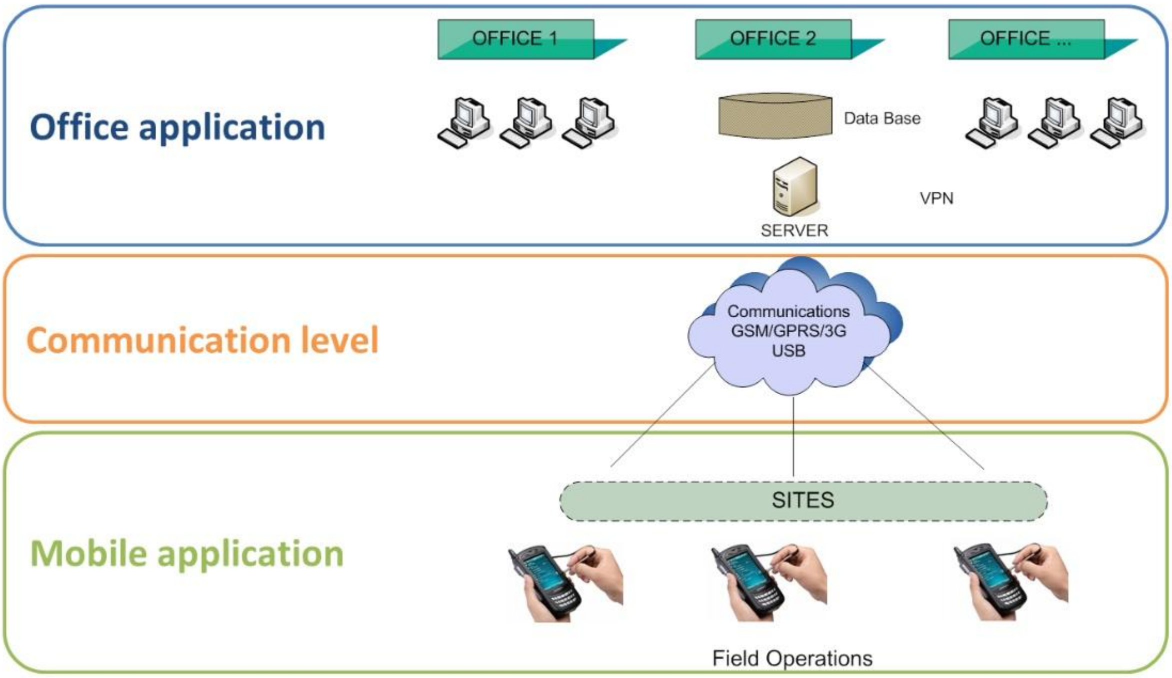

Figure 31. The Maintenance Master consists of an office application and a mobile application, both synchronized and communicated via wireless or USB.

These mobile applications were validated in the line San Severo-Peschici (Italy) in the railway system of Ferrovie de Gargano. Two field tests were performed dealing with the inspection activities in track and structures defined as part of the preventive maintenance in Ferrovie de Gargano. 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.

1.3.4 Description of main results of the Performance Measurement System for impact assessment

In order to measure the effectiveness and efficiency of ACEM-Rail system in a quantitative way, a set of 24 Maintenance Performance Indicators (MPIs) was defined. These indicators were 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) within three levels (company, system and unit). Within ACEM-Rail, a similar MPI's matrix structure which has added two extra groups (on social and environmental issues) was developed. Figure 32 below presents ACEM-Rail MPI's. The detailed definition of each MPI (e.g. MPI_{E1} can be found in the public deliverable D8.1 which can be downloaded from the project website).

		Indicator Level		
		Level 1 Company Level	Level 2 System Level	Level 3 Unit Level
Indicator Group	Economical indicators	MPI_{E1}	MPI_{E2} , MPI_{E3}	MPI_{E4}, MPI_{E5}
	Operational indicators	MPI_{O1}	MPI_{O2} , MPI_{O3}	MPI_{O4}, MPI_{O5}
	Technical indicators	MPI_{T1}	MPI_{T2}	MPI_{T3}, MPI_{T4}, MPI_{T5}
	Social indicators	MPI_{S1}	MPI_{S2} , MPI_{S3}	MPI_{S4}
	Environmental indicators	MPI_{N1}	MPI_{N2}	MPI_{N3}, MPI_{N4}, MPI_{N5}

Figure 32. Architecture of Maintenance Performance Indicators used in ACEM-Rail

The Performance Measurement System developed constructed upon these MPIs has shown its suitability for assessing the improvements achieved in the whole railway system by the implementation of the ACEM-Rail developments. ACEM-Rail project included an estimation of the economic, social and environmental benefits that were expected at the end of the project. This estimation was made before the project started. After the final evaluation of the ACEM-Rail performance, the following conclusions were achieved:

- The economic, organizational and technical impacts are similar to the expected ones, according to the ACEM-Rail objectives.
- The social benefits could not be assessed because of the partial implementation in FdG, nevertheless this impact is considered small in this context due to the limited influence of track quality in customers' satisfaction in Gargano.
- The environmental impact –reduction of CO_2 emissions- is higher than expected due to the enormous savings in travel distance by maintenance crew enabled by the better scheduling of maintenance tasks and organization of trips and the removal of the paper-based workflow.

1.3.5 Validation of the results

As already mentioned in Section 1.3.2, three inspection technologies were validated at the Wegberg-Wildenrath test and validation centre (Germany), owned by SIEMENS in July 2012:

- Eddy Current and acceleration sensors
- Non-contact thermographic testing system
- Hollow-shaft acoustic sensor

On the other hand, all the technologies embarked on commercial train together with the fibre optic system were validated in a real railway infrastructure, the line San Severo-Peschici, located in Puglia (Italy) and owned by Ferrovie de Gargano (FdG). This validation included several tests/runs that were time separated within the period in between January 2012 and September 2013. The technologies validated in FdG are listed below:

- Laser profiler and Inertial pack
- Eddy Current and acceleration sensor
- Hollow-shaft acoustic sensor
- Fiber optic sensors

Regarding the validation of the mobile tools for aiding and monitoring the execution of maintenance tasks, as already mentioned in Section 1.3.3.4, they were successfully demonstrated at the line San Severo-Peschici on June 2013, by inspecting both track and structures.

On the other hand, the Infrastructure Subsystems Management and the ICT decision support tools for optimal maintenance planning described in described in 1.3.3 were tested on simulated scenarios due to the incomplete implementation of the system in the Ferrovie de Gargano's organizational structure, on the one hand, and the simplicity of the line San Severo-Peschici for proving the benefits of some of the optimization algorithms (those for operational planning), on the other hand. These scenarios were constructed upon infrastructure data from FdG and other Infrastructure Managers. Therefore the feasibility of application to a real railway environment was also proved.

Finally, the economic, social and environmental impact of ACEM-Rail was also assessed for FdG environment using the ACEM-Rail's MPI's system consisting on 24 indicators.

1.4 Potential impact, main dissemination activities and exploitation of results

In this chapter the project impact is summarized, followed by all dissemination and exploitation activities and achievements.

1.4.1 Potential impact

One of the main features of the ACEM-Rail approach is that it tackles the problem of track maintenance in a comprehensive way covering the different stages and agents involved. Therefore, as a whole, the ACEM-Rail project will mean an important step forward in the state of the art of railway maintenance.

ACEM-Rail has achieved some progress beyond the state of the art in the following fields:

1. Progress beyond the state of the art has been achieved in relation to automated and unattended track monitoring embarked on commercial trains (conventional/high speed and passengers/freight). This allows very frequent measures of track state and therefore very accurate knowledge on track condition and degradation estimation. Besides, ACEM-Rail has also produced some advances in the use fibre optic technologies for monitoring the state of the track and the operation of rail services. All of this will allow evolving from classical railway maintenance policies based on predictive/corrective maintenance to a more cost-effective and reliable maintenance based on conditions/predictions. On the other hand, the instrumentation system proposed will generate a large amount of data that will have to be efficiently managed and structured. For that reason item 2 below is developed.

2. Progress beyond the state of the art has been achieved in relation to asset management systems for linear infrastructures and, in particular, for railway. ACEM-Rail has developed an Infrastructure Subsystem Management (ISM) system which manages and centralizes all the information on the railway system in the same platform and allows for the communication and interaction of the different modules of the ACEM-Rail approach. The ISM system is the tool that allows automating the maintenance process. It also provides the shell to allocate Decision Support Tools to help Railway Infrastructure Managers. This tool was developed on top of a commercial tool (IBM MAXIMO). Its development was modular to facilitate its gradual application in a real railway system.

3. A Performance Measurement System is proposed to evaluate the economic, social and environmental impact of the maintenance process and, in particular, of the ACEM-Rail system

4. Besides, the achievement shown in item 2 above in relation to maintenance of railway systems can be very easily transferred to the management of other linear infrastructures such as roads. Therefore the Infrastructure Subsystem Management (ISM) system developed within ACEM-Rail also is also step forward for the management, automation and optimization of road maintenance.

The combination of items 1 and 2 above allows an important modernization and automation of the railway maintenance which will allow for:

- An **important reduction in the cost** because of the more efficient use of human/technical resources and because of a longer life of the track due to the fact that it will be better maintained (closer monitoring and more efficient management). The reduction of the costs of maintenance operations will be due to the automated inspection techniques embarked on commercial train to automatically inspect the track (the expensive measurement trains, used today, will not be required), to the intelligent maintenance tools developed to optimize and automate the process (reducing time and resources) and to the longer life of the track because of the better maintenance of the track.

- An **improvement in the safety of rail services** because of the better condition of the track **and** a **reduction in maintenance crew working accidents** because of the better and more assisted working condition of the maintenance crew.

- An **improvement of the quality of rail services** due the better comfort conditions (because of the better quality of the track) and the fewer disruptions of rail services (because of better maintenance tracks and more robust to uncertainties planning of maintenance tasks) **and** also **an improvement on the reliability of the system** due to same reasons.

- A reduction in the number of trips of the maintenance crew and as a consequence a **reduction in CO2 emissions** in these trips due to the reduction of paper work because of the mobile tools developed and the better planned trips because of the optimization algorithms.

- Finally, **the capacity of the track will be enlarged** because of the better management of time slots for maintenance tasks. On the one hand, the time slots for special inspection trains will not be required as the track would be inspected at the same time that rail services are provided. On the other hand, the planning of maintenance tasks is optimized and is more robust to uncertainties and, as a consequence, ~~the~~ less maintenance time slots are required. Besides, the better assistance to operator in field also reduces the time for the execution of maintenance tasks. The addition of all these factors allow for an enlargement of time slots for rail services which will produce an **increase in rail freight services**. Hence, **less CO2 emissions** and other pollutants will be expelled because of the market share transferred from freight road transport to freight rail transport (being rail transport greener than road one.

Thus, the ACEM-Rail Project has achieved important benefits, both socio-economic and environmental. In summary, the Project has increased the cost-effectiveness and the automation degree of railway infrastructure maintenance. All of this helps to improve the competitiveness of European rail transport significantly reducing inspection and maintenance costs and increasing the safety, quality and reliability of rail services. Moreover, all of this also contributes to the reduction of pollutants expelled to the atmosphere for a greener and more sustainable European transport system.

1.4.2 ACEM-Rail beneficiaries

One of the most important aspects to consider in any research project is to identify potential stakeholders or main beneficiaries of the technology developed in the project.

The main stakeholders/beneficiaries/customers of the products and results developed in the ACEM-Rail project are:

- Railway authorities and operators
- Transport planners and engineers
- Rail maintenance and repair services companies
- Railway infrastructure planners and designers
- End-users of rail services

1.4.3 Main dissemination Activities

During the three years of the project, the ACEM-Rail partners were highly active in disseminating the project's results in high-quality conferences and journals, liaising with related research projects, making promotional material, among other activities. 19 scientific papers have been prepared, submitted, accepted for publication, and presented in conferences. Besides, 49 dissemination activities have been conducted, including industrial workshops attended and fairs. The project's main dissemination activities are organized below in 3 categories: publications, workshops and, other activities.

1.4.3.1 Publications and Scientific Conferences

During the project numerous publications were written such as press releases, a project website, scientific contributions to scientific journals and conferences as well as scientific theses carried out by students.

Publications at conferences and journal papers have been one of the major instruments to disseminate ACEM-Rail research results to the scientific community. This guarantees, on the one hand, that the research of ACEM-Rail goes beyond the current state of the art and facilitates, on the other hand, the possibility that the research can be carried on even after the project's completion.

The dissemination activities covered a set of different events, including the following scientific conferences:

- IEEE Sensors Conference
- World Congress on Railway Research (WCRR)
- International Conference on Railway Technology: Research, Development and Maintenance (RAILWAYS)
- Transport Research Arena (TRA)
- International Conference on Road and Rail Infrastructure (CETRA)
- International Conference on Operations Research and Enterprise Systems (ICORES)

- European Workshop on Optical Fiber Sensors (EWOFS)
- International Conference on Stochastic Programming (ISCP)
- International Conference on Soft Computing Technology in Civil, Structural and Environmental Engineering (CSC)
- Euro Working Group on Transportation (EWGT)
- European Transport Conference (ETC)
- Pan-American Conference of Traffic and Transportation Engineering and Logistics (PANAM)
- Spanish Conference on Railway Innovation
- Transport Engineering Conference (CIT)

The list of project publications is given in the Tables A1 (peer-reviewed publications) and Table A2 (dissemination activities).

1.4.3.2 Workshops, Exhibitions and Scientific Theses

Some partners have attended to exhibitions or have organized technical meetings/workshop with national authorities (see Table A2).

Moreover, the project consortium organized a Public Final Workshop, which was held during the European Transport Conference (ETC2013), in a special double-session:

- Open ACEM-Rail Final Workshop on *'Towards a More Efficient and Sustainable Railway Maintenance'* in Frankfurt (Germany), on 30 September 2013. Presentations and papers from ACEM-Rail members were given.

On the other hand, the PhD Thesis *'Generalized Bin Packing Problems'* has been completed at Politecnico di Torino (POLITO) in 2013. In this regard, some ACEM-Rail results are currently in use in lecturing in specialized Railway course.

1.4.3.3 Other dissemination activities

The ACEM-Rail Team has produced promotional materials, as website, posters, flyers and newsletters.

The **logo** (Figure 33) was designed at the initial stage of the project and was used in the documents produced during the project (brochure, presentations, newsletters, deliverables, etc…), both internal and external ones.

Figure 33: ACEM-Rail Logo.

The ACEM-Rail project generated two **brochures** (Figure 34 and Figure 35):

- One of them at the beginning of the Project with general information on the project and information interesting for prospective users.

Figure 34: First version of the ACEM-Rail Brochure.

- Another brochure was produced at the end of the Project. This flyer is focused on the key achievements and on the demonstration pilots.

Figure 35: Brochure for the Final Project Workshop.

Other dissemination materials were the **Posters** (Figure 36). An initial poster was produced and used on exhibition booths of Partners within some events, as EXPO Ferroviaria 2012 or Defektoskopie 2011. Moreover, another poster was also produced and displayed in the Final ACEM-Rail Project Workshop as publicity material.

Figure 36: ACEM-Rail Posters, (a) ACEM-Rail Poster showed at EXPO Ferroviaria 2012 and (b) ACEM-Rail Poster for the Final Project Workshop.

On the other hand, three informative **newsletters** (Figure 37, Figure 38 and Figure 39) have been produced and published (at the 9th, 18th and 30th month); including interviews (to Partners and former Project Officer), key achievements reached, work status and news of upcoming events. Each Newsletter was adjusted to current project state and described selected issues related to the project's development.

The following Figures show all published newsletters.

Figure 37: Pages of the first issue of ACEM-Rail Newsletter.

Figure 38: Pages of the second issue of ACEM-Rail Newsletter

Figure 39: Pages of the third issue of ACEM-Rail Newsletter

1.4.4 Exploitation activities and achievements

This section focuses on foreseen exploitation of project results. A general description is provided here.

ACEM-Rail has produced interesting outcomes which can be exploited in the field of instrumentation technologies (Block 1 in Section 1.3.1) and in the field of Infrastructure Subsystem Management and Decision Support Tools (Block 2 in in Section 1.3.1). In most cases, some more research and development activities are necessary to be able to meet market demands at a reasonable price. In other cases, there are results that can be exploited in the very short term.

Regarding instrumentation technologies a brief summary of main possible foreseen exploitation is presented below:

- The most mature technology developed within ACEM-Rail for track inspection is the technology developed by DMA based on laser profiler and inertial pack. DMA is going to offer the unattended monitoring capability for every track inspection car they produce, be it required or not, because it eliminate the operator errors in the defect localization. This technology is ready for market exploitation.

- The inspection technology based on the hollow shaft acoustic sensor developed by Fraunhofer- IZFP-D needs some more developments mainly in the field of data post processing and automated defect recognition. The partner Fraunhofer-IZFP hasn't foreseen any exploitation at this stage.

- The technology developed by SIEMENS based on Eddy Current performs very well when the track is in a good condition and the probe can be closer to the rail. For poor maintained tracks that present more geometry defects, the probe cannot be that much close to the rail (because it can crash with it) and the signal is noisier and produces worse results. The accelerometer sensor system also has some problems when locating the exact position of the rails. A possible collaboration between SIEMENS and DMA was mentioned during the last meeting of the project in order to avoid these positioning problems. SIEMENS foresees exploitation of their results in three products as shown in Table B2 (confidential).

- The technology on stimulated Brillouin scattering in optical fibre developed by SUN has shown promising results in retrieving information for structural heath monitoring of railway infrastructure and to retrieve information about the rail traffic. Further research is required to improve both the spatial resolution and the acquisition rate of the proposed sensors. In any case, at this stage, it is foreseen the commercial exploitation of Interrogation unit for distributed strain and temperature measurements.

- The algorithms developed by Scan Master for the processing of the data provided by the ultrasonic railway inspection systems can also be commercially exploited.

Regarding the Infrastructure Subsystem Management (ISM) and Decision Support Tool, the following results are subject to commercial exploitation, after some more research and development activities:

- The ISM is a very promising tool that will significantly improve the effectiveness of the maintenance process not only in railways but in general in linear infrastructures. To get the system closer to the market for a commercial application, the communications and interfaces of the ISM with the optimization algorithms and the mobile tools have to be automated. A collaboration of some partners of the ACEM-Rail (CEMOSA, US, Fraunhofer IVI and DMA) is foreseen for this commercial exploitation.

- Software tools for long-term tactical infrastructure maintenance planning and short-term operational infrastructure maintenance planning can be subject to commercial exploitation by Fraunhofer IVI.

- The mobile tools to help the operator infield and monitor the execution of maintenance tasks are subject to be commercially exploited by OPTIM-AL.

On the other hand, ACEM-Rail project has also produced an important general advance of knowledge to most of the partners. In particular:

- CEMOSA has advanced its knowledge and expertise in the following fields: requirements, characteristics and capabilities of sensors technologies for rail monitoring; analysis of maintenance procedures for railway (technical requirements, costs and resources), RAMS and LCC railway infrastructure design and asset management and logistic planning of maintenance operations. CEMOSA is now in a better position to offer more added value to its customers in the railway sector. In particular, CEMOSA is in a better position to provide the following new or improved services:
    - Technical assistance to Infrastructure Managers for the sensor selection and design of the monitoring system for the inspection of the track/pavement, the subgrade and structures. Data analysis and evaluation of the infrastructure condition. Estimation of defect degradation.
    - Technical assistance to Infrastructure Managers for the implementation of an ISM system, including organisational changes, sequential implementation and evaluation framework
    - Technical assistance to Infrastructure Managers for optimized RAMS and LCC oriented management of railway maintenance system.
    - RAMS and LCC oriented design for new and upgraded railway infrastructures
- US has advanced its knowledge in the field of asset management and logistic planning of maintenance operations.
- SIEMENS has advanced its knowledge in the implementation of common techniques for vehicles inspection (Eddy Current, accelerometers) to infrastructure monitoring. The automation level of this system (i.e. power on, measurement and power off without human intervention) is also a new achievement for this company.
- DMA has advanced its knowledge in the improved accuracy of the profiler, which enables de detection of a wider range of track defects, as well as the web-based management of acquired data.
- FhG-IZFP has advanced its knowledge in the field of railway inspection. The used sensor, hollow-shaft acoustic sensor and Thermographic, have been widely applied to wheel monitoring, but this project is the first approach to infrastructure monitoring.
- FhG-IVI has advanced its knowledge in the field of maintenance planning. The new developed algorithms have demonstrated to be more cost-effective than current optimisation techniques and they can be applied to any linear infrastructure.
- SUN has advanced in its knowledge in the field of railway inspection. The Brillouin fiber optic sensor have been widely used in the monitoring of engineering structures, such as bridges, but few experiences exist dealing with the monitoring of train services because of the technical difficulties with the dynamic acquisition of data. The new interrogation unit allows exploring this new application.

- SM has advanced in its knowledge in the interpretation of raw data from ultrasonic inspection by the application of Fuzzy Logic techniques.

- OPTIM-AL has advanced in its knowledge by the application of computer aid tools to the railway maintenance sector. Previous experience of this company was related to the building and industrial sector. This project has increased the business opportunities for this technology provider.

- POLITO has advanced in its knowledge related to the evaluation of track condition by the use of quality parameters. The gathered data during the measurement campaigns within this project enabled further development in the evaluation and prediction algorithms.

1.4.5 Spin-off companies

The creation of spin-off companies has become an important mechanism to commercialise or exploit research results, especially for the university. In this regard, one spin-off has already born from the ACEM-Rail Project: Optosensing s.r.l. (www.optosensing.it) from Second University of Naples (SUN), constituted on date 01/08/2013. Figure 40 shows the Optosensing logo.

Figure 40: Optosensing Logo

A future spin-off could be founded by another partner (Fraunhofer IZFP-D) for the commercial exploitation of the hollow-shaft acoustic sensor.

1.5 Consortium and Contact details

The composition of the consortium guarantees an optimal processing of the project targets. The consortium is made up of the following organizations:

1. CEMOSA (Project Coordinator, Spain)
2. University of Seville (Scientific Manager, Spain)
3. Fraunhofer (Germany)
4. Politecnico di Torino (Italy)
5. Seconda Universita degli Studi di Napoli (Italy)
6. Optim-Al Ltd (Bulgaria)
7. DMA (Italy)
8. Tecnomatica (Italy)
9. SIEMENS (Germany)
10. ScanMaster Ltd. (Israel)

The contacts details can be addressed to www.acem-rail.eu and www.acem-rail.com

2 Use and dissemination of foreground

Section A (public)

This section includes two tables:

- Table A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.

- Table A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

TABLE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

N.	Title / DOI	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access ?	Type
1	Differential pulse-width pair BOTDA with fast fall-time pulses 10.1109/ICSENS.2011.6127187	Aldo Minardo, Luigi Zeni , Romeo Bernini	2011 IEEE SENSORS Proceedings		IEEE		01/10/2011	897-900	No	Conference
2	Long-range distributed Brillouin fiber sensors by use of an unbalanced double sideband probe 10.1364/OE.19 .023845	Romeo Bernini, Aldo Minardo, Luigi Zeni	Optics Express	Vol. 19/ Issue 24	Optical Society of America	United States	09/11/2011	23845-23856	Yes	Peer reviewed
3	High-Spatial- and Spectral-Resolution Ti me-Domain Brillouin Distributed Sensing by Use of Two Frequency-Shifted Optical Beam Pairs 10.1109/JPHOT.2012.2219301	A. Minardo, L. Zeni , R. Bernini	IEEE Photonics Journal	Vol. 4/ Issue 5	Institute of Electrical and Electronics Engineers Inc.	United States	01/10/2012	1900-1908	Yes	Peer reviewed
4	Distributed Sensing at Centimeter-Scale Spatial Resolution by BOFDA: Measurements and Signal Processing 10.1109/JPHOT.2011.2179024	R. Bernini, A. Minardo, L. Zeni	IEEE Photonics Journal	Vol. 4/Issue 1	Institute of Electrical and Electronics Engineers Inc.	United States	01/02/2012	48-56	Yes	Peer reviewed
5	Spatial Resolution Enhancement in Preactivated BOTDA Schemes by Numerical Processing 10.1109/LPT.2 012.2192424	Aldo Minardo, Romeo Bernini, Luigi Zeni	IEEE Photonics Technology Letters	Vol. 24/ Issue 12	Institute of Electrical and Electronics Engineers Inc.	United States	01/06/2012	1003-1005	No	Peer reviewed

N.	Title / DOI	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access ?	Type
6	Differential Techniques for High-Resolution BOTDA: An Analytical Approach 10.1109/LPT.2 012.2202223	Aldo Minardo, Romeo Bernini, Luigi Zeni	IEEE Photonics Technology Letters	Vol. 24/ Issue 15	Institute of Electrical and Electronics Engineers Inc.	United States	01/08/2012	1295-1297	No	Peer reviewed
7	Modal analysis of a cantilever beam by use of Brillouin based distributed dynamic strain measurements 10.1088/0964-1726/21/12/125022	Aldo Minardo, Agnese Coscetta , Salvato Pirozzi, Romeo Bernini, Luigi Zeni	Smart Materials and Structures	Vol. 21/ Issue 12	Institute of Physics Publishing	United Kingdom	01/12/2012	125022	No	Peer reviewed
8	Real-time monitoring of railway traffic using slope-assisted Brillouin distributed sensors http://dx.doi.org/10.1364/AO.52.003770	Aldo Minardo, Giuseppe Porcaro , Daniele Giannetta , Romeo Bernini, Luigi Zeni	Applied Optics	Vol. 52/ Issue 16	Optical Society of America	United States	01/01/2013	3770-3776	No	Peer reviewed
9	The stochastic generalized bin packing problem http://dx.doi.org/10.1016/j.dam.2011.1 0.037	Guido Perboli, Roberto Tadei , Mauro M. Baldi	Discrete Applied Mathematics	Vol. 160/ Issue 7-8	Elsevier	Netherlands	01/05/2012	1291-1297	No	Peer reviewed
10	Job Order Assignment at Optimal Costs in Railway Maintenance	F. Heinicke , A. Simroth, R. Tadei, M. Baldi	Proceedings of the 2nd International Conference on Operations Research and Enterprise Systems		SciTePress		01/02/2013	304-309	No	Conference
11	On a novel optimisation model and solution method for tactical railway maintenance	F. Heinicke, A. Simroth, R. Tadei	Proceedings of the 2nd International Conference on		Department of Transportati	Zagreb, Croatia	01/05/2012	421-427	Yes	Conference

N.	Title / DOI	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access ?	Type
	planning		Road and Rail Infrastructure		on, Faculty of Civil Engineering, University of Zagreb					
12	The Stochastic Generalized Bin Packing Problem	G. Perboli, R. Tadei, L. Gobbato, M. M. Baldi	Proceedings of the XIII Int. Conference on Stochastic Programming		Elsevier		09/07/2013	1291-1297	No	Conference
13	A New Method to Evaluate Track Conditions over Time	N. Bosso, A. Gugliotta and N. Zampieri	Proceedings of the First International Conference on Railway Technology: Research, Development and Maintenance		Civil-Comp Press	Stirlingshire , UK	01/04/2012	Paper 47	No	Conference
14	Asymptotic results for the Generalized Bin Packing Problem	M. M. Baldi, T. G. Crainic, G. Perboli, R. Tadei	Proceedings of the 16th Euro Working Group on Transportation		Elsevier		04/09/2013		Yes	Conference
15	Characterisation of Rail Tracks by Means of Hollow Shaft Integrated Acoustic Sensor Systems	F. Schubert, M. Barth, U. Hoenig, H. Neunuebel, Mareike Stephan, A. Gommlich , L. Schubert, B. Frankenstein	Proceedings of the European Transport Conference 2013		Association for European Transport	Frankfurt	01/10/2013		Yes	Conference
16	A logical framework and	F. Cores, N.	Proceedings of the		Association	Frankfurt	01/10/2013		Yes	Conference

N.	Title / DOI	Author(s)	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Date of publication	Relevant pages	Open access ?	Type
	integrated architecture for the rail maintenance automation	Caceres, F.G. Benitez, S. Escriba, N. Jimenez-Redondo	European Transport Conference 2013		for European Transport					
17	Automated and Cost Effective Maintenance for Railway (ACEM-Rail)	N. Jimenez-Redondo, N. Bosso, L. Zeni, A. Minardo, F. Schubert , F. Heinicke , A. Simroth	Proceedings “Transport Research Arena 2012”		Elsevier		24/04/2012	1058-1067	Yes	Conference
18	Automatización y optimización del mantenimiento de la vía (ACEM-Rail)	N. Jimenez-Redondo, N. Caceres, F. J. Cores	Proceedings of the 10th Transport Engineering Conference		Editorial Universidad de Granada		01/06/2012	Paper 142	No	Conference
19	Sistema inteligente de automatización de la gestión del mantenimiento de vía	N. Jimenez-Redondo, P. Cembrero , F. Cores, F.G. Benitez	Proceedings of the 7th Spanish Conference on Railway Innovation		UNED	Zaragoza	01/05/2012	547-560	No	Conference
20	Generalized Bin Packing Problems	Mauro Maria Baldi			Politecnico di Torino	Corso Duca Degli Abruzzi 24, 10129, Torino, Italy	28/02/2013		Yes	Thesis

TABLE A2: LIST ODF DISSEMINATION ACTIVITIES

No.	Type of activities[1]	Main leader	Title	Date	Place	Type of audience[2]	Countries addressed
1	oral presentation to a wider public	CEMOSA	6th Spanish Conference on Railway Innovation	30/03/2011	Malaga, Spain	Scientific community (higher education, Research) - Industry - Civil society - Policy makers	National (Spain)
2	oral presentation to a scientific event	SCANMASTER	Annual convention of the Israeli Branch of Non-Destructive testing	01/06/2011	Israel	Scientific community (higher education, Research)	Regional
3	Exhibitions	SCANMASTER	Defektoskopie 2011	07/09/2011	Ufa, Russia	Industry	International
4	Oral presentation to a scientific event	SECONDA UNIVERSITÀ DEGLI STUDI DI NAPOLI	IEEE Sensors 2011	28/10/2011	Limerick, Ireland	Scientific community (higher education, Research) - Industry - Civil society - Policy makers	International
5	Oral presentation to a scientific event	SECONDA UNIVERSITÀ DEGLI STUDI DI NAPOLI	COST Action TD1001 - Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications (OFSESA)	01/11/2011	Jena, Germany	Scientific community (higher education, Research)	International
6	Exhibitions	SCANMASTER	11 International Exhibition and Conference for Non-Destructive Testing and Technical Diagnostics	01/03/2012	Moscow, Russia	Scientific community (higher education, Research) - Industry	International
7	Exhibitions	DMA	EXPO Ferroviaria 2012	28/03/2012	Turin, Italy	Scientific community (higher education, Research) - Industry - Civil society - Policy	International

[1] Dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.
[2] Type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias.

No.	Type of activities[1]	Main leader	Title	Date	Place	Type of audience[2]	Countries addressed
						makers - Medias	
8	Oral presentation to a scientific event	POLITECNICO DI TORINO	The first International Conference on Railway Technology: Research, Development and Maintenance	20/04/2012	Las Palmas de Gran Canarias, Spain	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
9	Organisation of Workshops	OPTIM-AL EOOD	Technical Meeting - Metropolitan PLC (Metro Sofia)	17/04/2012	Sofia, Bulgaria	Industry - Policy makers	National (Bulgaria)
10	Oral presentation to a scientific event	CEMOSA	Transport Research Arena (TRA2012)	24/04/2012	Athens, Greece.	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
11	Oral presentation to a scientific event	FRAUNHOFER	2nd International Conference on Road and Rail Infrastructure (CETRA 2012)	07/05/2012	Dubrovnik, Croacia	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
12	Oral presentation to a scientific event	CEMOSA	7th Spanish Conference on Railway Innovation (VII Congreso de Innovación Ferroviaria)	10/05/2012	Zaragoza, Spain	Scientific community (higher education, Research) - Industry	National (Spain)
13	Oral presentation to a scientific event	UNIVERSITY OF SEVILLE	10th Transport Engineering Conference (CIT2012)	21/06/2012	Granada, Spain	Industry - Civil society - Policy makers - Medias	National (Spain)
14	Organisation of Workshops	Tecnomatica	Seminar Infrastructure Maintenance and ACEM-RAIL	29/11/2012	Sofia, Bulgaria	Scientific community (higher education, Research) - Industry	National (Bulgaria)
15	Oral presentation to a scientific event	FRAUNHOFER	2nd International Conference on Operations Research and Enterprise Systems (ICORES 2013)	16/02/2013	Barcelona, Spain	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
16	Oral presentation to a	SECONDA	5th European Workshop on Optical	20/05/2013	Kraków, Poland	Scientific community	European

No.	Type of activities[1]	Main leader	Title	Date	Place	Type of audience[2]	Countries addressed
	scientific event	UNIVERSITÀ DEGLI STUDI DI NAPOLI	Fiber Sensors (EWOFS'2013)			(higher education, Research)	
17	Oral presentation to a scientific event	POLITECNICO DI TORINO	XIII International Conference on Stochastic Programming (ISCP2013)	09/07/2013	Bergamo, Italy	Scientific community (higher education, Research)	International
18	Oral presentation to a scientific event	FRAUNHOFER	The Third International Conference on Soft Computing Technology in Civil, Structural and Environmental Engineering (CSC2013)	06/09/2013	Cagliari, Sardinia, Italy	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
19	Oral presentation to a scientific event	POLITECNICO DI TORINO	16th Euro Working Group on Transportation (EWGT2013)	05/09/2013	Porto, Portugal	Scientific community (higher education, Research)	European
20	Oral presentation to a scientific event	UNIVERSITY OF SEVILLE	41st European Transport Conference (ETC 2013)	01/10/2013	Frankfurt, Germany	Scientific community (higher education, Research) - Industry - Policy makers - Medias	European
21	Oral presentation to a scientific event	FRAUNHOFER	41st European Transport Conference (ETC 2013)	01/10/2013	Frankfurt, Germany	Scientific community (higher education, Research) - Industry - Policy makers - Medias	European
22	Organisation of Workshops	CEMOSA	FP7 Final Workshop: Towards a More Efficient and Sustainable Railway Maintenance	30/09/2013	Frankfurt, Germany	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	European
23	Press releases	SECONDA UNIVERSITÀ DEGLI STUDI DI NAPOLI	Transporti Ferroviari, sensori hi-tech per la sicurezza (newspapre Il Mattino)	16/05/2011	Italy	Civil society	Regional
24	Exhibitions	CEMOSA	9th World Congress on Railway Research	23/05/2011	Lille, France	Scientific community (higher education,	International

No.	Type of activities[1]	Main leader	Title	Date	Place	Type of audience[2]	Countries addressed
						Research) - Industry - Civil society - Policy makers - Medias	
25	Flyers	CEMOSA	First ACEM-Rail brochure	01/04/2012	Spain	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
26	Flyers	CEMOSA	Final ACEM-Rail brochure	17/09/2013	Spain	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
27	Posters	DMA	ACEM-Rail Poster for EXPO Ferroviaria 2012	28/03/2012	Turin, Italy	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
28	Posters	UNIVERSITY OF SEVILLE	ACEM-Rail Poster for Final Workshop in ETC2013	30/09/2013	Frankfurt, Germany	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	European
29	Articles published in the popular press	CEMOSA	New in the local newspaper "Diario Sur"	17/11/2011	Malaga, Spain	Civil society	Local
30	Press releases	CEMOSA	Article in EURAILmag Business & Technology. Issue 27	01/04/2013	France	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	European
31	Press releases	CEMOSA	Article in Spanish Railway - Newsletter 10/2013	02/07/2013	Spain	Scientific community (higher education, Research) - Industry	International

No.	Type of activities[1]	Main leader	Title	Date	Place	Type of audience[2]	Countries addressed
32	Press releases	CEMOSA	New in Spanish Railway - Bulletin of 17th July 2013	17/07/2013	Spain	Scientific community (higher education, Research) - Industry	National (Spain)
33	Articles published in the popular press	CEMOSA	Article in digital magazine ASICMA. Issue 9	01/09/2012	Spain	Scientific community (higher education, Research) - Industry	National (Spain)
34	Press releases	FRAUNHOFER	Article in Fraunhofer IZFP Annual Report	01/01/2012	Germany	Scientific community (higher education, Research) - Industry	National (Germany)
35	Press releases	FRAUNHOFER	Article in Fraunhofer IVI Annual Report	01/01/2012	Germany	Scientific community (higher education, Research) - Industry	National (Germany)
36	Articles published in the popular press	OPTIM-AL EOOD	Article in digital newspaper "TechNews Ltd"	15/03/2011	Bulgaria	Civil society	National (Bulgaria)
37	Articles published in the popular press	OPTIM-AL EOOD	Article in digital newspaper "Saga Technology"	15/03/2011	Bulgaria	Industry - Civil society	National (Bulgaria)
38	Articles published in the popular press	OPTIM-AL EOOD	Article in digital newspaper "IDB Bulgaria"	15/03/2011	Bulgaria	Civil society	National (Bulgaria)
39	Articles published in the popular press	OPTIM-AL EOOD	Article in digital magazine for logistic "Logistika"	13/12/2012	Bulgaria	Industry - Civil society	National (Bulgaria)
40	Articles published in the popular press	OPTIM-AL EOOD	Article in digital magazine for infrastructural construction "STROITELI"	22/02/2013	Bulgaria	Scientific community (higher education, Research) - Industry - Civil society	National (Bulgaria)
41	Articles published in the popular press	OPTIM-AL EOOD	Article in digital magazine "IT Forum"	14/03/2011	Bulgaria	Industry - Civil society	National (Bulgaria)
42	Articles published in the popular press	OPTIM-AL EOOD	Article in digital newspaper "Computerworld"	14/03/2011	Bulgaria	Industry - Civil society	National (Bulgaria)
43	Interviews	OPTIM-AL EOOD	Interview to three ACEM-Rail' partners (CEMOSA, US and OPTIM) and published in magazine Logistika	12/12/2012	Bulgaria	Scientific community (higher education, Research) - Industry - Civil society	National (Bulgaria)
44	Oral presentation to a wider	Tecnomatica	Oral presentation of the project	01/06/2012	Foggia, Italy	Industry - Civil society	National (Italy)

No.	Type of activities[1]	Main leader	Title	Date	Place	Type of audience[2]	Countries addressed
	public		during the presentation of the Rail Tram by Gragano Railway line, in Italy			- Policy makers - Medias	
45	Web sites/Applications	CEMOSA	ACEM-Rail fact sheet in ECOWEB	29/06/2013	Austria	Scientific community (higher education, Research) - Industry	European
46	Web sites/Applications	CEMOSA	ACEM-Rail project website	01/02/2011	Spain	Scientific community (higher education, Research) - Industry - Civil society - Policy makers - Medias	International
47	Press releases	CEMOSA	Article in newsletter of TECNIBERIA (Spanish Association of Engineering, Consulting and Technical Services)	24/02/2012	Spain	Scientific community (higher education, Research) - Industry	National (Spain)
48	Press releases	CEMOSA	New in SOST (Spanish Office for Science and Technology) website	14/02/2011	Brussels	Scientific community (higher education, Research) - Industry	European
49	Oral presentation to a wider public	CEMOSA	Presentation in Regional Info-day on Transport	29/05/2012	Seville, Spain	Scientific community (higher education, Research) - Industry	National (Spain)